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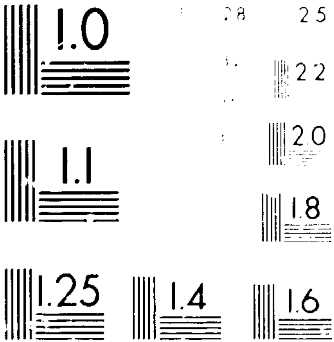

MICROCOPY RESOLUTION TEST CHART

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International Conference on Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

12237

Key Note Address

Prof. Dr. Herman F. Mark,
Polytechnic Institute of Brooklyn,
New York

treat this as ONE volume

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DR. HERMAN MARK, recipient of the 1960 Perkin Medal for "Outstanding contributions to Applied Chemistry" is the founder of the Polymer Research Institute at the Polytechnic Institute of New York, the first of its kind in the U.S. He has worked on polymer theory and developed new polymers as well as methods used today to determine molecular weights of polymers. He also discovered the kinetics of free radical polymerisation. He has been Professor of Organic Chemistry at the Polytechnic Institute of New York and also the dean of the faculty there. Prior to that he was Professor of Organic Chemistry at the University of Vienna and Director of the Chemical Institute there. He has also been the research Director of the Canadian International Paper Co. He has directed scientists in the first preparations of polystyrene, polyvinyl chloride, polymethyl methacrylate and two synthetic rubbers Buna S and Buna N. Mark is the founder of the Journal of Applied Polymer Science and Encyclopaedia of Polymer Science and Technology.

STRUCTURE AND PROPERTY OF FIBRES

S. M. ATLAS AND H. F. MARK

It is now convenient to classify fibers not any more by their chemical composition but by the preferred end-use. There will be discussed:

I. Comfort Fibers

II. Commodity Fibers

III. Industrial Fibers

I. Comfort fibers are those which are used in close proximity with our body in the form of wovens, knitted and fleeced fabrics, and in apparels and clothing. Presently, next to cotton, wool and silk the following synthetics are preponderantly used: polyamides, polyesters, polyacrylics and polyolefins. There is little expectation that another chemical composition will enter this area in a large scale but there will be many innovations which produce specialty applications such as the hard elastic fibers, the multicomponent fibers, and other materials which are being obtained by surface treatments or special spinning methods which give such important properties as anti-soiling and anti-static. Considerable innovation has been made and is still being made in processing methods such as matrix fibers, non-wovens, texturizing and increasing speed and uniformity of production.

II. Commodity fibres are those which are not in direct contact with our body but are close to us wherever we are — at home, at work, in school, in all transportation facilities and during relaxation. These comprise upholstery, carpets, curtains, wall covers, tents, and many other items. The fibres used for their production are essentially the same as for comfort fibers. Emphasis here is on safety from burning, dusting, and decaying. Innovations are essentially : better flameproofing agents, permanent finishing to prevent dusting. Soiling, and microbial attack. Some new chemical compositions may have a chance to enter this field such as polyvinylidene chloride, polyvinylidene fluoride, Kynol, Nomex and similar systems.

III. Industrial fibers — emphasis is here on high modulus high tensile strength combined with toughness and thermostability. The most important representatives of this group are carbon fibers, aramids, arylates, glass fibers and aluminium oxide compositions. This field is in a rapidly expanding state with many innovations being made such as less expensive fiber production, better combination of rigidity and toughness, improved resistance against heat and chemicals and others. The uses of these fibers are mainly for the reinforcement of thermoplastics and thermosetting resins. Long fibers are used in the reinforcement of rubber in tyres, hoses and transport belts and in the reinforcement of plastics in the form of prepegs. Short fibers are used in composites which start to replace metals in airplanes, cars, boats, in the form of sheet molding compounds (SMC and reaction injection molding) RIM.

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Inauguration of the Demonstration Plant For Synthetic Fibres

Introductory Address by

Mr. J. G. Parikh,

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Introductory address by Mr. J. G. Parikh, Director, Sasmira at the Inauguration of the Demonstration Plant for Synthetic Fibres held on 4th April, 1982.

Today is a memorable day in the annals of Sasmira and man-made fibre and textile industry in this country. Inauguration of the Demonstration Plant for Synthetic Fibres is a landmark in the history of Sasmira.

On such an auspicious occasion we are most fortunate to have as our Chief Guest Mr. Pranab Mukherjee, Union Finance Minister to inaugurate this prestigious project. Mr. Mukherjee before taking over the portfolio of Finance was in charge of the Ministry of Commerce, with which Sasmira is linked. The implementation of this project is largely due to the positive assistance, encouragement and guidance received from the Ministry under his stewardship. My colleagues and myself extend a very cordial welcome to him this morning.

Sasmira which was set up in 1950, has been actively associated with the progress and development of man-made textile industry. Sasmira's activities comprise of research and development, market and techno-economic studies, technical service, testing and technical education.

Realising the importance of trained technical personnel to man the man-made textile industry, Sasmira has launched various courses covering all the process stages of textile manufacture. The Demonstration Plant for synthetic fibres, which is being inaugurated today, by Mr. Pranab Mukherjee, has given a new dimension to the training programme of Sasmira. With the facilities created in fibre technology, a Diploma Course in Man-made Fibre Manufacture has already been initiated. This Diploma course is fully aided by the Ministry of Commerce, Government of India. Shortly, it is intended to add two more training programmes in this field on Certificate and Post-graduate levels. Besides it is proposed to conduct courses for operators and provide skilled operators for the industry.

Setting up of the Demonstration Plant for synthetic fibres is the beginning of the realisation of the aspirations of Sasmira to serve the entire spectrum of man-made fibre and textile industry.

The Demonstration Plant consists of polymerisation and polycondensation units, spinning line, staple fibre unit and draw twisting equipment. The plant can polymerise Nylon 6, Nylon 66 and Polyester and spin these three materials to textile and technical filaments and staple fibre tow. The take up unit covers up both speed ranges — high speed spinning with draw winding and the conventional spinning speed range. Draw twisters have been provided for both textile and technical yarns, staple fibre unit with drawing lines for processing of staple fibre tow of the three materials. The capacity of the polymerisation unit is 500 kg. per day for polyester polymer, 400 kg. for Nylon 66, and 250 kg. for Nylon 6. The polymerisation equipment has been designed with maximum flexibility for utilising it for any of the three products.

As a part of the Demonstration Plant Project a Fibre Research Laboratory has been set up. The laboratory is equipped with most modern equipment for analysis of monomers, polymers and intermediates, auxiliaries and fibres. The laboratory has been planned for carrying out R & D work on bench scale to be later transferred to the Demonstration Plant for commercial exploitation. The facilities of the laboratory are already being utilised by fibre and chemical manufacturers.

The utility and the objectives of the plant have been elaborately discussed in the four day International Conference on Man-made Fibres for Developing Countries concluded on 1st April, 1982. We had with us world renowned scientists and national representatives from eleven developing countries, some of whom are present with us to witness this function. They have had the opportunity to visit our laboratories and understand what India can offer to the developing countries in this field. With this Conference we have established close relationship with the Developing Countries and these bonds will be further strengthened with the opening of Sasmria facilities for the Developing Countries.

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International Conference on Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

Introductory address by

Mr. J. G. Parikh

Director, Sasmira

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UNIDO • GOVERNMENT OF INDIA • SASMIRA

Introductory address by Mr. J. G. Parikh, Director, Sasmira at the inauguration of the International Conference on Man-made Fibres for Developing Countries held at SASMIRA on 29th March, 1982.

The International Conference on Man-made Fibres for Developing Countries is meeting at a time when man-made fibres are assuming increasing economic importance in meeting the clothing needs of the world and more so of the developing countries. We are therefore fortunate to have with us Mr. L. K. Jha, an eminent economist and the Chairman of the Economic Administration Reforms Commission as Chief Guest to inaugurate the Conference. My colleagues and myself in Sasmira, members of the faculty and students of the Institute extend him a very cordial welcome this morning. Mr. Jha has held numerous important national and internatonal assignments representing Government of India, such as Governor of Reserve Bank of India, Governor for India in International Monetary Fund, Ambassador to U.S.A., Chairman, U.N. Group of eminent persons on Multinational Corporation, Member, International Commission on International Development Issues, etc.

We have amongst us the world renowned polymer scientist, Prof. Dr. Herman F. Mark from Polytechnic Institute of New York. His presence at this scientific Conference dealing with synthetics adds significance to this International meet. Dr. Mark is going to actively participate in the Conference and deliver a keynote address at the inaugural session. The Conference is sponsored by United Nations Industrial Development Organisation, Government of India and Sasmira. Dr. D. G. A. Butaev, Director, Division of Industrial Operations, UNIDO, has come all the way from Vienna to attend the Conference.

The International Conference on Man-made Fibres for Developing Countries has been conceived for exchange of thoughts and mutual experience amongst the developed and developing countries with a view to evolve a programme for the growth and development of man-made fibres in the developing countries. Experts of all branches of technology and textile research, engineers from man-made fibre and textile converting plants and economists from developed and developing countries are meeting at this gathering.

National experts from fourteen developing countries which include Argentina, Bangladesh, Brazil, China, Colombia, Egypt, Indonesia, Iraq, Mexico, Peru, Romania, Thailand, Turkey and Venezuela are with us to participate in the Conference. I welcome them to this meet and wish them success in their deliberations.

Next to being properly fed, the need to be clothed ranks as one of the most basic needs of human requirements. It is evident that with world population growing at the rate it is, many problems lie ahead in providing these essentials. It is also evident that as living standards rise, especially in the developing countries, so will the demand for fibres, for apparel, home furnishings and industrial use. The factors which play a part in the supply of natural fibres are land availability, climate and output per acre. These are finite bearing a very close relationship to food production. Synthetic fibres depend on the supply of hydro-carbons of which reserves are not finite either, but which do not affect the food supply.

Important to the Conference is the fact that growing population of the world is expected to reach the five billion point sometime around 1988. The critical factors to be considered for future requirements are food, where will these people live and what will they wear? The major population growth will occur in the developing countries. This represents a challenge for the man-made fibre and textile industry in developing countries to make available staggering proportions for themselves and the developed countries as well.

During the Conference, papers on the scientific and technological aspects of modern development of technology on man-made fibres will be presented by the experts from developed countries and India. This would provide the required base in selection for adopting the required technologies for different countries. The developing countries which are represented in this Conference will be presenting the situation of the industry in their countries bringing out the basic needs for man-made fibres. The discussions will also bring out the requirements of the respective Developing Countries for technology, raw material, expertise and training.

SASMIRA is a research association which is commit towards the growth and promotion of science and technology in man-made fibres and textiles. With the creation of facilities in man-made fibre technology by setting up the Demonstration Plant for synthetic fibres and the Fibre Research Laboratory, SASMIRA offers a wide range of services in the development of technology, training, techno-economic studies and technical consultancy. During the four days of the Conference the delegates to the Conference will get an opportunity to familiarise themselves and understand what Sasmira is and what it can do for the developing countries.

The industry is gaining importance in India because of the discovery of oil in different parts of the country. India has tremendous scope to increase the availability of man-made fibres, specially synthetic fibres.

It is not possible for a country to be self-sufficient in all respects. It is applicable for both the developed and developing countries. The knowledge and resources have to be shared and the developed and developing countries should come forward to share their facilities and knowledge for the progressive development of the fibres and textiles. In the case of developing countries, it is necessary to tap their resources to find out as to from which stage this industry needs to be set up, and what part of the fibres and textiles is required to be shared from other countries. The real purpose of holding the

Conference would be realised if agreed policy options are evolved for utilisation of the different technologies and fibres for the respective developing countries according to their needs.

Man-made fibres are basically the product of science and technology and the progress in the production of man-made fibres is directly related to the technological advances pioneered by the scientists and technologists. Constant rationalisation, improvement and automation of production processes are the key factors for advancement of process technology. Man-made fibres may be described as tailormade fibres because they can be adopted to meet the requirements of various textile applications during their production.

The advancement of technology in the developed countries has been tremendous, whereas that in developing countries is rather slow. This has resulted in a technological gap which needs to be bridged with studied requirements of the present and future needs of the developing countries keeping in mind the resources available with them. The Conference sessions will discuss all the aspects related to the technological and economic aspects essential for a planned development of the industry in respective developing countries.

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International Conference on
Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN DEVELOPING COUNTRIES

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Contents:

Country : INDONESIA

Speaker: **Dudun Sugandi**
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THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN INDONESIA

1. Introduction:

This paper is submitted to the "International Conference on Man-made Fibre" as a country paper, conserning the situation of synthetic fibre industry in Indonesia. This country paper will become a subject of discussion and exchange of idea among the participants.

This Man-made Fibre Conference is sponsored by SASMIRA representing the Government of India, UNIDO from UNDP and GTZ from the Federal Republic of Germany. This conference will be held at SASMIRA Premises in Bombay (India) from 29th March 1982 to 1st April 1982.

To cope with the present situation of synthetic fiber industry in Indonesia, this paper is compased of five parts.

Population growth and the increase of per capita income serve as a back ground of the increase of textile consumption year by year. The increasing consumption speed by the development of textile industry in 1970's.

Along with the development of the textile industry, raw material supply has become a big problem due to inadequate production of fiber in Indonesia. The problem becomes more serious with the tendency of using man-made fiber in larger and larger proportions. For this reason, a synthetic fiber industry in Indonesia is a feasible opportunity from the viewpoint of the supply of textile raw material.

II. Development of Textile Industry and Consumption in Indonesia.

Three main factors that stimulate the development of textile consumption in Indonesia are :

1. Demand for textiles occupies the second place in priority after food.

2. Population growth.
3. Increase of per capita income.

Indonesia population is estimated 151 millions in 1981 and will be increased to 167 millions in 1985. This population factor is one of the quantitative factors. Qualitative factors like development of culture are also dominant in determining the demand of textiles.

The increase of per capita income as shown in Table II-1 indicates per capita income of Rp 59.500,- in 1975 and it is estimated at Rp 105.000,- in 1985 (US$ = Rp 625,-). This tendency goes parallel with the economic development in Indonesia.

Table II-1

Income per Capital and Population (1975 - 1985)

Year	Income per Capita (Rp)	Population (1.000 (Person)
1975	59,500,-	132
1980	77,700,-	148
1985	105,100,-	167

i US$ = Rp 625,--

This increase of per capita income has direct relationship with per capita consumption of textiles ; so it is estimated at 12,49 m in 1981 and up to 14,36 in 1985 as shows in Table II-2.

Table II-2

Estimated Textiles Consumption per Capita (1977 - 1985)

Year	Grams	Meters
1977	1396.88	11.8
1978	1431.25	11.45
1979	1468.75	11.75
1980	1510.00	12.08
1981	1561.25	12.49
1982	1615.00	12.92
1983	1672.50	13.38
1984	1732.50	13.86
1985	1795.00	14.36

If we observe closely we will find out that the influence of population growth on the increase of textile consumption is not so sensitive. The increase of per capita income from 1981 to 1985 amounting to 35% will effect an increase of per capita textile consumption of 15%. The reasons for this are more or less as follows :

1. The income level is still relatively low.
2. The demand for textile is not so diversified because Indonesia is a tropical region.
3. The demand for goods is more diversified with the cultural background.

Based on the above factors and results of several surveys conducted in the past it is estimated that the textile consumption in Indonesia figures out in Table II-3. Those estimates don't include quantities for export of textiles and garments in relation to the transfer of textile production pattern from developed to developing countries.

The overall development of textile consumption has stimulated the development of textile industry in Indonesia. In 1970's the development of textile industry is very rapid although at that time the textile production still did not fulfil the entire requirement.

Table II-3

Estimated Textiles Consumption (1977 - 1985)

Year	Population (1.000.000 Person)	Textile Cons'n (1.000.000 Meter)
1977	138	1,542.84
1978	141	1,614.45
1979	145	1,703.75
1980	148	1,787.84
1981	151	1,885.99
1982	155	2,002.60
1983	159	2,127.42
1984	163	2,259.18
1985	167	2,398.12

The rapid development is obvious in the spinning sector. The development in the weaving sector is not so well as spinning, because this sector should adjust itself with the development of textile consumption and it should wait until the balance of production is reached in the spinning sector.

III. The Development of Synthetic Fiber Requirement

1. Background

As aforementioned the development of textile consumption has stimulated the development of textile industry resulting in the decrease of textile import.

The growth of the textile sector so far is aimed the following objectives:

1. To fulfill the domestic requirements and improving the balance of supply and demand.
2. To create the balance of production between upstream and downstream industries in the textile sector.
3. To reduce dependency on foreign sources.
4. To develop export capacities.
5. Transfer of textile technology.

Those objectives have positioned textile industry at an important place in the arena of industries in Indonesia.

This success has raised another problem, namely the supply of fiber especially synthetic fiber. The fiber consumption in Indonesia in the last 8 years shows a relatively high increase, 28%, and its contribution to the total fiber consumption has exceeded 50%.

Factors in the background are :

1. The increase of synthetic fiber consumption.
2. The domestic production of synthetic fiber has started and developed.
3. Quotas of textile imports.
4. Limited sources of natural fiber in Indonesia.

2. Development of Consumption:

The synthetic fiber consumption will increase substantially in the future be in line with the increase of textile consumption due to the change of consumer's taste and scarcity of natural fiber supply in Indonesia.

From the prospect of textile consumption development it could be estimated that the per capita synthetic fiber consumption of 1.4 kgs in 1977 will raise to 1.7 kgs in 1983 and in 1994 the figure could be projected to 2.52 kgs per capita. If we include the population growth rate factor we will find that the total synthetic fiber requirement in 1983 is 270 million kgs, in 1988 around 382 million kgs. and in 1994 about 515 million kgs. These result in an average annual increase of about 6%.

The synthetic fibre as a substitute of the natural fiber will be increasingly consumed as aforementioned. This increase is not only effected by the increase of total textile fiber consumption but also effected by the increase of synthetic fiber contribution to the total textile fiber consumption.

The tendency of the increasing contribution of synthetic fiber as described by "Textile Organon" in Table III-1.

Table III-1

Contribution of Synthetic Fibre to the total Fibre consumed (World)

Year	Total Fibre (1000 Ton)	Synt'c Fibre (1000 Ton)	Contribution (%)
1960	14,916	702	4.7
1965	18,445	1,976	10.7
1970	21,561	4,700	21.8
1974	26,587	7,485	28.2
1977	27,879	9,047	32.5

Resource :Textile Organon

Table III-2

Contribution of Synthetic Fibre to the Total Fibre Consumed (Indonesia)

Year	Total Fibre (1000 Ton)	Synt'c Fibre (1000 Ton)	Contribution (%)
1972	142.3	32.8	23
1973	151.2	46.0	30.4
1974	149.9	57.0	38
1975	163.3	73.9	45.3
1976	190.0	98.0	51.6
1977	203.0	110.0	54.1

Table III-2 shows synthetic fiber consumption situation in Indonesia where the contribution is higher than the world situation. In 1977 the contribution level is 54.1%. It is estimated that the contribution will be levelling off at 63% in 1988.

Table III-3 shows that polyester fiber is the largest component. The consumption of nylon and acrylic in the textile sector tends to decline and using of nylon and acrylic outside the textile sector is relatively small.

Table III-3

Synthetic Fibre Consumption (Indonesia)

Year	Nylon	Acrylic	Polyester	
			Ton	%
1972	10,000	2,100	20.700	63.1
1973	13,400	2,700	29,900	65
1974	14,500	2,600	39,900	70
1975	16,200	3,400	54,300	73.5
1976	18,000	5,000	75,000	76.5
1977	19,000	5,000	[illegible]5,000	78.2

IV. The Synthetic Fibre Industry

The consumption of synthetic fiber was started in 1968. Fiber types used were polyester, nylon filament and textured nylon. All requirements were imported until 1973.

The production of domestic synthetic fiber was started in 1973 with nylon filament. The production of polyester fiber and filament was started in the following years.

The present production capacities are as follows :

Nylon filament	33	tons / day
Polyester filament (flat & poy)	180	tons / day
Polyester fiber	136	tons / day
Rayon (under construction)	34.7	tons / day

Nylon fiber, Rayon filament, Acrylic and others are not yet product. Nylon filament is produced by two mills with a capacity of 10 tons / day in 1974 and 33 tons / day at the present time. Since the consumption development is not so promising, for the fine being, it was not necessary to increase nylon production.

In the polyester sector there are 6 mills operating, of which 2 mills exclusively produce polyester SF (staple fiber), one mill produces polyester SF and YF (filament yarn), and the other three produce FY. The capacity of the two rayon fiber plant is 34.7 tons/day, which is too small (under economic unit), but it fulfills the present requirement. From the development of production pattern we may conclude that polyester production plays an important role.

V. The Balance of Supply and Demand for Polyester Fibre.

From the discussion of the development of synthetic fiber consumption and industrial capacities it could be concluded that in Indonesia the consumption is larger than the domestic production. In order to fulfill the requirement the balance should be reached by import of synthetic fiber especially polyester.

Table V-1

Estimated Market Condition of Polyester Fibre (SF)

year	Domestic Prodin	Demand	Ton / Year Non Consumed	
			Ton	%
1977	44,880	51,600	6,800	13
1980	44,880	66,800	21,920	32.8
1983	54,780	80,100	25,220	31.6
1988	54,780	114,600	59,820	52.2
1994	54,780	171.900	117,120	68.1

Table V-1 shows a conservative picture of the balance situation for polyester SF exclusively. This balance situation is based on the assumption that the domestic production capacity remains constant from 1983 while the demand for polyester Sf develops.

Prospective demand for total polyester (SF and FY) from 1983 to 1994 is picturized on Table V-2. The increase of demand up to 1988 is estimated at 7.5% annually and in the superceeding period around 7% annually.

From the situation described in Table V-2 we could notice that the gap between the domestic production and the domestic demand (especially for polyester SF) becomes larger and larger. For this reason capital investment in this industrial sector would a fairly good opportunity.

Table V-2

Estimated Polyester Fibre Consumption (1983 - 1994)

Year	SF (Ton)	FY (Ton)	Total (Ton)
1983	80,000	53,400	133,500
1984	86,100	57,400	143,500
1985	92,600	61,700	154,300
1986	99,500	66,300	165,800
1987	107,000	71,000	178,300
1988	114,600	76,400	191,000
1989	122,600	81,800	204,400
1990	131,200	87,500	218,700
1991	140,400	93,600	234,000
1992	150,300	100,100	250,400
1993	160,800	107,100	267,900
1994	171,900	114,600	286,500

Country : PERU

Speaker : **Humberto Dulanto Alfaro**

Instituto de Investigacion Technologica
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Peru.

THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN PERU

Introduction

Peruvian textile industry is in a prominent place among the production enterprises, employing 20% of the total of manufacturing industry persons and paying the best salaries.

The structure of textile industry has been changed considerably in the last twenty years. The area of Lima occupies the 80% of total employment, then it is followed by Arequipa, Cuzco, Huancayo, and in low scale Ica and Piura.

Most of textile industries depend greatly on few ones which supply them the raw material. Those are the factor of great incidence in the costs and obtaining them in quantity, opportunity, price and conditions of suitable payment.

We must remark that in Peru there are only few enterprises that are suppliers of rayon, polyester, polyamide and acrylics, all of them artificial and synthetic fibres of strong development in the last years.

Because of various reasons, there are competently big and small enterprises in spinning, weaving and needle industry. That has facilitated the permanent incorporation of new small enterprises in an excessive number of establishments for our reduced national market.

Our small market requires a diversification of products that goes against standarization and the production of long series of manufacturing. There is not the duly standarization of qualities, thus products of low quality compete to advantage with prices which don't keep relation with their costs because of bad information or disregard among the consumer public.

It is evident that this way is leading to a conglomerate of industries, which although they can maintain into our domestic market, at the moment customs barriers would be opened and they intend to compete in wider markets no protected, they will do in conditions of unfavourable costs and most critical is that they will not have suitable experience to adjust them in a fast way to those new demands. In this sense, we must recognise that we need higher economic and technological resources.

1. Production capacity

1.1 Installed capacity: Due to various factors by which textile industry in Peru is running through, it has been determined approximately that real efficiencies in synthetics and artificials fibres reach in average: at spinning mills: 80% and at weaving: 90%.

Synthetics and Artificials

	Spinnings	Weavings	
	(tons)	ton	metres
Installed Capacity efficiency 100%	17,047	12,629	46,783
Highest real capacity	13,638	11,360	42,105

1.2 Utilized capacity: In 1979 spinning and weaving production reached the following volumes:

Spinnings	Weavings	
(ton)	ton	Metres in thousands
12,202	9,003	35,391

1.3 Useless capacity.

	Spinnings	Weavings
Manufactured fibres	11%	21%

2. Raw material

2.1 Production

Production in Peru, generally, has developed with an accelerated rate of growth (23%), increasing its participation into industrial sector.

In 1979, total production reached 27, 113 tons corresponding approximately the 93% to synthetic fibre production and the 7% remainder to artificial fibre production.

Within synthetic fibres, we can observe that production of acrylic fibres share with 63% followed by polyester fibres with 27% and the polyamides with 10%.

2.2 Consumption

In general terms, the production of synthetic and articial fibres supplies requirements of market, generating a small surplus for export.

Nevertheless, if we analize in an independent way, the production of polyester and polyamide filaments, we observed that:

- In Peru most of types known as the most commercials in international market, satisfying the consumption.
- About Polyester, the most representative types in regard to its production are the Denier 150 and the 70/75, with 74% and 23% respectively.

  The types less significant (45,55 Denier) are those of less consumption, since in Peru there is a reduced number of machines which use those types.
- About polyamide, consumed quantities have had a constant demand with a tendency of decreasing. Most of those filaments are used in manufacture of hosiery and socks.

3. Market

Production of synthetic and artificial sector has been the most dynamical within spinning and weaving production, with growth rates of approximately 17% and 13% respectively. It is also reflected in the increase of percent participation of synthetic and artificial sector in relation to total production of textile sector.

4. Demand

It has been determined that the growth rate for spinnings was about 16.6% and for weavings about 11.5%, being the greatest within textile sector.

Among other factors, increase of demand depends mainly on increase of population and on purchasing power of it.

5. General appreciation

5.1 Textile industry in Peru, in regard to spinning and weaving activity, in 1979, used about 88% and 82% of its installed capacities respectively, these percentatges have decreased about 10% in relation to 1979 because the country is passing a crisis.

5.2 Export of textile products to other countries must be foster in order to neutralize recessive effects on production due to the contraction of domestic market.

Country : THAILAND

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THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN THAILAND

Synthetic fiber production in Thailand began in 1969 by producing polyester fiber, followed by nylon 6 production in 1970. Nowadays there are six companies who produce synthetic fibers. The production capacity are 50,000 metric tons per year for polyester staple fiber, 20,000 metric tons per yea for polyester filament yarn, 2,500 metric tons per year for polyester partially oriented yarn and 17,000 metric tons per year for nylon filament yarn. The mentioned production is close to capacity.

Thailand has population of 46 millions in 1981 and the annual growth rate is 2.4%, i.e. one million people. The approximate amount of 50% of the synthetic fiber production is for domestic use, 45% for producing goods for exporting and the remaining 5% for direct export.

The domestic consumption of polyester and nylon from 1976 to 1981 (first quarter) is shown in Table 1. The synthetic fiber manufacturers had planned to increase their production to support the expanding spinning mill in 1981. But the main worry is that South Korea and Taiwan appear to be planning to expand synthetic fiber production quite substantially which will affect world market prices. However the Thai Government has placed surcharge of 20% on these fibers and filament yarns to help the domestic manufacturers.

For acrylics and wool, the domestic consumption is small due to the tropical climate in Thailand. However, some of the fibers and yarns are imported to be used in knitted garments and carpets for exporting. Table 2 shows the amount of the imported fibers and yarns of acrylics and wool from 1977 to 1979. The imported fibers are spun into woollen yarn.

Since the synthetic fibers are blended with cotton and rayon, it is worthwile to mention these two fibers. There is one rayon manufacturer whose production is approximately 9,000 metric tons per year. Most production are locally consumed.

For cotton, the total consumption of cotton fiber in 1980 is over 100,000 metric tons and the 80-90% of this amount is imported. The cotton yarn consumption in 1976 to 1980 is shown in Table 3. Actually Thailand herself has good trend in producing long staple cotton fiber with excellent quality. The reasons why Thailand has to import most of the cotton is Thai farmers have no intention for growning cotton unlike most other crops which flourish in Thailand. Also cotton cultivation needs constant attention and higher capital investment. However, the Thai government has planned to promote cotton cultivation under the fourth five-year economical and social development planning (1982 to 1987) in order that the Thai herself has enough cotton to cover the consumption as well as exports.

For the textile industry situation, Thailand is one of the leading textiles exporters in the Asian region exporting some 400,000 sq. yards of the fabrics and over 100 million pieces of garments in a year. The exports income ranges about 10,000 million baht (U. S. $ 500 millions) for all textiles products making textile. Thailand's top foreign exchange earner in the manufacturing sector. The industry has a combined capacity of 1,350,000 spindles, 57,000 looms and 37,500 knitting machines. Production is in the region of 2,000 million sq. yards, between 60-70% of which are consumed locally and the rest exported.

Since the nature of the textiles industry tends to have periodical booms and slump years, 1978-1979 was the peak of market demand for textiles and 1980 the market demand began weakening. Therefore the Thai government is persuading textile manufacturers to aim for a higher quality market and increasing garment exporting.

The Thai government established a textile centre named Textile Industry Division (TID) which is in the Department of Industrial Promotion, Ministry of Industry in 1972 under the Co-operation of UNIDO. The TID has responsibilities for textile industry policy and rendering technical assistance as well as training industrial staffs in order to upgrade the textile quality and increase productivity. The TID also has started some research works on Thai cotton classification and grading, Thai silk finishing development and jute technology.

There are also some other institutes which contribute textile technology, namely

— Chulalongkorn University

— Institute of Science and Technology Research

— Institute of Technology and Vocational Education, Bangkok Technical Campus.

Table 1

Domestic Consumption of Synthetic Fibres

Metric Tons

	Polyester Staple Fiber	Polyester Filament Yarn	Nylon Filament Yarn
1976	27,671	10,825	11,153
1977	32,374	11,212	10,454
1978	41,611	10,036	11,578
1979	43,873	10,689	11,857
1980	46,455	12,018	13,022
1981 1st Quarter	13,481	3,038	3,428

Source : The Thai Synthetic Fiber Manufacturers' Association

Table 2

Import of Acrylics and Wool

Metric Tons

	Acrylic		*Wool*	
	Fiber	*Yarn*	*Fiber*	*Yarn*
1977	*857*	*160*	*44*	*187*
1978	*1,480*	*207*	*12*	*284*
1979	*2,743*	*970*	*78*	*467*

Source : Foreign Trade Statistics of Thailand

Table 3
Consumption of Yarn

Tons:

	1976	1977	1978	1979
Cotton Yarn				
Production	85,870	93,766	102,044	104,395
Import	116	59	41	301
Export	882	2,872	2,501	768
Domestic Consumption	85,104	90,953	99,584	103,928
Man-made Yarn				
Production	76,331	88,370	103,596	111,702
Import	5,777	3,413	3,930	6,146
Export	11,648	14,603	19,151	14,696
Domestic consumption	71,060	77,180	88,369	103,152

Source : The Thai Textile Manufacturing Association

THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN TURKEY

IA - Polyester Yarn and Fibre Production Capacities in Turkey

1. Existing situation in polyester industry

Established capacities for polyester fibre and polyester yarn in Turkey are indicated as follows:

COMPANY NAME	POLYESTER YARN CAPACITIES	POLYESTER FIBRE CAPACITIES	
SASA	9000 Ton/year	34.000 ton/year	
FILAMENT	4785 "	-	
POLYLEN	5000 "	-	
SANCAK TUL	5500 "	-	
SIFAS	4000 "	-	
MNS	2100 "	7.000 Ton/year	
TOTAL	30.285 Ton/year	41.000 ton/year	

MNS have been stopped since 1979 due to the difficulties to import TPA and EE from the foreign countries.

2. Editional predetermined capacities

a) SASA provided allowance for 9000 ton/year polyester yarn and 14,000 ton/year polyester fibre establishment.

b) FILAMENT provided allowance for 4785 ton/year polyester yarn additional establishment.

c) AR Sentetik Kimya Sanayii A. S. provided allowance for 6900 ton/year polyester yarn establishment.

Predetermined times for trial operations for these establishments are for SASA 1982 (for yarn), 1979 (for fibre); for FILAMENT 1980 and for AR Sentetik 1979

If we consider these establishments will start operation in 1982 and within 1-2 years reach their exact capacities, for 1984 approximated polyester fiber and polyester capacities are indicated as follows:

	EXISTING CAPACITIES AT THE END OF 1978	APPROXIMATED CAPACITIES IN 1984
POLYESTER YARN	30.285 ton/year	50.970 ton/year
POLYESTER FIBRE	41.000 ton/year	55.000 ton/year
TOTAL	71.285 ton/year	105.970 ton/year

IIA - Production, Import, Export and Consumption

Production, import, export and consumption values for polyester fibre and polyester yarn are indicated in the following table.

(ton)

	YEARS	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
PRODUCTION	POLYESTER YARN	125	462	639	2302	3781	5826	2854	6853	12700	17200
	POLYESTER FIBRE	–	3360	6106	8060	11374	14224	16232	16000	26600	27485
	TOTAL	125	3822	6745	10362	15155	20060	19086	22853	39300	44685
IMPORT	POLYESTER YARN	1279	804	849	789	411	611	1077	1127	367	285
	POLYESTER FIBRE	5586	2304	424	–	–	123	3087	4281	634	25
	TOTAL	6865	3108	1273	789	411	734	4164	5408	1091	310
EXPORT	POLYESTER YARN	–	–	–	–	–	–	–	–	–	–
	POLYESTER FIBRE	–	1,5	233	500	975	1299	–	456	2083	1515
	TOTAL	–	1,5	233	500	975	1299	–	456	2083	1515
CONSUMPTION	POLYESTER YARN	1404	1266	1488	3091	4192	6437	3932	7980	13067	17485
	POLYESTER FIBRE	5586	5964	6530	7580	10759	13048	19319	19825	25151	25995
	TOTAL	6990	7230	8018	10671	14951	19485	23250	27805	38218	43480

IIIA - Demand Projection

Demand projection between 1976 and 1985 is indicated as follows:

(ton)

YEARS	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
POLYESTER YARN	9340	10920	12780	14950	17200	19770	22740	26150	29550	33400
POLYESTER FIBRE	23000	26680	30950	35900	41290	47480	54600	62790	70950	80180
TOTAL	32340	37600	43730	50850	58490	67250	77340	88940	100500	113580

When preparing this demand projection old years situations, producers considerations, future capacity level of Turkey and general situations of the world markets are considered and following demand increase speeds are accepted.

YEARS	POLYESTER YARN	POLYESTER FIBRE
Intermediate value between 1975-1979	% 17	% 16
Intermediate value between 1979-1983	%15	% 15
Intermediate value between 1983-1987	% 13	% 13

Considering real consumption production values for polyester yarn 17.500 ton/year and for polyester fibre 26.000 ton/year (total 43.500 ton/year) and using above mentioned demand increase speeds we can obtain following demand projection

(Ton)

YEARS	POLYESTER YARN	POLYESTER FIBRE	TOTAL
1978	20.475	30.160	50.535
1979	23.956	34.484	58.782
1980	27.549	40.233	67.782
1981	31.681	46.268	77.949
1982	36.434	53.209	89.643
1983	41.895	61.190	103.089
1984	47.346	69.148	116.494

If we compare the values in this demand projection at 1984 (namely 47.346 polyester + 69.148 polyester fibre yarn = total 116.494 ton poliester) with established capacity at 1984 it is understood that most of the demands will be provided by means of conventional productions. But there will be only 11.000 ton/year less production.

If we consider polyester yarn production and polyester fibre production separately in 1984 polyester yarn production capacity will be enough for conventional demand but there wil be 15.000 ton/year less production for polyester fibre production capacity.

IVA - Polyester Raw Materials and Their Providing Possibilities

The main raw material for polyester fibre and polyester yarn is dimethyl-terephtalat (DMT) or terephtalic acid (TPA). For the production of one ton polyester cips 0,9 ton TPA or 1,05 - 1,1 ton DMT is used. 1,05 ton cips are consumed. For 1 ton polyester yarn. But 1,03 ton cips are consumed during the production of 1 ton polyester fibre. Second raw material for polyester production is ethylene glycol (EG). 0,40 - 0,44 ton EG are used for the production of 1 ton polyester cips. The imported values for the raw materials used polyester production in Turkey are indicated in the following table:

RAW MATERIAL / YEARS	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
DMT	143	6294	8311	11095	11035	15337	22450	23125	-	-
TPA	4	7	-	179	34	189	539	2468	7459	7839
EG	828	2969	4276	3964	5854	6528	10429	11282	13745	25750

But in Turkey only SASA have been used DMT as the main raw material in polyester yarn and fibre production. DMT demands were provided by means of import until 1977. After that time with 60.000 ton/year capacity DMT production units of SASA company was commenced. And now in addition to reply local demands, SASA is exporting DMT to the foreign countries.

If we consider that the new polyester yarn and fibre investments of SASA will be commenced in 1982 with % 25 capacity, in 1983 will reach a % 50 capacity and in 1984 will reach a % 100 capacity.

In this case the total cips demands for old and new establishments are indicated in the following table :

(TON)

YEARS		1978	1979	1980	1981	1982	1983	1984
POLYESTER YARN	EXISTING	9.000	9.000	9.000	9.000	9.000	9.000	9.000
	NEW	-	-	-	-	2.250	4.500	9.000
	TOTAL	9.000	9.000	9.000	9.000	11.250	13.500	18.000
	CIPS DEMAND	9.450	9.450	9.450	9.450	11.813	14.175	18.900
POLYESTER FIBRE	EXISTING	34.000	34.000	34.000	34.000	34.000	34.000	34.000
	NEW	-	-	-	-	3.500	7.000	14.000
	TOTAL	34.000	34.000	34.000	34.000	37.500	41.000	48.000
	CIPS DEMAND	35.020	35.020	35.020	35.020	38.625	42.230	49.440
TOTAL CIPS DEMAND		44.470	44.470	44.470	44.470	50.438	56.405	68.340
NECESSARY DMT VALUES		48.917	48.917	48.917	48.917	55.482	62.046	75.174

This table indicates that the demand of DMT in Turkey will be increased to 75.000 ton/year. Therefore 60.000 ton/year existing capacity of SASA will not be enough at that time.

Other polyester yarn and fibre producers in Turkey are using TPA as the main raw material. Considering approximately increased capacities of other polyester producers between 1978-1984, in the following table necessary TPA values are indicated according to the total polyester cips demands:

(TON)

	YEARS	1978	1979	1980	1981	1982	1983	1984
POLYESTER YARN	EXISTING	21.285	21.285	21.285	21.285	21.285	21.285	21.285
	NEW	-	-	-	-	2.921	5.843	11.685
	TOTAL	21.285	21.285	21.285	21.285	24.205	27.028	32.970
	CIPS DEMAND	22.349	22.349	22.349	22.349	25.416	28.329	34.619
POLYESTER FIBRES	EXISTING	7.000	7.000	7.000	7.000	7.000	7.000	7.000
	NEW	-	-	-	-	-	-	-
	TOTAL	7.000	7.000	7.000	7.000	7.000	7.000	7.000
	CIPS DEMAND	7.210	7.210	7.210	7.210	7.210	7.210	7.210
TOTAL CIPS DEMAND		29.559	29.559	29.559	29.559	32.626	35.589	41.829
NECESSARY TPA VALUE		26.603	26.603	26.603	26.603	29.363	32.030	37.646

Until today TPA has been imported from foreign countries. And this situation will go on until the II. Petrokimya anlage (Aliaga) will be commenced in 1984. Here 70.000 ton/year TPA will be produced. After then the whole local demands will be replied easily.

Necessary EG values for polyester yarn and fibre productions are indicated in the following table:

(TON)

YEARS	1978	1979	1980	1981	1982	1983	1984
EG VALUES THAT WILL USE DMT	19.567	19.567	19.567	19.567	22.193	24.818	30.070
EG VALUES THAT WILL USE TPA	11.824	11.824	11.824	11.824	13.050	14.236	16.732
TOTAL EG VALUES	31.391	31.391	31.391	31.391	35.243	39.054	46.802

Also EG has been imported until today. This will go on until the II. Petrokimya anlage (Aliaga) will be commenced in 1984. Here 60.000 ton/year EG will be produced.

And initial raw material of DMT, namely P-ksilen will be imported also until the II. Petrokimya anlage will commence.

IB - Acrylic Fibre Production Capacities in Turkey

1. Established capacities

The evaluation of the acrylic fibre established capacities are indicated in the following table :

COMPANIES	1972	1973	1974	1975	1976	1977	1978
AKSA	5.250	5.250	10.000	10.000	40.000	40.000	40.000
YALOVA ELYAF	-	-	-	-	-	7.000	7.000
TOTAL	5.250	5.250	10.000	10.000	40.000	47.000	47.000

2. Predetermined additional capacities

—AKSA has reached a 48.000 ton/year capacity in 1979 and 56.000 ton/year additional capacity will be commenced in 1982.

—YALOVA ELYAF SANAYII was applied to provide allowance for 5500 ton/year additional capacity in 1979, but this allowance was not taken.

—SASA was attempt to provide allowance for 20.000 ton/year acrylic fibre establishment but then SASA was not able to deliver project, therefore at the end of 1978 this allowance was stopped.

IIB - Production Values for Acrylic Fibre

Practical production values for AKSA and YALOVA ELYAF are indicated in the following table :

COMPANY YEARS	AKSA	YALOVA ELYAF	TOTAL
1972	6.000	-	6.000
1973	9.000	-	9.000
1974	10.000	-	10.000
1975	10.000	-	10.000
1976	17.000	-	17.000
1977	29.000	6.000	35.000
1978	35.000	4.000	39.000
1979	40.000[X] 45.000[XX]		

X This value was guaranteed by AKSA
XX This value was approximated by AKSA

IIIB - Import Values

Imported acrylic fibre values between 1972 and 1978 are indicated in the following table:

YEARS	IMPORTED VALUES
1972	6.523
1973	2.867
1974	12.337
1975	8.871
1976	12.107
1977	6.072
1978[x]	171 250

x in 1978 imported acrilic fibre values were decreased.

IVB - Exportede Values

In 1978 2000 ton/year acrylic fibres were exported to foreign countries.

According to the AKSA managers opinion there is possibility to export 10.000 or 15.000 ton/year acrylic fibre, but capacity of the plant is not enough.

VB - Consumption of Acrylic Fibre

Local consumption of acrylic fibres is indicated in the following table: (Production + import — export = consumption)

YEARS	CONSUMPTION VALUES
1972	12.523
1973	11.867
1974	22.337
1975	18.871
1976	29.107
1977	41.072
1978	37.250

VIB - Demand Projection

Demand projection of acrylic fibre in Turkey is indicated in the following table :

(Production + import — export = consumption)

YEARS	CONSUMPTION VALUES
1976	22.650
1977	27.170
1978	32.610
1979	39.130
1980	45.780
1981	53.570
1982	62.670
1983	73.320
1984	82.850
1985	93.620
1986	105.790
1987	119.550

When preparing this table following predetermined demand speeds are accepted:

Between 1975 - 1979 yearly % 20
,, 1979 - 1983 yearly % 17
,, 1983 - 1987 yearly % 13

— In 1975 the real demand level was 19.000 ton/year
In 1976 real demand level was 29.107 ton/year instead of 22.650 ton/year
Between 1975 and 1976 demand increased by % 53 instead of % 20.

In 1977 the real demand value is 41.072 ton/year instead pf 27.107.

Between 1976 and 1977 demand increase % is % 41 instead of % 20.

In 1976 and 1977 the demand of acrylic fibre was more than the approximated demand values.

In 1978, acrylic import was boundered, therefore there is a reltive demand decrease in this year.

That's why if we accept the real demand value in 1978 as 37.000 ton/year and using above mentioned yearly demand increase speeds demand projection for acrylic fibre is indicated in the following table : (Between 1979-1985)

YEARS	ACRYLIC FIBRE DEMAND
1979	44.400
1980	51.948
1981	60.779
1982	71.111
1983	83.200
1984	94.016
1985	106.238

VIIB - Necessary Establishments according to estimated demand:

If we compare established capacities with the above mentioned demand projection, in 1985 there will be approximately 40.000 - 50.000 ton/year less production. If we consider export possibilities also, it is necessary to establish a new acrylic plant with 50.000 ton/year capacity. That's why not AKSA has a new modification. We hope that at the end of 1982 AKSA will commence it with 56.000 ton/year additional capacity.

VIIIB - Acrylic Fibre Raw Materials :

1. Acrylonitryl

Until now this main raw material for acrylic has been imported. This will go on until the II, Petrokimya Komplex (Aliaga) will be commenced in 1984

1,01 ton acrylonitryl is necessary for the production of 1 ton acrylic.

If we want to reply the whole local demandwith local production, necessary acrylonitryl values are indicated in the following table:

YEARS	ACRYLONITRYL DEMAND
1979	44.844
1980	52.467
1981	61387
1982	71.822
1983	84.032
1984	94.956
1985	107.300

The production program situated in II. Petrokimya Komplex is indicated in the following table :

YEARS	PRODUCTION PROGRAM
1979	-
1980	-
1981	35.000
1984	52.500
1983	63.000
1984	70.000
1985	70.000

If we compare the demands of acrylonitryl between 1979 and 1985, it is obvious that there is not any possibility to reply all the local acrylonitryl demands. After then by reason of some less possibilities, above mentioned production program is prolonged 3 years. In this case it will be commenced in 1984 instead of 1981.

2. Dimethyl Formamid or Dimethyl Acetamid

The second important raw material used in acrylic fibre production is dimethyl formamid or dimethyl acetamid. So far this raw material has been imported and there is not any attempt to establish some plants for the production of above mentioned raw materials. Therefore we hope that it will be provided by means of import also in future.

The necessary dimethyl formamid value for 1 ton acrylic fibre production is 0.07 tons.

If we think to reply all the local acrylic fibre demands by means of production, necessary DMF values are indicated in the following table :

(TON)

YEARS	DMF DEMANDS
1979	3.108
1980	3.636
1981	4.255
1982	4.978
1983	5.824
1984	6.581
1985	7.437

IC - Polyamid Fibre and Yarn Capacities in Turkey

1. Established Capacities

Established polyamid fibre and yarn capacities are indicated in the following table :

COMPANIES		POLYMERIZATION		FIBRE		YARN	
		Ton/day	ton/day	Ton/day	Ton/day	Ton/day	Ton/day
SİFAS	Ny 6	22,8	8208	11,0	3960	19,6	7056
	Ny 66	4,5	1620	-	-	1,0	360
İMSA		17,0	6120	-	-	14.0 3.0	5040 1080
TEKST İPLİK		13,0	4680	-	-	13,0	4680
TOTAL	Ny 6	52,8	19008	11,0	3960	49,6	17856
		4,5	1620			1,0	360

2. Demand Projection

Demand projection for polyamid fibre and yarn is indicated in the following table :

(TON)

NAME YEARS	POL YAMİD YARN	POLYAMID FIBRE	NYLON CORD YARN	TOTAL POLYAMID
1976	9.900	4.000	4.000	17.900
1977	10.600	4.600	6.000	21.200
1978	11.400	5.300	7.200	23.900
1979	12.200	6.100	8.000	26.300
1980	13.100	7.000	10.000	30.100
1981	14.000	8.000	11.000	33.000
1982	15.000	9.200	13.600	37.800
1983	16.100	10.200	15.000	41.300
1984	17.200	11.200	15.600	44.000
1985	18.400	12.300	16.000	46.700
1986	19.700	13.500	16.000	49.200
1987	21.000	14.800	16.000	51.800

ID - Additional Predetermined capacities according to the 4. Planning Period (1977 - 1982) for five years

In 4. planning period between 1977 and 1982 predetermined additional synthetic capacities are indicated in the following:

1. **For Polyamid investments**
   a) Polyamid fibre — 10.000 ton in 1979
   b) Nylon cord yarn — 15.000 ton in 1980

2. **For Polyester investments**
   a) Polyester fibre — 20.000 ton in 1981

3. **For acrylic investments**
   a) Acrylic fibre — 20.000 ton in 1981

If above mentioned capacities can add during 4. planning period (namely between 1977 - 1982) this will be enough for local demands.

But during 5. planning period 1982 - 1987 following additional capacities will be useful.

a) 4000 ton/year polyamid yarn investment in 1985
b) 40.000 ton/year polyester fibre capacity between 1983 and 1985
c) 20.000 ton/year polyester yarn capacity between 1985 and 1987
d) 40.000 ton/year acrylic fibre capacity (with polymerization unit) in 1984

By the reason of above mentioned additional fibre and yarn capacities between 1977 and 1987 following polymerization additional capacities will be also useful.

a) 10.000 ton/year nylon — 6 in 1979
b) 15.000 ton/year nylon — 66 in 1980
c) 10.000 ton/year nylon — 6 polymerization in 1985
d) Polyester Polymerization
    20.000 ton/year in 1982
    30.000 ton/year in 1984
    30.000 ton/year in 1986

IE — Capacity Distribution of Synthetic Fibre and Yarn Establishments in Turkey in 1981

In the attached table all present synthetic fibre and yarn investments are indicated.

IF — Demand Projection Curves

In the attached diagrams demand projections are indicated separately for synthetic fibre and yarns in Turkey.

CAPACITY DISTRIBUTIONS OF SYNTHETIC YARN AND FIBRE ESTABLISHMENTS IN TURKEY AT 1981

POLYESTER

COMPANIES	POLYMERIZATION		FIBRE		YARN		NOT
	Ton/Day	Ton/Year	Ton/Day	Ton/Year	Ton/Day	Ton/Year	
SASA	[illegible] [illegible]	43800 75000	94.0 131.0	34800 48000	25.0 67.0	[illegible] 24000	
FILEMENT	15.0 30.0	5400 [illegible]	20.0	7200	16.0 30.0	5400 [illegible]	[illegible]
POLYLEN	[illegible]	[illegible]	-	-	13.0 16.0	5000 5760	[illegible]
SIFAS	[illegible]	[illegible]	-	-	13.0 15.0	4680 5400	
MINSABUNCU	12.0	4320	7.0	[illegible]	5.0	[illegible]	
SANCAKTUL	[illegible]	[illegible]	-	-	5.3	[illegible]	
NERGIZ	-	-	-	-	13.0	[illegible]	Necessary cips will be bought
TOTAL	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	[illegible] 57720	[illegible] [illegible]	[illegible] [illegible]	

POLYAMID

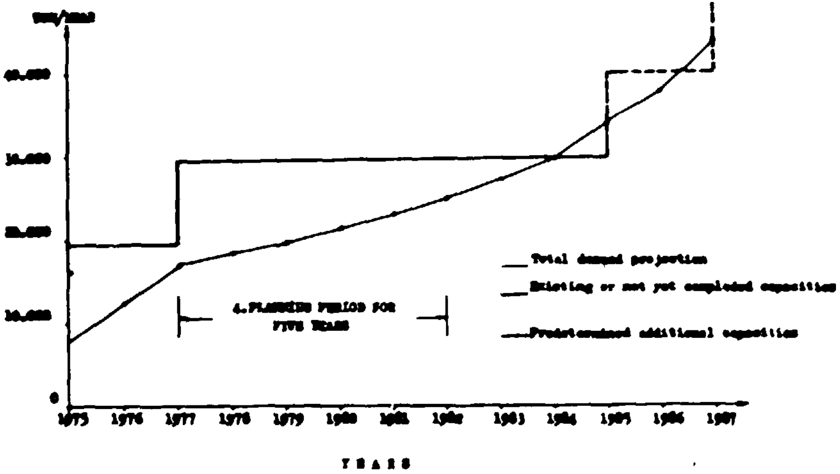
SIFAŞ Ny 6 Ny 6.6	22.0 4.5	[illegible] [illegible]	[illegible] -	[illegible] -	[illegible] 1.0	[illegible] [illegible]	
INSA	17.0	[illegible]	-	-	14.0 3.0	5040 [illegible]	[illegible]
TEKSIPLIK	13.0	[illegible]	-	-	13.0	[illegible]	
TOTAL Ny 6	52.0 4.5	[illegible] 1520	[illegible]	[illegible]	[illegible] 1.0	[illegible] [illegible]	

AKRILIK

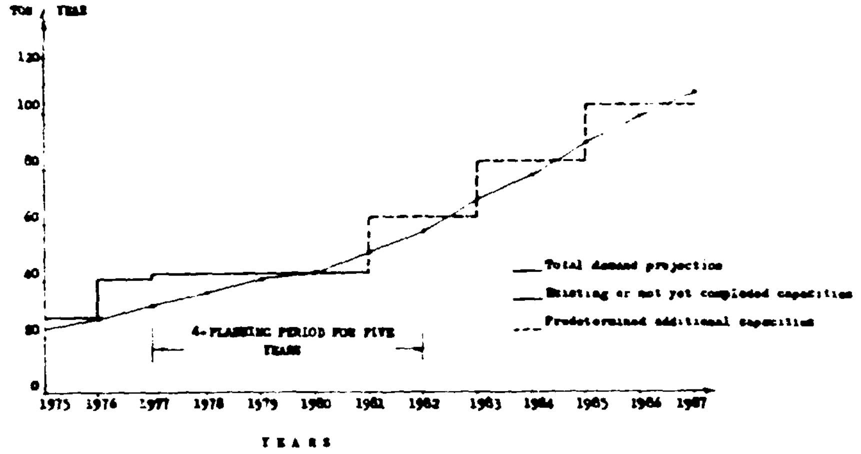
AKSA	133.0 166.5	48000 56000	133.0 156.5	48000 56000			
YAL AKRILIK	22.0	8000	22.0	8000			
TOTAL	155.0 177.5	56000 64000	155.0 177.5	56400 64000			

GEN TOTAL	402.1 528.6	[illegible] [illegible]	267 368	96480 125680	150.6 [illegible]	[illegible] [illegible]	

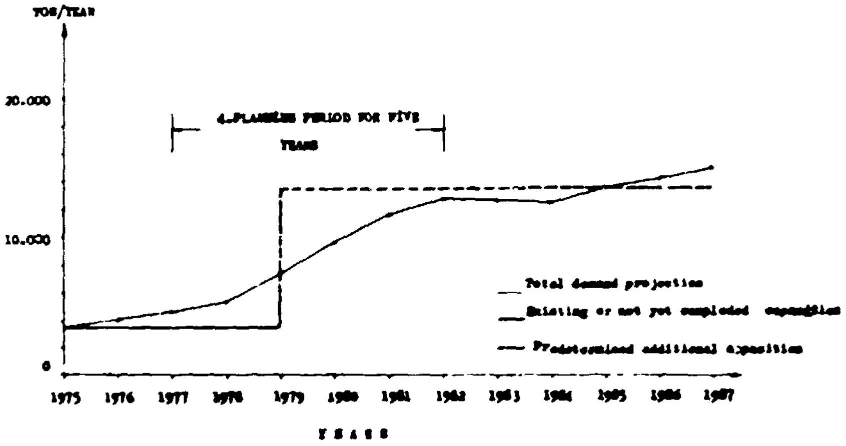
POLYESTER YARN TOTAL DEMAND PROJECTION EXISTING (OR ERECTIONS ARE GOING ON) AND PREDETERMINED ADDITIONAL CAPACITIES



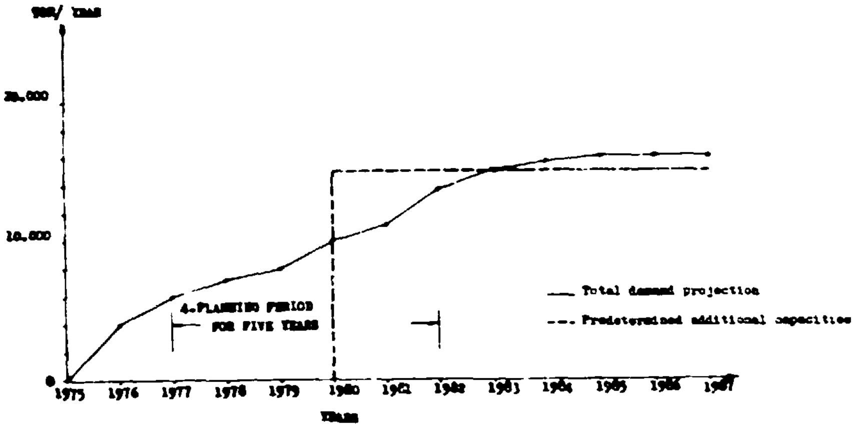
POLYESTER FIBRE TOTAL DEMAND PROJECTION - EXISTING (OR ERECTIONS ARE GOING ON) AND PREDETERMINED ADDITIONAL CAPACITIES



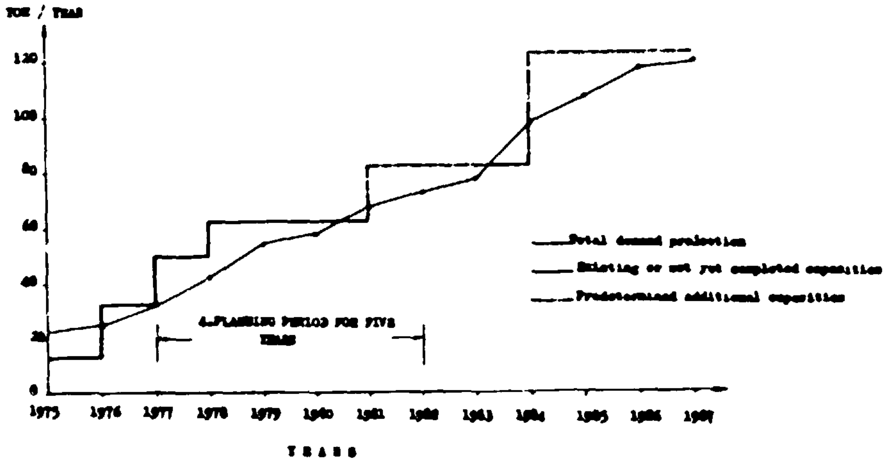
POLYAMID FIBRE TOTAL DEMAND PROJECTION EXISTING AND PREDETERMINED ADDITIONAL CAPACITIES



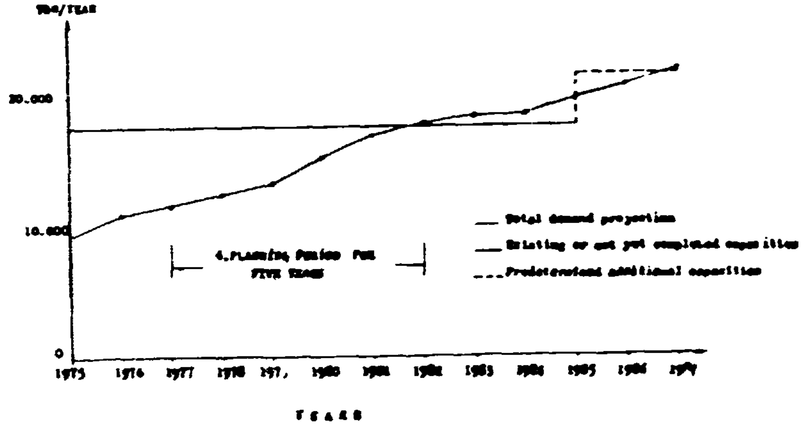
NYLON CORD YARN TOTAL DEMAND PROJECTION
PREDETERMINED ADDITIONAL CAPACITIES



ACRILIC YARN TOTAL DEMAND PROJECTION
EXISTING (OR ERECTIONS ARE GOING ON) AND
PREDETERMINED ADDITIONAL CAPACITIES



POLYAMID YARN TOTAL DEMAND PROJECTION
EXISTING AND PREDETERMINED ADDITIONAL CAPACITIES



Country : CHINA

Speaker : **Guo Ji-Yun**

Director,
Textile Academy
Ying Jia Fen, Beijing,
China.

THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN CHINA

The development of the chemical fibre industry in the People's Republic of China initiated in the sixties. In the fifties, only some preparatory work had been done for this development, such as setting up small chemical fibre plants, and establishing special schools for training technical personnel, etc.

In the early sixties, a group of medium-sized viscose fibre plants were built, this caused the viscose fibre industry to develop to a fair scale. In the meantime, synthetic fibre industry also made some progress. Complete sets of equipment for manufacturing polyamide fibre, polyvinyl alcohol fibre and acrylic fibre were introduced from abroad. In 1965, output of chemical fibre amounted to 50,000 tons, among which, about 45,000 tons of man-made fibre and about 5,000 tons of synthetic fibre.

In the seventies, synthetic fibre industry in China achieved comparatively rapid progress, a group of vinylon plants were set up, technology and equipment for producing synthetic fibres with petroleum and natural gas as raw material were also introduced. Four large-sized modern synthetic fibre plants were set up in Shanghai, Tianjin, Liaoyang and Sichuan. In 1980, the output of chemical fibre amounted to 450,000 tons, with about 14,000 tons of man-made fibre and about 310,000 tons of synthetic fibre.

The average Annual Growth Rate of Chemical Fibres Output

From 1966 to 1970, 15%; 1971-1975, 8.9%; 1876-1980, 23.8%. The average annual growth rate was 15.76%.

Now the production capacity of the chemical fibre industry in China is 650,000 tons, with 130,000 tons for viscose fibre, 520,000 tons for synthetic fibre. The ratio between viscose fibre and synthetic fibre is 20 : 80.

The varieties of viscose fibre now available are ordinary viscose-cotton type and viscose-wool type, polynosic, filament and strong viscose.

Pure viscose fibre "artificial cotton" and "artificial wool" may make up the inadequacy of natural fibre resources of cotton and wool. "Artificial weaving silk suitable for top covering of quilt and material for clothing. Another main usage of viscose fibre is as material for blending. We have a kind of fabric which is the blend fabric of viscose fibre with polyster, and the other kind called "three in one" worsted is the blend fabric of viscose fibre, wool and nylon.

Synthetic fibre in China now mainly consists of polyester, polyamide, acrylic and vinylon, there are also small amount of polyvinyl chloride fibre and polypropylene fibre.

"Polyester-cotton cloth" made of 65% polyester staple and 35% cotton has been widely used for clothing.

"Wool-polyester" made of blend yarn of wool-type polyester staple and wool, and the "three in one" made of blend yarn of wool-type polyester staple, wool and viscose fibre, are used for principal material of outer clothing.

Stretch knitted fabrics and stretch woven fabrics are used for principal material of outer clothing too.

The varieties of nylon includes filament, high stretch and staple.

Because of its fine durability, polyamide gaberdine made of blend of staple, wool and viscose once had a good market. However, as wool/polyester/viscose "three-in-one" fabric came in, the demand for them was much greater than that for polyamide gaberdine for their fine stiffness and lower price. So more usage of polyamide staple has to be sought.

High-stretch polyamide yarn is mainly used for knitting stretch hoses.

Filament is used for tyre cord, conveyer, rope and fishingnet, etc.

Acrylic fibres are mainly staples : wool type and cotton type. Pure acrylic or blended with wool are used for knitting yarn and artificial fur. It also can be blended with viscose or cotton for clothes and sportswear.

Polyvinyl alcohol fibres now available are staples and stretch-breaking yarn, the latter is used to manufacture conveyers and tyre cords.

Pure polyvinyl alcohol staples or blended with 50% cotton are mostly used for denims, a small amount is used for quilt lining and underwears.

Polyvinyl chloride staples are mainly used for filter gauze of industrial use.

The varieties of polypropylene fibres now available are split-fibre, cotton-type, filament and stretch yarn.

Split fibres are used for plait, packing material and rope.

Staple blended with 50% cotton can be used for clothes. Filament for mosquito net and top covering of quilt. Stretch yarn is used to manufacture bedspreads, carpets and towelling socks. The usage of polypropylene fibres is being developed.

Scope of Chemical Fibre Plants (According to planned max. production capacity):

Raw material manufacturer:

Pulp	35,000 tons/year
Caprolactam	6,500 tons/year
Nylon-66 salt	46,000 tons/year
Dimethyl terephthalate (DMT)	91,000 tons/year
Acrylic nitrile	50,000 tons/year
Polyvinyl alcohol	45,000 tons/year
Polypropylene	35,000 tons/year

Spinning-mills :

Viscose staple	15,000 tons/year
Viscose filament	7,000 tons/year
Polyester filament	3,000 tons/year
Polyamide staple	5,000 tons/year
Acrylic staple	47,000 tons/year
Polyvinyl alcohol staple	33,000 tons/year

Production velocity at present :

Spinning process :	Wet spinning 45-80 m/m	
	Melting spinning	1200-1300 m/m (staple) 1500 m/m (filament)
Drawing spinning:	Multifilament drafting twist	100 m/m
False twisting process:	Spindle twist 320,000-400,000 r.p.m. Linear velocity:	140 m/m
Average labour productivity in the country:	7 tons/person/year	
In better areas:	33 tons/person/year	

With the development of chemical fibre production, the scientific research system of chemical fibres in China has primarily been established. But an integral research structure has not been formed yet.

The basic studies are mainly in regard to structure and properties of chemical fibres: polymerization, spinning and mechanism of finishing.

Applied studies includes: aromatic polyamide fibre, elastic fibre, polyacrylinitrile having fine hydroscopic property, polyester high speed spinning, polyacrylic high speed spinning, profiled fibre, etc. Greater progress has been made in research work on composite, profiled, finish, dry spinning polyvinyl alcohol filament, POY DTY process, etc.

In order to meet the market demands, great attention has been devoted to research work on quality, design and variety of chemical fibrefabrics, and also to the development of new type fabrics such as wool-like, lenin-like and silk-like fabrics.

Owing to the close combination of scientific research work on chemical fibre with production, chemical fibre production in China has gained considerable benefit. But the scientific and technological work still can not meet the increasing demand of chemical fibre production, and a rather great gap exists between the world advanced level and ours.

The Chinese government and UNIDO have agreed to cooperate to set up a synthetic fibre research centre, this will play a good role in developing scientific research work on synthetic fibre and in training technical personnel. It is in line with the needs of the modernization construction in China as well.

Through over twenty years efforts, a foundation has been laid for chemical fibre industry in China. Together with the development of chemical fibre industry, the structure of raw material for textiles in China has already been changing, the proportion of chemical fibre in the raw materials for textiles has been gradually increasing. Now natural fibre constitutes 80% of the total, and chemical fibre constitutes 20%. To solve the problem of clothing of a population of 1,000 million people, besides the increasing of natural fibre production, great efforts are still needed in the future to raise the output of chemical fibre, so as to meet the increasing needs of the growing population. Therefore, the developing of chemical fibre industry in China has its broad prospects.

Country : COLOMBIA

Speaker : **Luis G. Jaramillo**

Sales & Marketing Manager
Polimeros Colombianos S.A.,
Medellin, Colombia.

THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN COLUMBIA

1. Introduction

This paper has been written to present the situation of the synthetic fibre in my Country in accordance with the expected participation in the International Conference on Man-Made Fibres sponsored by Unido and Sasmira.

I have summarized some information which should give the participants a clear idea of how this business is going on within my Country. It is also given as a basis for exchanging experience in the field.

I want to thank the Unido for the opportunity given me to attend this Seminar and represent my Country, Colombia.

2. The Consumption in Colombia:—

Historically, cotton has been the predominant textile fibre for the textile production in the country, although the growth of synthetics has tended to reduce the cotton share. For example, in 1953 the overall raw material consumption was 40,000 tons of which 72% was cotton. In 1960 the share reached 77%. Since 1968, though, the growth of synthetic fibres, mainly polyester, has followed the same general trend exhibited by other Latin American Countries similar to Colombia, like Mexico and Brazil. This has been at the expense of cotton. However, the forecast for 1983 shows that cotton will takeup 40% of the total fibre consumption.

The attachment I shows the Colombia fibre market for the 1978-1983 period. With this we can observe how cotton is loosing importance at the expenses of the non cellulosics fibres. we observe also, how the polyester fibre show the best growth in comparison with the other fibres. However, in polyester consumption, the Staple form in our country is still low in comparison with the volume of cotton used at the present in Mexico, a country similar to Colombia. The ratio of cotton to polyester has been reduced from 22.8 tons of cotton per ton of Staple fibre in 1970 to less than

6 tons of cotton per ton of Staple fibre in 1979. The same ocurred in Brazil. See attachment 2.

The major reasons for this disparity in Colombia seem to be:

1. The demand for yarns in export market has tended towards 100% cotton and Colombian mills, particularly Coltejer, are heavily commtted to the export market.
2. There have been limitations in terms of equipment capable of handling blended fabrics.
3. There has not been a sustained push by the fiber producers and for mills to develop new polyester fabrics in either blends or 100% form.

These factor have contributed to the fact that Colombian polyester Staple producers have remained significantly below the potential consumption during the last few years.

3. Production of Synthetic Fibres in Colombia:—

At present, Colombia produces the following synthetic and artificial fibres: Polyester, both filament and staple form, textile and industrial Nylon, Acetate and Polypropylene. The plant of viscose owned by Celanese was shut down four year ago.

The present fibres producers are the following:

Celanese:	Polyester (FY, POY, S.F.) Textile Nylon, Acetate (FY, S.F.)
Enka:	Polyester (POY, S.F.) Textile Nylon, Nylon Tire Cord
Vanylon:	Textile Nylon
Polymer de Colombia:	Polypropylene
Zylette	Polyester (POY)
Polimeros Colombianos:	Polyester (POY, FY, S.F.)

The first synthetic fibre company established in the country was polimeros Colombianos which started operations in 1964 as a joint venture between Coltejer, the number one textile company in Colombia and United Merchants & Manufacturers from U.S.

Celanese and Enka de Colombia are companies having foreign capital investment. The remaining are 100% owned by Colombian investors. Those have technology support from their main houses. The rest have some special programms through Engineering Companies like Zimmer, Snia, etc.

Polimeros at present does not have any technology support programs. At the end of 1976, United Merchants sold its shares to Polimeros. Polimeros started a survey around the world to get technological assistance and in 1978 signed a contract with the Du Pont Company in the United States. This contract has been executed with good success and currently is being reviewed for possible extension.

Celanese probably will close operations during this year. The economic situation in the country and financial problems affecting Celanese's operation, will be deciding factors to achieve this steps.

The attachment No. 3 shows the actual capacity and production in 1981.

4. Present Technology Status and Plans for the Future :—

As we stated before with the exception of Enka and Celanese, the other companies have been established, based mainly in Engineering Companies, which through special assistance programs provide the required technology for the operation.

Enka and Celanese have direct technical support from the head offices.

Since 1975, POC and P.O.Y. operations based on the most up to date equipment available. Enka did the same in 1976 and Celanese in 1977. The equipment used in this operation has been provided by Barmag without exception. Recently a new company, Zylette, obtained through a specialized Italian Company, the technology to produce light deniers in polyester, based on high speed spinning, also using Barmag equipment.

DTY operations have been changed from pin to friction drawtex with good success. However, the normal production speeds are no greater than 540 mts per minute.

Most of the polyester which represents the major production among the synthetics is sold in texturized form, so, the flat yarn commonly called FY, has been decreased substantially.

Summarizing, in polyester filament, the country is at present producing a very good quality to satisfy the market equipment.

In the Staple form however, there have not been any big improvements and the three producers have modest mills. The fiber normally produced belongs to commodity good with a tenacity in the range of 4.8, 5.2 grms/denier.

Some projects for the coming future have been studied by the different companies, but due to the economic cycle we are facing and mainly due to the imports, most of them illegal and in the form of finished goods, these projects seem to be very delayed. The situation of Celanese itself, unclear for the time being, makes a break as far as new investments is concerned.

In polyamides, as we do not have a very big consumption, the mills have normal operations based on conventional spinning systems. We do not foresee trasendental improvements in this field. For example, spinning techniques fall in the range of low speeds and the H.S.S is not in the minds of any producers for the time being.

In the chips productions, POC, Enka and Celanese have facilities based in batch wise plants. All the sizes are too small to think of conversion to continuous operation. We have the idea that only facilities starting with 20.000 or 30.000 tons a year can be justified for conversion to C.P. operation.

POC has shut down this operation since 1976 and it seems to be difficult to start it up again. The new project to replace most of its old facilities has been frozen and new plans are expected for this year to redesign the basis and the back ground in which the premises were established.

Enka de Colombia has been permanently trying to renovate its old equipment and some improvements shall be done mainly in its Staple fibre facility. In the Filament side, the normal goods now proceed from the POY operation.

5. Market Conditions and Prices:—

Effective January the first, the main textile producers announced an increase in all fabric prices. These increases are based in the current cost escalation affecting this business. However, the fiber producers, which during 1981 increased their prices by 27% on the average, will not effectuate an equivalent increase for the first quarter of 1982. An agreement exists between the producers and any increase must be agreed among them. The main problem is the abnormal imports which in spite of the government protection remains very strong.

The cotton industry, through the government has announced an increase of 28% for 1982 in the domestic prices. Last year the cotton spinners bought raw cotton at $1.54 per kilo. For this year and based in the exchange rate of Col. $ 60 per US$, the announced price would be $1.83 per kilo when polyester in the Staple form remains at $2.65. The ratio is now based on this, 1.45 times more, when five years ago it was 3.0. This trend shows that we are reaching the levels prospected for the 80's in which the ratio will be between 1 and 1.5, thus more and more polyester will be consumed at the expense of cotton.

As a prediction, Staple prices in Latin America will remain above prices of raw cotton, carrying a premium of 25-40%, depending on the raw material costs. These premiums are based on raw cotton prices. When waste factor, financing costs and so forth are taken into account, the premium for polyester staple at the mill level is reduced to approximately 10-20%. The attached is an example of these relationships in some countries. See attachment 4.

In the long run, it is expected that the polyester price premium will remain at this 10-20% level.

As far as filament is concerned, producers are awaiting more favourable conditions to increase its prices. If some facts remain unchanged, it will be difficult to reach an agreement to increase prices. However, based on the negotiations going on between cotton spinners and producers of this raw material, the government has announced a close on imports of textile to protect the domestic industry and also to bite the smuggling of finished goods. This action could help, the synthetic industry which in 1981 was running below their installed capacity.

Domestic polyester filament prices for 150 denier for texturing are 3.18 per kilogram and for 75 denier 4.53 per kilogram.

On this we can observe how the ratio 75/150 is 1.42 when in normal international markets this ratio is 1.18. The low profitability of 150 denier is the main reason for forcing the decision for the increase of price.

With the other synthetics, like polyamides, the status is more in accordance with the economics of the industry and a recent increase in all the titles has been accepted by the market without too much disturbance. See attachment 5.

Colombian prices at 30 January 1982:

		Col $/Kilo	US$/Kilo
Polyester	150 POY	190	3.18
	75 POY	271	4.53
	150 DTY	217	3.63
	75 DTY	327	5.47
	75 FY	279	4.66
	150 FY	210	3.51
Nylon	40/8	408	6.82
(Flat)	50/10	400	6.69
	70/24	333	5.57
	100/24	322	5.38

Current one dollar equivalent to peso 59.81.

6. Conclusion:—

Making a comparison between the total Colombian Fiber Market and the Production of 1981, we observe that there is an abnormal behaviour of the business. The main reason obviously is smuggling of materials which are coming into the country in both forms, as finished goods and raw materials. This situation is affecting greatly the entire industry, mainly the textile business which in the last two years has been reducing its working force trying to balance the overcapacity resulting with this competitor.

As a final result, the fiber business would be affected in the same way. This means that the problem of low profitability, working at low levels will tend to reduce man power and most importantly plans for expansion and new investments seems to be unclear and too risky.

ATTACHMENT 1

COLOMBIAN FIBRES MARKET 1978-1983

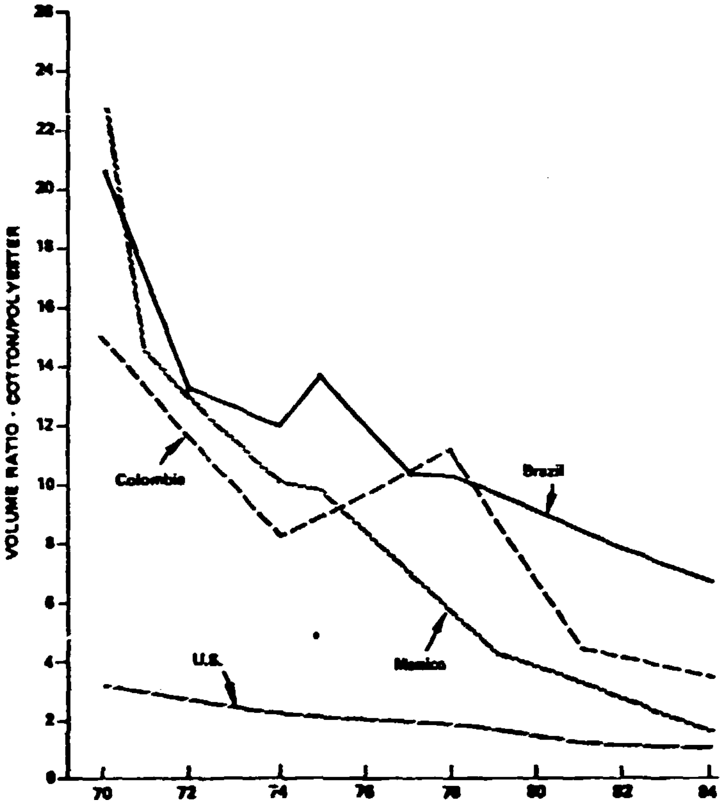
TONS/YEAR

YEAR	COTTON	POLYESTER FILAMENT	POLYESTER S.F.	NYLON	CELLULOSICS	WOOL	ACRYLICS	TOTAL
1978	61.000	20.650	6.968	6.300	7.000	3.300	8.400	113.618
1979	61.400	25.300	7.700	6.600	7.000	3.300	9.200	120.500
1980	59.800	29.700	8.900	6.800	6.500	3.000	10.000	124.700
1981	58.200	34.000	10.200	7.100	6.000	2.800	10.800	129.100
1982	56.600	38.200	11.700	7.400	5.500	2.600	11.600	133.600
1983	54.800	42.400	13.500	7.700	5.000	2.400	12.400	138.200
% of total in 1983	39.7	30.7	9.8	5.6	3.5	1.7	9.0	100.0
Annual Growth	-2.9	13.8	15.1	3.2	-8.8	-8.3	7.7	3.5

Data Source: Coltejer

ATTACHMENT 2

COTTON/POLYESTER STAPLE VOLUME RATIOS



Data Source: Coltejér-Celanese

ATTACHMENT 3

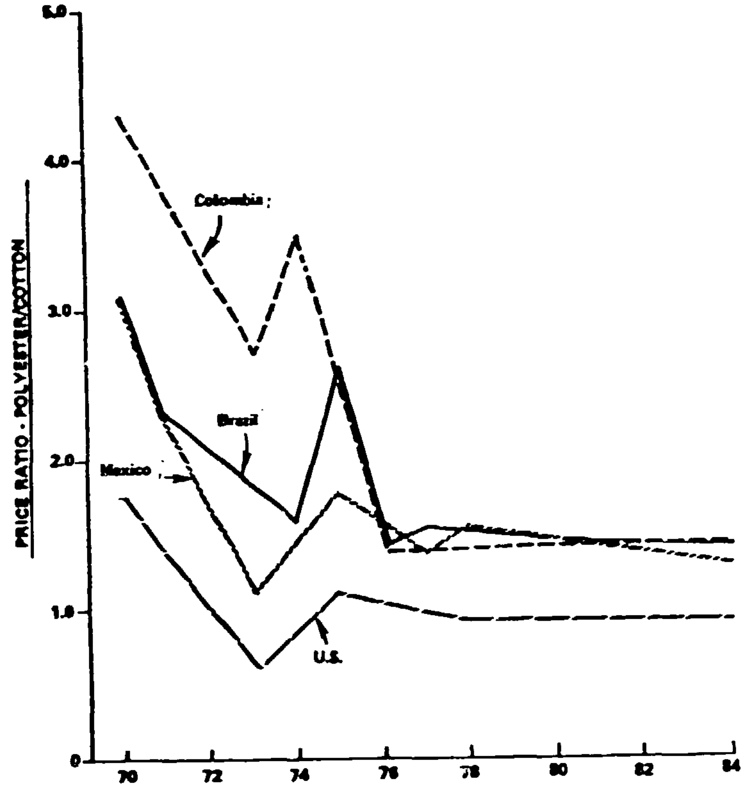
POLYESTER FIBER CAPACITIES - COLOMBIA

(TONS PER YEAR)

COMPANY	LOCATION	FEEDSTOCK	1981 CAPACITY			1981 PRODUCTION			%
			F	S	TOTAL	F	S	TOTAL	
Celanese Colombiana Celanese 49%	Cali	TPA & Imp. chip	7.200	2.600	9.800	5.400	1.200	6.600	22.5
Enka de Colombia AKZO 49%	Medellín	DMT	10.500	5.000	15.500	10.500	4.700	14.700	50.0
Polímeros Colombianos	Medellín	Imp. chips	6.700	3.000	10.000	4.300	2.600	6.900	23.5
Zylette	Bogotá	Imp. chips	1.500	-	1.500	1.100	-	1.100	4.0
TOTAL POLYESTER			25.900	10.600	36.800	20.800	8.500	29.300	100.0

ATTACHMENT 4

POLYESTER STAPLE/COTTON PRICE RATIOS



Data Source: Coltejer-Celanese

ATTACHMENT 5

OTHER SYNTHETIC FIBER CAPACITIES - COLOMBIA 1981

	VANYLON	CELANESE		ENKA	
	NYLON	NYLON	ACETATE	NYLON	TIRE CORD
Capacity	8.400	2.600	5.400	2.200	6.500
Production	4.300	2.000	3.500	1.200	5.700

TOTAL CAPACITY NYLON:	13.200
TOTAL PRODUCTION	7.500

THE SITUATION OF THE SYNTHETIC FIBRE INDUSTRY IN BANGLADESH

MEER TABARRAK HUSAIN,
Senior Manager, Zeenat Textile Mills Ltd., Tongi, Dacca, Bangladesh

Between 20.34^0 & 26.38^0 North Latitude and between 88.01^0 and 92.41^0 East Lengitude People's Republic of Bangladesh was born on 26th March 1971. After 264 days war it got liberated from Pakistan's occupation.

Area : 143,998 square kilometres.

Capital : DACCA
Area of DACCA: 320 square Kilometres.
Population of Dacca: 3 million (approx)

Main Seasons : Winter (Nov. - Feb.)
Summer (March-June)
Monsoon (July - October)

Climate : Temperature Maximum 34^0c
Minimum 11^0c
Rainfal Maximum 345 cm
Minimum 120 cm
Humidity Maximum 99%
Minimum 36%

Principal crops : Rice, Jute, Tea, Tobacco, Sugar Cane, Pulses, Oilseeds, Potatoes, Vegetables, Bananas, Mangoes, Pineapples, Coconuts etc.

Principal Industries : Jute, Textile, Chemicals, Steel & Engineering, Tea etc.

Principal Minerals : Natural Gas, Lignite & Limestones.

Principal Exports : Jute & Jute goods, Tea, Hides & Skins, Newsprint, Fishes, Rayon & Readymade Garments.

Foreign Trade : Export (f.o.b.) : 12509 million Taka
Import (c.i.f) : 40144 million Taka

Population : In 1971 : 71 million
1981 : 90 million

POPULATION ESTIMATES & GROWTH RATE

Year (January)	Population(million)			Average annual growth rate in %	Crude birth rate	Crude death rate
	Male	Female	Total			
1971	36.7	34.3	71.0	2.4	43.0	18.0
1975	40.3	37.7	78.0	2.6	39.7	16.5
1980	45.2	42.4	87.6	2.3	35.9	14.2
1985	50.3	47.4	97.7	2.2	32.7	13.7
1990	55.3	52.2	107.5	1.9	30.5	13.0
1995	60.3	57.1	117.4	1.8	28.6	12.6
2000	65.1	61.8	126.9	1.6	26.6	11.6

TEXTILES

Textile Industry occupies a pre-eminent position in the economy of Bangladesh. Although in broader sense Jute comes under the purview of Textiles, but in Bangladesh Jute is being treated as a separate sector of Industry. Textile Industry provides clothing which as a basic need stands next to food in order of importance. It mades substantial contribution to the economy in termsof value added and employment. It accounts for about one fourth of the contribution of the manufacturing sector to the Gross Domestic products and provides direct employment to over one million people. The handloom industry alone employs about 0.85 million while the large textile mills employ 75,000 people. Over 60,000 people are engaged in History and specialised textile. The industry has a wide scope for expansion in Bangladesh which has surplus and relatively cheap labour and large domestic market. It has also high potential for earning foreign exchange through export of garments and specialised textiles.

PRESENT CONSUMPTION AND PRODUCTION OF YARN

Name of Yarn	Present consumption in million kgs.	Present country production in million kgs	Import from abroad in million kgs.
Cotton	53.88	46.24	7.64
Wool 50% + Acrylic 50%	0.09	0.09	-
Polyester	0.18	-	0.18
Polyamide	2.72	0.70	2.02
Polyacrylic	0.13	-	0.13
Rayon	1.20	2.20	-
TOTAL:	58.20	49.23	9.97

PRESENT CONSUMPTION AND PRODUCTION OF FABRICS

Name of Fabrics	Present consumption in million metres	Country production in million metres	Import from abroad in million metres
Cotton fabrics	518.10	477.59	40.51
Synthetic fabrics	70.96	48.10	22.86
Silk & Art Silk Fabrics	31.46	31.46	-
Secondhand clothing	249.72	-	249.72
TOTAL:	870.24	557.15	313.09

PRODUCTION FACILITIES AVAILABLE IN THE COUNTRY

PUBLIC SECTOR

Sl. No.	Type	No. of unit	Installed Machines	Working Machines	Production capacity	Present actual production(80-81)
1.	Cotton Spinning	58	11,11,000 Spindles	10,17,400 Spindles	77.62 mil. kgs.	46.24 mil.kgs.
2.	Wool+Acrylic(50% + 50%) Spinning	1	2,200 Spindles	1,400 Spindles	0.14 "	0.02 " "
3.	Nylon 6 filament yarn	1	1,260 Spindles	900 Spindles	0.85 "	0.70 " "
4.	Reg.Rayon filament yarn	1	1,173 Spindles	1,173 Spindles	3.00 "	2.20 " "
5.	Cotton weaving	26	7,592 looms	6,652 looms	127.65 mil. metres	78.61 " metres
6.	Wool + Acrylic (50% + 50%) weaving	1	45 looms	35 looms	0.20 "	0.18 " "
7.	Nylon 6 weaving	2	160 looms	153 looms	2.49 "	1.56 " "
8.	Nylon 6 warp knitting	1	14 Machines	8 Machines	0.68 "	0.68 " "
9.	Textile finishing	17			60.35 "	45.26 " "
PUBLIC SECTOR TOTAL:		108			81.61 " kgs. 191.37 mil. metres	49.16 " kgs. 126.29 mil.metres

PRIVATE SECTOR

Sl. No.	Type	No.of unit	Installed machines	Production capacity (2 Shift basis)
1.	Hand Loom	1968	2,50,000 looms	365.75 million metres
2.	Synthetic looms	57	792 "	6.51 " "
3.	Silk looms	3	56 "	0.28 " "
4.	Synthetic warp knitting	24	109 machines	17.94 " "
5.	Ordinary Power loom(cotton)	44	396 looms	5.43 " "
6.	Specialised Textile for Bed sheet, Bed cover, Towel, Canvas, etc.	42	796 "	19.59 " "
7.	Textile finishing complete (Dyeing, Printing & other finishing).	120	7 complete units	37.03 " "
			32 Mech. Zigger	2.19 " "
			118 "	6.03 " "
			207 Printing tables	14.72 " "
			4 complete calender-ing plant	21.03 " "
			2 complete raising unit	0.18 " "
			6 complete plant for Mercerising of yarn	0.64 " kgs.
8.	a) Hosiery(Body)	261	1,903 machines	5.17 " "
	b) Socks	123	562 "	8.41 " pairs
	c) Sweater		107 "	0.06 " "
	d) Muffler	70	74 "	1.06 " "
9.	a) Readymade garments for export	24	-	1.18 " pcs.
	b) Readymade garments for home	64	-	5.66 " "
10.	Specialised textiles for export	2	-	.79 " "
	Specialised textiles for home	8	-	.61 " "
11.	Tape, lace & Braid	45	5,330 Heads	1.45 " kgs.
12.	Sewing Thread	55	1,211 Machines	5.27 " "
13.	Twine	35	14,580 Spindles	0.62 " "
	PRIVATE SECTOR TOTAL:	2,945		498.08 million metres 9.53 " pairs 6.84 " pcs. 13.15 " kgs.

DEVELOPMENT IN THE NEAR FUTURE

By 1985 the population of Bangladesh is expected to be 100 millions for whom targetted requirement of cloth is 1097.28 million metres at the rate of 10.97 metres per head. By that time the requirement of yarn is estimated at 136.05 million kgs. of which 7.25 million kgs. will be imported from abroad & 128.80 million kgs. will be locally produced. Apart from catering to the home requirement, Bangladesh desires to be in the export market with certain textile items. To this end the Government has worked out the following Investment schedule for the period from 1980 to 1985.

PUBLIC SECTOR

Investment in million Taka

Sl. No.	Category	Physical Target	Investment		Total Investment
			Local Tk.	Foreign Exchange	
1.	Balancing,Modernisation & Replacement of old machines of existing mills	9,46,000 Spindles 7,488 looms in 50 mills	682.40		682.40
2.	On going Projects	1,12,500 Spindles	199.70	225.00	424.70
3.	New Spinning mills	4,25,000 "	1,047.00	1,260.00	2,307.00
4.	Cotton,Ginning, Bailing & storage		132.00	108.00	240.00
5.	Polyester cotton plant & finishing plant.	1 plant 1 plant	81.60	96.50	178.10
6.	Studies,Research & Laboratories		39.30	7.90	47.20
7.	Handlooms Promotional facilities and services		195.30	54.80	250.10
8.	Sericulture Projects		103.80	15.40	119.20
TOTAL:			2,481.10	1,767.60	4,248.70

PRIVATE SECTOR

Investment in million Taka

Sl. No.	Category	Physical Target	Investment		Total Investment
			Local Tk.	Foreign Exchange	
1.a)	Textile finishing (Mechanised & semi mechanised)	14 Units 86 "	272.40	282.00	554.40
b)	Balancing, Modernisation & Replacement of existing Textile finishing		20.00	40.00	60.00
2.a)	Synthetic Textiles	1200 looms	240.00	240.00	480.00
b)	BMR of existing synthetic textiles		10.00	10.00	20.00
3.a)	Specialised Textile (cotton group)	400 looms	80.00	80.00	160.00
b)	BMR of existing ones		5.00	10.00	15.00
4.a)	Horizontal power loom	3400 looms 10 sizing units	150.00	233.80	383.80
b)	BMR of existing loom		5.00	10.00	15.00
5.a)	Spooling & Thread Ball manufacturing	5 units	50.00	50.00	100.00
b)	BMR of existing units		2.00	4.00	6.00
6.a)	Tape, lace, Braid & Webbing		2.00	4.00	6.00
b)	BMR of existing units		0.50	1.00	1.50
7.a)	Hosiery & knitting		20.00	50.00	70.00
b)	BMR of existing units		10.00	12.50	22.50
8.a)	Readymade garments		88.00	112.00	200.00
b)	BMR of existing units		5.00	10.00	15.00
9.a)	Sericulture, Reeling & Filature including Ericulture	50 power looms 2500 Handlooms	120.00	145.00	265.00
b)	BMR of existing units		2.50	5.00	7.50
10.a)	Waste cotton spinning & manufacturing Absorbent cotton	23 units	68.70	68.70	137.40
b)	BMR of existing units		4.00	10.00	14.00
11.a)	Handlooms	50,000 looms	75.00	1.00	76.00
b)	BMR of existing looms		3.00	0.50	3.50
12.	Manufacturing of stretched/Texturised/ Twisted Nylon yarn	4 units	20.00	20.00	40.00
13.	Wollen & Worsted yarn	3200 Spindles 20 looms	20.00	20.00	40.00
14.	Twine & fishing net	10 units	25.00	25.00	50.00
	TOTAL INVESTMENT IN PRIVATE SECTOR		1,298.10	1,444.50	2,742.60

Apart from the above there is vast scope for setting up 100% export oriented textile industries in the Export Processing Zones of Bangladesh. Such a zone nearby the Sea Port and Airport of Chittagong has already been developed with necessary facilities and has been inviting both foreign and local enterpreneurs for investment.

RISING POPULARITY OF MAN-MADE FIBRE

In Bangladesh till the end of 1950s cotton was the most popular fibre being used in textiles, with the dawn of the sixties polyamide fibre entered into the field of textiles and enchanted the people to fastionably wear garments made of this fibre. But in the seventies Polyamide fibre's popularity for apparels shrunk seriously. It has, however, attained a cozy accommodation in the fields of twine for fishing Net, Socks and Mosquito Nets. The usage of Polyester has been gradually rising. More and more people are using polyester and polyester + cotton blended clothing. It seems that the use of polyester will continue in the country for quite considerable span oftime. Recently Acrylic has started to drive out the use of wool.

Candidly but laconically speaking, in Bangladesh coming are the days when man-made fibres will have more potential market while the market of natural fibre is not likely to grow with any accelerated velocity.

EVOLUTION OF SYNTHETIC FIBRES IN BRAZIL

ERNESTO JOSÉ FALCETTA

1. Generalities

Natural Fibres were almost the only fibres used in Brazilian industry well into the fifties. From then on the first plants appeared based on European Technology and, later on, also on the American and Japanese ones.

On 1955, RHODIA begun their first Plant of synthetic fibres and from 1960 on production and consumption presented a steady growth and diversification of fibres started.

On the seventies synthetic fibres had already surpassed the artificial fibres on production capacity and its market demand was larger. This situation increased remarkably by the last years of the seventies depressing considerably the artificial fibres market so that some artificial fibres plant had to close down for economic reasons.

As shown on graphic 01 during the 1970's artificial fibres varied between 50,0 to 64,0 m. tons/year and are still expected to drop to 55,0 m.tons/year until 1985.

In comparison, during the same period, synthetic fibres quintuplicated its production being expected for 1985 a production of 500,0 m. tons/year.

Meanwhile, cotton and wool following international trend kept sationary (See graphic 2, 3 and 4), having cotton reached the same values of production and sales on 1980/81.

2. Synthetic Fibres

Production of synthetic fibres begun to 1955 with RHODIA producing NYLON 6.6., continuous filament, then staple and tyre cord. On 1961 they installed a Plant of Polyester and, on 1968, an Acrylic Plant.

Main synthetic fibres produced in Brazil at the moment are NYLON and POLYESTER.

Since their beginning synthetic fibers were a success very well accepted by the brazilian market and a had a constant growth. Nevertheless, last year following international economic trend and answering Government politics trying to reduce inflation and increase exports, synthetic fibres production was slowed down. Sales of synthetic fibres amounted to 12,0 m.tons on 1963, 57,0 m.tons on 1970 and on 1980 they were already larger than 300,0 m.tons. Among these the polyester has now the largest capacity production installed. (See graphics 1, 5 and 7).

Now, are being produced:

a. Polyamides.

a.1. Polyamid 6.6.

There are two makers of Polyamid 6.6., RHODIA and CELANESE. Its raw materials, adipic acid and diamine-hexametilen. are produced locally by RHODIA but a part has to be imported. All types of fibres are produced for both textile and tires industries.

a.2. Polyamid 6.

This fibre is produced by a larger number of industries such as BANYLSA, CIA BRASILEIRA DE SINTETICOS, DE MILLUS, COBAFI, NOVEL SPUMA and BRASIL VISCOSE, and so on.

Its raw material the caprolactam is produced locally by NITRO—CARBONO CO., at Camacari, State of Bahia. (See graphic 6).

b. Polyester

There are 8 industries producing polyester fibre and continuous filament of polyester with a total capacity of more than 100,0 m.tons/year installed on 1980 thus surpassing the market necessities up to 1983. Its raw material the DMT is produced locally and surpasses the market needs in almost 60,0 tons/year which are exported. (See graphic 7)

c. Acrylic

There are only two producers of acrylic fibres, FISIBA and RHODIA, both totalizing a production capacity of 24,0 m. tons/year on 1980 and sales amounting to 21,0 tons on the same period. (See graphic 8) Before 1980, its raw materials had to be imported but with the installation of ACRINOR has a capacity of 60,0 tons/year and BASF produces several other products besides DMF.

On 1981 due to economic factors the market had a cool down and not only the acrylic fibres but also all the other fibres had a decrease in consume of 12 to 18%.

d. Elastometric Fibre

This fibre is exclusive of DU PONT of Brazil and their capacity was on 1980 of 400 tons/year.

e. Polypropylene Fibre

This is a very new development and fibre is being produced in continuous filament, staple and raffia by approximately 40 industries.

Polypropylene polymer is produced by two plants, the POLIBRASIL with brazilian and SHELL capital and a capacity for 50,0 m.tons/year, the other, the POLIPROPILENO S/A with brazilian capital and know-how of Imperial Chemical Industries (U.K.), has a capacity for 50,0 m.tons/year.

3. Fibres Consumption Per Capita

These values are of approximately 2.23 kg/per capita/year which are low ones compared with any developed country.

1980 sensus showed a population of 119 070 865,0 so consumption per capita should increase to 3.36 kg/per capita/year.

As a developing country with tremendous potentialities brazilian fibres market is under a steady growth, very specially the synthetic fibres one. Even considering the world-wide petroleum problem which is an important factor affecting this expected growth as Brazil still imports 70% of his petrol needs, we are sure that synthetic fibres production will go on interesting brazilian investors such as production of raw material has been, i.e., caprolactam, acrylonitrile, DMT and propylene, thus rendering of great value to Brazil any work connected with technological improvement and development in the field of synthetic fibres.

4. Textile Research and Study Institutions

Hereunder the names of the two main Brazilian Textile Institutions for Research and Study :

4.1 Cetiq

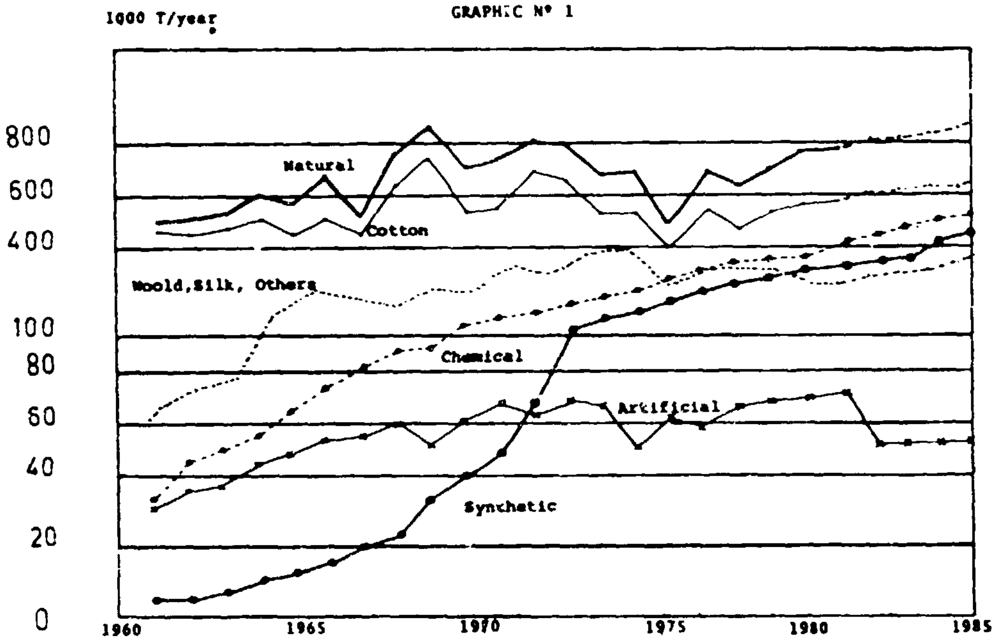
CENTRO DE TECNOLOGIA DA INDUSTRIA QUIMICA E TEXTIL
RUA DR. MANOEL CONTIN, 195 — RIACHUELO
CEP 20 961 — RIO DE JANEIRO RJ
BRAZIL
TLX : (021) 31 149 SNAI BR

4.2 Cetex

INSTITUTO DE TESQUISA TECNLOGICA ÁREA TEXTILE—
CIDADE UNIVERSITÁRIA SÃO PAULO UNIVERSITY SÃO
PAULO

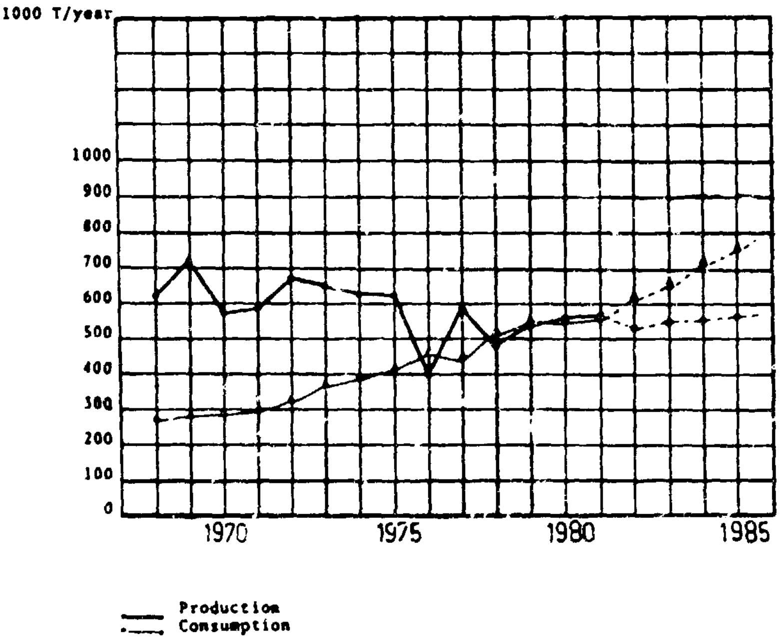
FIBRES TEXTIL BRAZILIAN PRODUCTION

GRAPHIC Nº 1



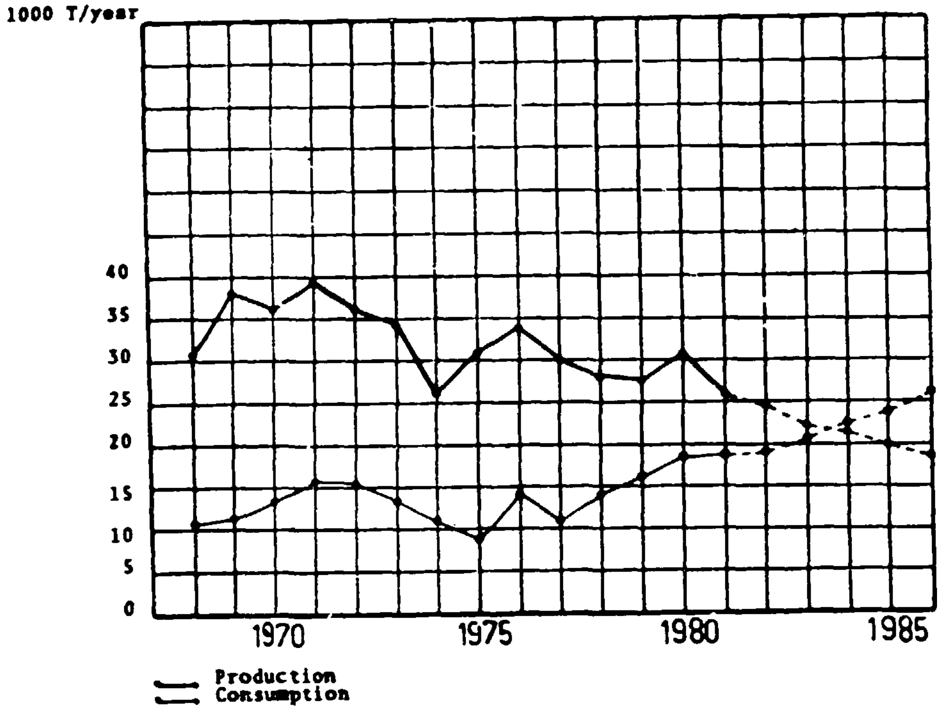
COTTON PRODUCTION AND CONSUMPTION IN BRAZIL

GRAPHIC Nº 2



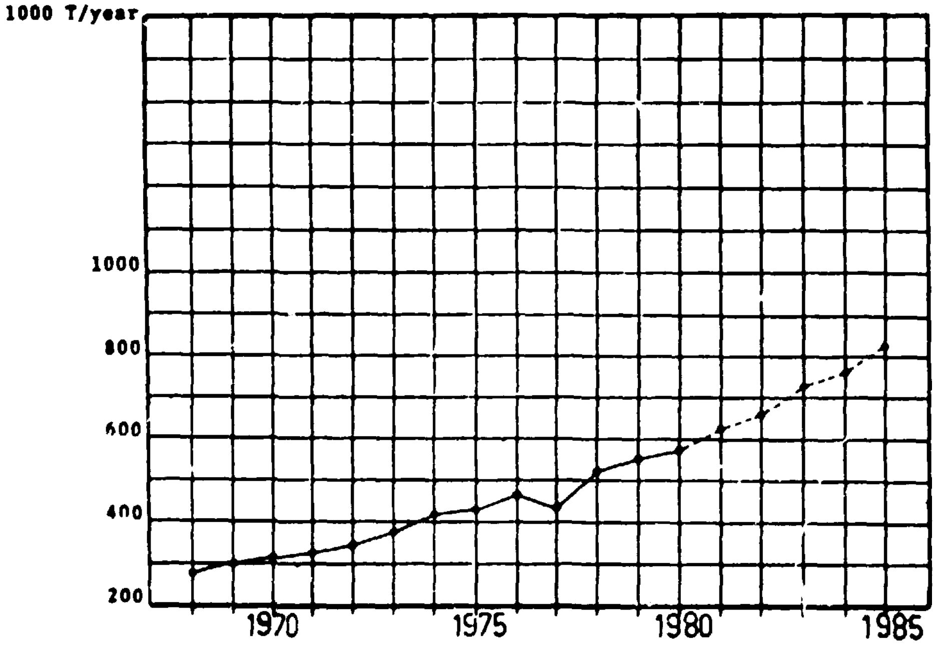
WOOL PRODUCTION AND CONSUMPTION

GRAPHIC Nº 3



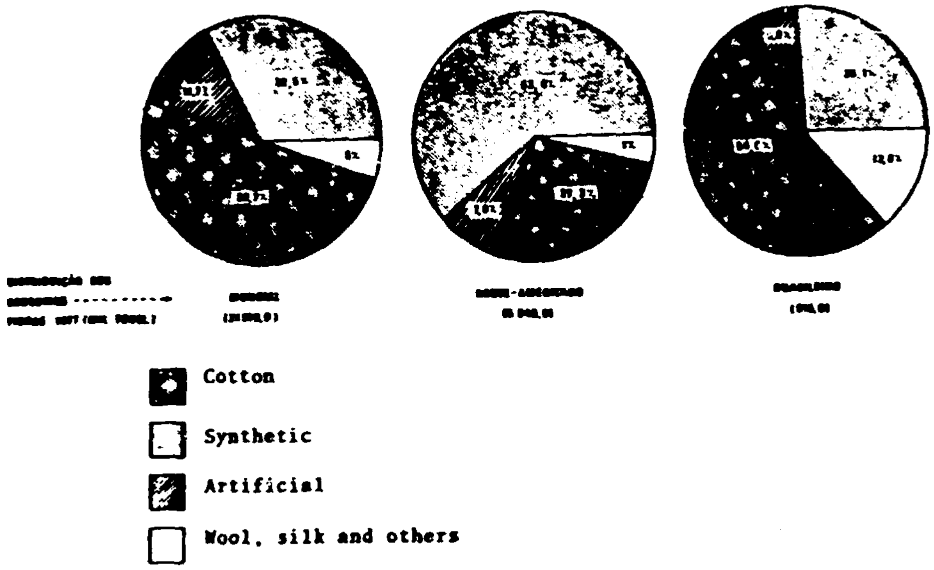
NATURAL FIBRES: COTTON AND WOOL CONSUMPTION

GRAPHIC Nº 4



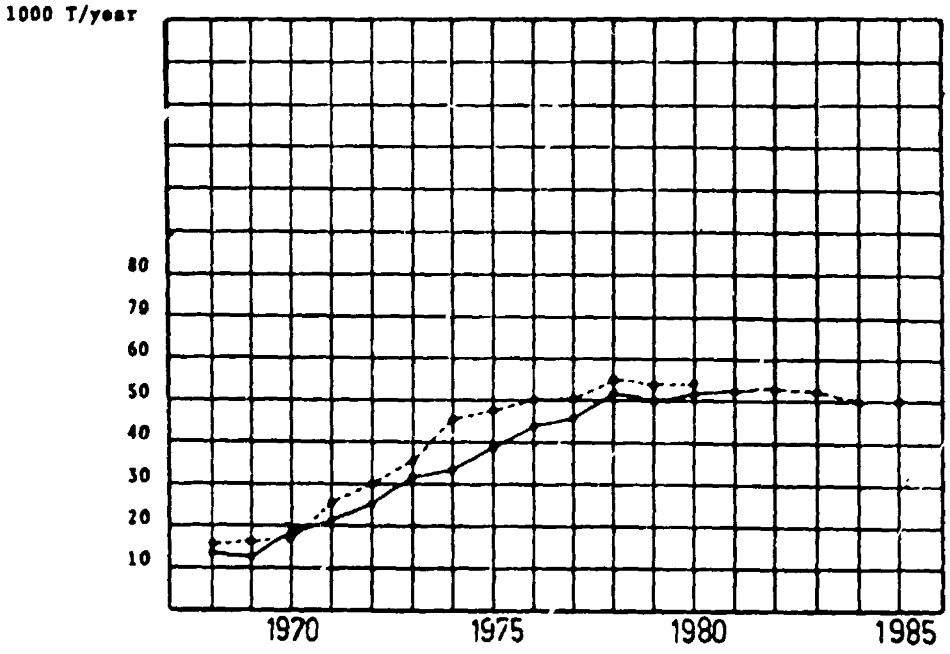
DISTRIBUTION OF FIBRES CONSUMPTION IN BRAZIL

GRAPHIC Nº 5



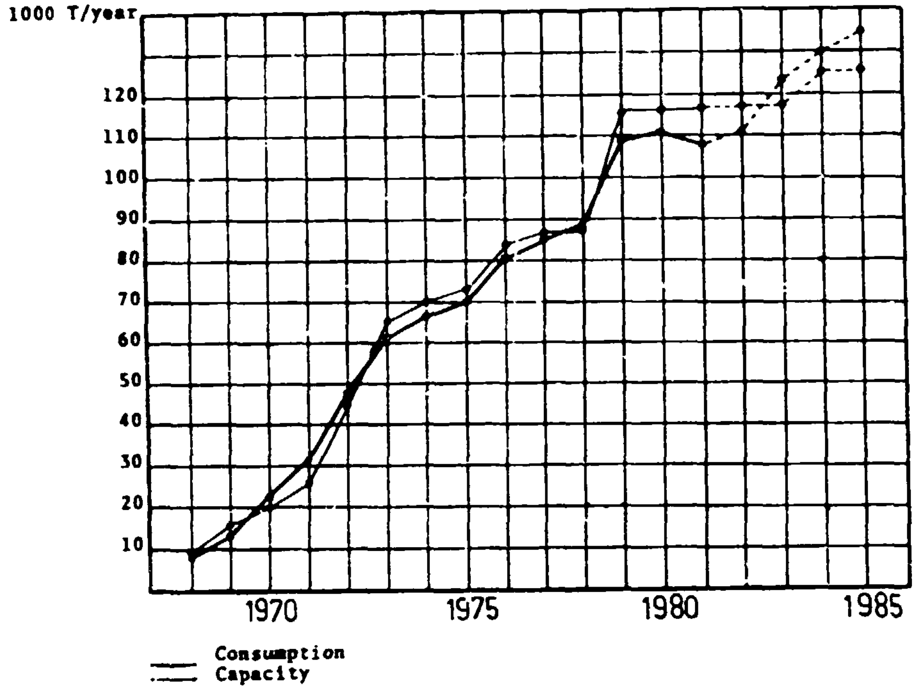
SYNTHETIC FIBER: POLYAMIDES CONSUMPTION AND CAPACITY

GRAPHIC Nº 6



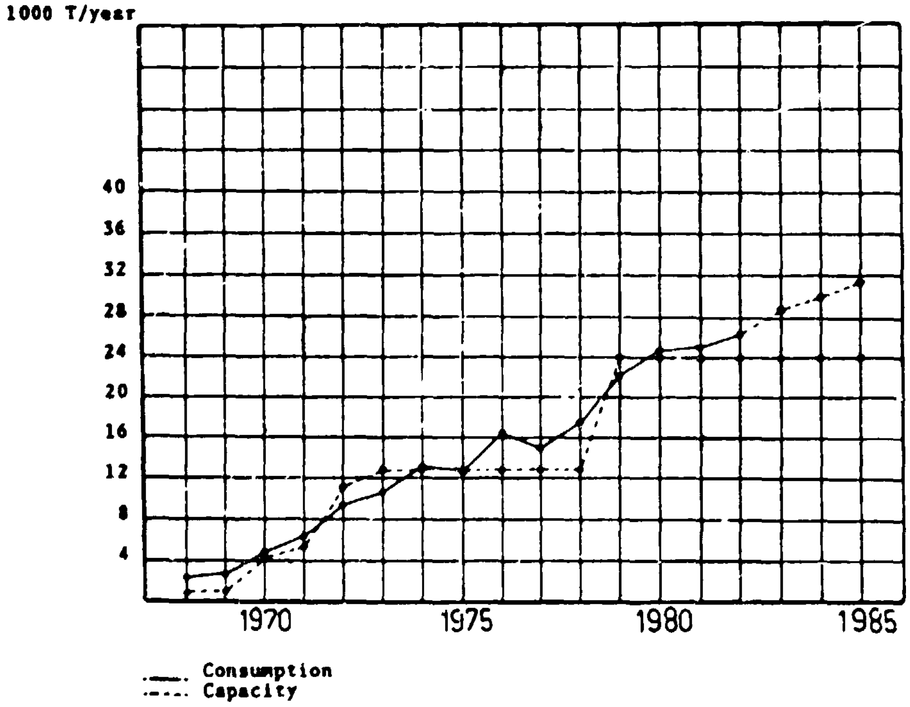
SYNTHETIC FIBERS: POLYESTER CONSUMPTION AND CAPACITY

GRAPHIC Nº 7



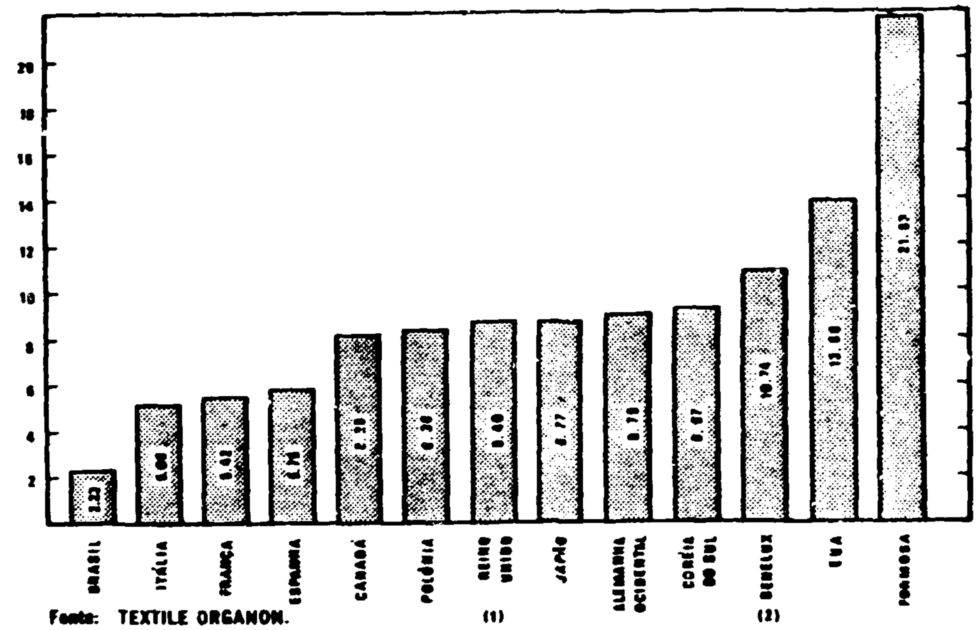
SYNTHETIC FIBER:ACRYLIC CONSUMPTION AND CAPACITY

GRAPHIC Nº 8



CHEMICAL FIBRES CONSUMPTION PERCAPITA YEAR 1976 Kgs/ YEARS

GRAPHIC Nº 9



Fonte: TEXTILE ORGANON.

(1) Inglaterra, Escócia, Irlanda e País de Gales.

(2) Bélgica, Holanda e Luxemburgo.

ANNEX 1

PRODUCTS AND MAKERS OF ARTIFICIAL FIBRES IN BRAZIL

1 Acrylic

- Fisiba — Fibras Sintéticas da Bahia S.A.
  (fibra cortada)
- Rhodia S.A.
  (fibra cortada)

2. Polyamides

- Artepesca S.A. Artigos de Pesca do Nordeste
  (monofilamento)
- Banylsa Tecelagem do Brasil S.A.
  (6 têxtil filamento contínuo)
- Brasil Viscose S.A.
  (6 fibra cortada)
- Celanese do Brasil — Fibras Quimicas Ltda.
  (6.6 têxtil filamento contínuo)
  (6.6. têxtil filamento contínuo texturizado p/ tapetes)
- Cia Brasileira de Sintéticos
  (6 têxtil filamento contínuo)
- Cobafi — Cia Bahiana de Fibras
  (6 industrial filamento contínuo)
  (tecidos de náilon p/ pneumáticos)
- De Millus S.A. Indústria e Comércio
  (6 textil filamento contínuo)
- Equipesca — Equipamento de Pesca S.A.
  (industrial filamento contínuo)
- Fiação Brasileira de Rayon — Fibra S.A.
  (6 têxtil filamento contínuo)
- Irmãos Mazzaferro & Cia. Ltda.
  (6 filamento industrial contínuo)
  (polímero de nailon 6)
  (mono e multifilamentos industriais de náilon 6)
  (cerdas de náilon 6)
- Manap — Manufatura Nacional de Plásticos
  (6 industrial filamento contínuo)
- Marcatto S.A. Indústria e Comércio
  (monofilamento)
- Monofil — Cia Indl. de Monofilamentos
  (6 industrial filamento contínuo)
- Novelspuma — Espuma de Nylon S.A.
  (6 têxtil filamento contínuo texturizado p/ tapetes)
  (6 industrial filamento contínuo)
- Rhodia S.A.
  (6.6 têxtil filamento contínuo)
  (6.6 fibra cortada)
  (6.6. industrial filamento contínuo)
- Rohm & Haas Brasil S.A. Química e Têxtil
  (6 têxtil filamento contínuo)
- S.A. Indústrias Reunidas Fábricas Matarazzo
  (6 têxtil filamento contínuo)
- Scara Ind. Têxtil Ltda.
  (monofilamento)

3 Polyester

- Banylsa Tecelagem do Brasil S.A.
  (têxtil filamento contínuo)
  (têxtil filamento contínuo texturizado)
- Celanese do Brasil — Fibras Quimicas Ltda.
  (têxtil filamento contínuo)
  (fibra cortada)
- Cia Brasileira de Sintéticos
  (têxtil filamento contínuo)
  (têxtil filamento contínuo texturizado-crú e tinto)
- Cobafi — Cia Bahiana de Fibras
  (fibra cortada — futura produtora)
- De Millus S.A. Indústria e Comércio
  (têxtil filamento contínuo)
- Polyenka S.A. Ind. Química e Têxtil
  (têxtil filamento contínuo)
  (textil filamento contínuo texturizado-crú e tinto)
  (polímero de poliéster)
- Polynor S.A. Ind. e Com. de Fibras Sintéticas da Paraiba
  (têxtil filamento contínuo)
  (fibra cortada)
- Rhodia S.A.
  (têxtil filamento contínuo)
  (fibra cortada)
  (industrial filamento contínuo)
  (polímero de poliéster)
  (bidim agulhado)
- Rhodia Nordeste S.A. Indústrias Têxteis e Químicas
  (têxtil filamento contínuo)
  (fibra cortada)
- Rohm & Haas Brasil S.A. Química e Têxtil
  (têxtil filamento contínuo)
  (têxtil filamento contínuo texturizado)
- Safron-Teijin S.A. Indústrias Brasileiras de Fibras
  (têxtil filamento contínuo)
  (têxtil filamento contínuo texturizado)
  (fibra cortada)
  (polímero de poliéster)

4. Polyolefinic

- Artepesca S.A. Artigos de Pesca do Nordeste
  (monofilamentos)

PRODUCTS AND MAKERS OF ARTIFICIAL FIBRE IN BRAZIL

— Brasmentol Caçapava S.A.
(fita ráfia)

— Brasil Viscose S.A.
(fibra cortada)

— C.A.T.A. Cia. Amazonia Têxtil de Aniagem S.A.
(fita ráfia)

— Cia. Fab. Yolanda S.A.
(fita ráfia)

— Cia. União Manufatora de Tecidos
(fita ráfia)

— Empla. — Embalagens Plásticas S.A.
(fita ráfia)

— Etrúria S.A. Ind. de Fibras e Fios Sintéticos
(fibra cortada)

— Fibrasa — Ind. e Com. de Fios e Embalagens S.A.
(fita ráfia)

— Fibrotex Tecelagem de Fibras S.A.
(fita ráfia)

— Fitesa/Olvebra — Fiação Têxtil de Embalagens Plásticas S.A.
(fita ráfia)

— Indústria Têxtil Tsuzuki Ltda.
(fita ráfia)

— Implasa — Indústria de Plásticos Zaniolo S.A.
(fita ráfia)

— Manap — Manufatura Nacional de Plásticos
(fita ráfia)

— Marcatto S.A. Ind. e Com.
(monofilamentos)

— Novoplast Ind. e Com. de Plásticos
(fita ráfia)

— Oscar Bergreen & Cia. Ltda.
(fibra cortada)

— Plabasa — Plásticos da Bahia S.A.
(fita ráfia)

— Plasminas — Plásticos Minas Ltda.
(fita ráfia)

— Plásticos Linil S.A.
(fita ráfia)

— Plásticos do Paraná Ltda.
(fita ráfia)

— Plastilira Indústria de Embalagens Ltda.
(fita ráfia)

— Qualitas Ind. e Com. Ltda.
(fita ráfia)

— Sacoplast/Planasa — Plásticos do Nordeste S.A.
(fita ráfia)

— Spumar S.A. Ind. e Com.
(fita ráfia)
(fio-filamento continuo)
(fibra cortada)

— Seara Ind. Têxtil Ltda.
(monofilamento)

— Cia. Jauense Industrial
(fita ráfia)

— Dicoplast S.A. Ind. e Com. de Plásticos
(fita ráfia)

5. POLIURETANO

— Du Pont S.A. Inds. Quimicas
(filamento têxtil — Lycra)

6. RAIOM ACETATO

— Rhodia S.A.
(têxtil filamento contínuo)
(mecha p/ filtro de cigarro)

7. RAIOM VISCOSE

— Brasil Viscose S.A.
(fibra cortada)

— Cia. Nitro Quimica Brasileira
(têxtil filamento contínuo)

— Fiação Brasileira de Rayon — Fibra S.A.
(têxtil filamento contínuo)
(fibra cortada)

— Rhodia S.A.
(fibra cortada)
(industrial filamento contínuo)

TEXTILE AND SYNTHETIC FIBRES INDUSTRY IN EGYPT

SAMIR E. BADAWI

Egypt and Textile Industries

Introduction

Textile manufacture in Egypt is considered as one of the big industries including both the public and private sector companies.

All Fibre Spinning is carried out by the public sector using about 2.5 million spindles.

An estimated 60% of total weaving capacity belongs to the public sector and the private sector holds about 40% of the total number of looms.

Approximately 30% of total knitting is done by the public sector companies.

These companies also accounts for 30% of the total readymade garment manufacturing of Egypt. The rest of the textile activity is accounted for by several hundred small private sector companies.

Present Consumption of Fabrics

Textile mill fibre consumption in Egypt in 1980 is shown in table (1)

Table (1)

Fibre Consumption in Egypt 1980

Cotton	179	thousand	tons
Wool	8	,,	,,
Cellulosic Fibres	7	,,	
Acrylic Fibres	2	,,	,,
Nylon Fibres	1	,,	,,
Polyester Fibres	3	,,	,,
Total	200	,,	,,

As illustrated by table (1), and as expected for a country like Egypt with big production of cotton, cotton is the predominant fibre used by the Egyptian textile industry—accounting for 85% of the total fibre utilized by the Egyptian textile industry.

Wool accounts for about 4% and Cellulosic Fibres produced domestically in the form of Viscose Staple and Rayon continuous Filaments share by 3.5% and synthetic Fibres most of the balance.

Population and Fibre Consumption in Egypt

(A) Population:

Population increases are growing at a rate of higher than 2% per year. Table (2) shows the estimated population in Egypt till 2000.

Table (2)

Estimated Population in Egypt Till 2000

Year	Population (millions)
1980	41.70
1982	43.63
1987	48.35
1992	53.91
1997	60.10
2000	64.16

(B) Per Capita Fibre consumption in Egypt.

The percapita Fibre consumption in Egypt is 4.8 kgm/year compared to 22.0 kgm/year in the U.S.A., 14 kgm/year in Western Europe and Japan and also lies below the average world consumption of 7.0 kgm/year.

The studies made by international consulting firms expected three possibilities in the development of fibre per capita consumption in Egypt based on the expected growth in the national income:

(1) an average increase of 0.2 kgm/year every 5 years till 2000.

(2) an average increase of 0.7 kgm/year every 5 years till 2000.

The second possibility is the most reasonable in the experts view.

But, as the textile industry is suffering through out the world from the unstable economical situation, we expect the rate of growth of per capita fibre consumption will increase most probably by 0.2. kgm/year till 1987, then by 0.7 kgm/year every 5 years till 2000.

Accordingly, taking into consideration the annual increase in population and the relation between the per capita Gross Domestic Product and the per capita fibre consumption, the projected consumption of textile fibres in Egypt can be estimated as follows in table (3)

Table (3)

Estimated Fibre Consumption in Egypt Till 2000

Year	Population (millions)	Per Capital Consumption kgm/year	Fibre Consumption (thousand tons)
1982	43.63	5	218
1987	48.35	5.7	276
1992	53.91	6.4	345
1997	60.10	7.1	427
2000	64.16	7.1	456

Situation of Synthetic Fibre in Egypt

As we mentioned earlier, Egypt is depending mainly on Cotton in Textile Industry.

World-wise, increasing competition from the Petro chemical based Synthetic Fibres against:

1. Cotton — facing increasing competition for fertile land by food stuffs.
2. Wool — an increasingly expensive and out put limited fibre, rapidly becoming a luxury fibre.
3. Rayon — with increased wood pulp and processing costs. Clearly, the synthetic fibres, helped by massive research and development programmes, have successfully penetrated the developed textile industries, and despeite the raw material price increases seem set to consolidate their position.

So, with the increased demand for textile fibre in Egypt, while keeping the rate of cotton production at the same level, it is evident that synthetic fibres are the future for Egypt and are forecast to increase their over all penetration to around 40-50% by 1990, which would seem the maximum to be achieved.

In general, the major synthetic fibre to be consumed in Egypt is Polyester, mainly as staple for blending with cotton and other fibres, Acrylic to lessen extent for knitting industries and nylon for outer wear and tuffted carpets, stockings.

Table (4) shows the forecast of fibre consumption in Egypt till 1992 in thousand tons from different types of fibres.

By this forecast, synthetic fibres can cover the fibre demands in Egypt while keeping the level of cotton production almost without alteration. For Cellulosic fibres, it will only be restricted to some end uses like lining and other traditional fabrics needed by the Egyptian markets.

Man made Fibre Production in Egypt

Egypt was introduced in man-made fibre production by 1946 when MISRAYON Company was established. The viscose rayon represents its first activity, then the company established in 1949 a Plant for manufacturing viscose staple fibre.

In 1954, ESCO C^o established another Plant for rayon continuous filament to cover the increased demand for rayon.

In 1957, MISRAYON C^o built a Plant of limited capacity for the production of nylon — 6 fibres and continuous filaments starting from Caprolactam and expansions of this plant was completed by 1980.

To enable the Egyptian Textile Industry to keep pace with the international development, MISRAYON, got the know-how from RHONE-POULENC, manufacturers of polyester fibre in France, known as Tergal, and established a plant for production of 26.000 tons polyester staple fibre for blending with cotton, viscose staple, wool and linen.

Its capacity will be doubled by 1985. Also due to the demand for polyester continuous filament for knitting and curtains, a plant of 3.000 tons is under erection by MISRAYON.

Concerning Acrylic Fibres, only conversion of Fibres is carried out in Egypt, as the demands are not enough to built a plant with economical capacity.

Table (4)

Estimated Fibre Consumption by Type Till 1992

	CONSUMPTION (Thousand tons)		
YEAR	1982	1987	1992
Cotton	180	180	180
Wool	8	10	10
Cellulosic Fibres	7	5	4
Acrylic Fibres	2	3	5
Nylon Fibres	3	4	6
Polyester Fibres	18	74	140
Total	218	276	345

Research Associations of Fibres

1. Textile Consolidation Fund:

State organization for the development of the Egyptian Textile Industry established in 1953, to :

1) Promote marketing of textiles in domestic and export markets.
2) Consolidate the textile industry through the elaboration of technical studies, establishment of laboratories, research institutes and training centers.
3) Grant, within its resources, loans to the textile mills to assist them in coping with international standards and quality.

2. Quality Control Center:

Textile Consolidation Fund developed its testing and control Center in Alexandria, in cooperation with UNIDO, into quality Control Center, equipped with the most up-to-date testing instruments.

The Q.C.C. main objectives are as follows:

- Imposing standard specifications of the textile industry products for local market and export.
- Evaluation of all mechanical as well as chemical properties of all final textile products made from natural and chemical fibres, which are ready for export.
- Evaluation of the different fibre properties and their spinning and processing performance as a help for the textile mills.
- Assisting different textile mills in developing in plant, quality control systems.
- Expansion in periodic training of quality control technicians of all textile mills.
- Start and gradual increase in the planned quality control program for all textile products for local market consumption.
- Holding periodical local and international conferences on textile quality control developments.

3. National Research Center (Textile Department):

Established in 1956, work in academic researches in textiles and interested in developing and modification of chemical properties of fibres, and cooperate with mills for solving different problems in textile industry, specially dyeing and finishing problems.

4. Faculty of Engineering, Alexandria University:

Has a Textile Department, graduating Textile Engineers and gives higher studies, beside cooperation with textile mills in solving their spinning and weaving problems of both natural and synthetic fibres.

THE SYNTHETIC FIBRE AND YARN INDUSTRY IN ROMANIA

DR. ENGINEER: SANDESCU FELICIA *SYNTHETIC FIBRES WORKS — SĂVINESTI*

The Romanian industry of synthetic fibre and yarns has developed within the Industrial Central from Săvinesti since 1959 starting from petrochemicals as raw materials. Now the production of synthetic fibres and yarns of the Central, consisting of 12 industrial works, is directed towards the following types of products :

- acrylic fibres and yarns
- polyamide fibres and yarns
- polyester fibres and yarns
- polypropylene fibres
- artificial fibres and films
- monomers: caprolactam, adipic acid
- auxiliaries: tetrachlorethan, ethylenglycol carbonate cyanuril chloride

Production of synthetic fibres and yarns in Romania:

Year	1965	1970	1978	1980
Production (in thousands tons)	3.3	23.5	131.3	140.9
Per capita output (kg)	0.2	1.0	6.0	6.4

The output of 6.4 kg per capita obtained in 1980 is placing Romania among the developed countries from this point of view, considering that the world average is of 6.6 kg/capita.

The first plant was erected in 1959 at the Synthetic Fibres Works — Savinesti. It was a caprolactam plant having a capacity of 2,000 t/year. Besides being a production unit this plant also represented a school to train up the Romanian specialists. Later, new production capacities were built, having original processes to obtain a caprolactam with a purity comparable with the best products on the world market.

On this basis, there have been commissioned new plants, to produce polyamide fibres and yarns, known as RELON. The first plant having a capacity of 2,000 t/year was put into operation in 1959 while the last with a capacity of 9 times higher was started up in 1980.

The last RELON plants are marked by a high technical level. These plants are producing silk like yarns, textured yarns (RELONTEX), technical yarns for the most various uses like: cord insertions having a high resistance, carpet fibres, polyamide chips for moulded pieces.

Acrylic fibre "MELANA" production started in 1962, using acrylonitril as raw material, obtained from methane gas and air. Later, Romanian petrochemical industry put into operation capacities to produce acrylonitrile by up-to-date processes-propylene ammonolysis.

On this basis, new acrylic fibre capacities were put into operation one in 1970 and a second one in 1973.

As a result, in 1975 acrylic fibre production was three times higher than in 1970.

The process to obtain MELANA fibre is based on an original Romanian technology, which was continuously improved along the years, using a nontoxic solvent — ethylenglycol carbonate. By using this solvent in well set conditions, one can obtain excellent fibres (bulky, with a very good touch and processing) these properties being superior in comparison with well-known acrylic fibres in the world.

Now, a variety assortments of acrylic fibres are produced: fibres like wool, cotton, carpet and fur fibres, tops, staple and tow, dyed fibres by original methods.

The polyester fibres TEROM production started in 1969 by using DMT and ethylenglycol produced by Romanian petrochemical industry. The first PES fibre plant has a capacity of 10,000 t/year and the last plants, put into operation in 1981 permitted to obtain a PES fibres and yarns output of about 6 times higher than in 1970.

There are also produced wool and cotton type, white and dyed, textured and technical yarns. Polypropylene fibres DUNATEX PP, the newest, generation of the Romanian fibre industry is also a valuable assortment used in the carpet industry and in some textile, assortments. Within our Industry Central artificial fibres and yarns and also produced such as: cotton type rayon, wool type rayon, viscose yarns, silk acetate, cord insertions.

The technical performances of the synthetic fibres and yarns were continuously improved our specialists activity being focussed on the improvement and diversification of assortments and on the reduction of production costs.

This fact was possible by judiciously using new materials and by reevaluting the by-products and waste materials as well as by using the power resources in an economical way.

As a result of the obtained performances, the export of Romanian synthetic fibres and yarns increased in the last decade by 50 times. Romania is exporting products to more than 30 countries.

Export dynamics

No	Product	Exported quantity vs that produced (%)	
		1975	1980
1.	Acrylic fibres	23.20	31.91
2.	Polyamide fibres and yarns	39.46	46.67
3	Polyester fibres and yarns	—	15.19

Due to their high quality, the Romanian fibres have acquired markets that are traditional now. Such markets are: China, Poand, U.S.S.R., France, Federal Republic of Germany, Yogoslavia, Austria, India, Eqypt, Switzerland.

Our fibres are appreciated both in the developed countries as well as in the developing countries.

The Romanian process to obtain acrylic fibres MELANA was used to built up a plant with a capacity of about 10,000 t/year acrylic fibres in the North Korea, providing licence, know-how and engineering.

The Romanian synthetic fibres and yarn industry will continuously develop due to the necessity to replace natural fibres and to their high quality which confer a wide range of applications.

The production of synthetic fibres and yarns based on traditional polymers: polyacrilonitrile, polyamide 6, polyester, polypropilene will be improved by using new polymers and new spinning methods. Thus high hygroscopicity will be obtained and so with a high comfort, profiled section having characteristics close to natural fibres, reduced imflammability and high stability.

A great attention will be paid to the research and production for textile finishes. All the R and D problems are carried out by well trained specialists, organized in a research center, coordonated by a Central Chemical Institute. In the next period, the growth perspective of the synthetic fibres and yarns and artificial too, is the following:

No.	Product	Production growth vs 1980 (%)		
		1983	1984	1985
1.	Acrylic fibres	4.0	4.3	20.0
2.	Polyamide fibres and yarns	72.0	75.0	92.0
3.	Polyesteric fibres and yarns	90.0	98.0	110.0
4.	Polypropilene fibres and yarns	30.0	70.0	90.0
5.	Artificial fibres and yarns	150.0	200.0	205.0

We have good cooperation relations with firms from socialist countries as : C.F.K. Schwarza (G.D.R.) Soiuzchimvolokno (U.S.S.R.) Slovchemia (Chechoslovakia) Chemitexlot (Poland) and also with traditional firms from capitalist developed countries : Chemtex, Konsanto, Hoechst, I.C.I. Sandoz, Cyba — Geigy, Th.Bohne and others.

Together with ROMALFA Co. ITALY a joint company RIFIL was built in 1974. The plant is processing Romanian acrylic fibres obtaining high profits.

Within the Synthetic Fibre and Yarn Central-Savinesti there are also machine-building departments provided with up-to-date equipment and obtaining high performances in this field. For the next period, the Synthetic Fibre and YARN Central — Savinesti has large possibilities to carry out an efficient export of textile products.

There are also, possibilities to export some original licences and know-how, modern and efficient technologies for acrylic and polyamide fibres, adipic acid, caprolactam, as well as a high output equipment specific to fibres manufacturing technologies.

Therefore, we are interested in initiation and promotion of cooperation actions both with the developed countries as well as with the developing countries.

THE SYNTHETIC FIBRES AND TEXTILE INDUSTRY IN ARGENTINA

PATRICIA NOEMI MARINO,
Argentina

1. Historical background

Argentina produces a wide variety of textile raw materials. Among the natural fibers produced we can say that the wool production in 1981 amounted to 160.000 tons (grease wool). Argentina's production of wool is such that she's able to export up to 76 % of her total, after taking care of her local requirements. She is the third exporter in the world and produce all kind of finess.

The cotton production for that year was 100.000 tons. The production is self sufficient in short staple cotton.

Argentina's synthetic fiber industry dates back to 1948. Afterwards came a 10 year period during which the industry and the consumers became conscious of the characteristics, advantages and end-uses of synthetic fibers, and the market grew progressively stronger.

The synthetic fiber production was 120 tons in 1950 and 500 tons in 1959. In 1963 the rate of growth began to increase in a way that led to its present importance. The production of synthetic fibers meets the internal requirements, except for some specialty fibers which are not produced locally because of their low demand (these fibers amounted to 0.13% of the total production).

Nowadays Argentina meets 98% of her internal requirements.

2. Present situation

2.1. Annual production of cellulosic and synthetic fibers from 1971 to 1980 (Table No. 1).

2.2. Wool world production (principals countries) (Table No. 2).

2.3. Argentinian textile mills. Situation in 1978 (Table No. 3).

3. Synthetic fibers produced.

3.1. Polyamide

6 and 6.6 polyamide cover 52.56 % of the total of synthetic non-cellulosic fibers produced; 31% is used for industrial purposes.

There are 10 mills producing polyamide 6, among which one manufactures 50% of the total; two others jointly, 35%, and the ramaining 15% is divided among 7 small ones who consume their own production.

There is only one factory producing polyamide 6.6. Poliamide 11 is not produced in Argentina.

The polyamides for textile uses are available as mat, semi-mat and brilliant varieties, with a fineness from 15 to 520 deniers. The yarns for industrial uses are produced from 840 to 1260 deniers for tire cord and from 1300 to 2600 deniers for carpets.

3.2. Polyester.

There are 4 mills manufacturing polyester fiber; two of them produce 80% of the total.

Polyester amounts to 30.57% of the local production of synthetic fibers. Its fineness varies from 40 to 250 deniers.

3.3 Acrylics.

Acrylic fibers contribute by 16.85% to the total production of synthetic fibers. There is a single plant producing acrylinc fibers in Argentina. It produces a copolymer composed of 85% polyacrylonitrile and 15% methylacrilate and sodium methylallysulphonate. It is produced by a wet-spinning process in which the copolymer is dissolved in nitric acid and later coagulated in dilute nitric acid.

3.4. Continuous filament and staple fibers

In Argentina 59% of the fibers are produced as continuous filament and 41% as staple fiber.

- 60% of the polyamide continuous filament is texturized
- 70% of the polyester production is sold as staple fiber to be used in the wool or cotton spinning systems; the remaining 30% is sold as continuous filament, of which 70% is texturized.
- acrylic fiber is not produced as continuous filament.

4. Future prospects.

The demand for synthetic fibers is affected by the following:

- As Argentina is a producer of natural fibers, there is less of a demand for synthetic fibers.

— Prices of fibers still tend to favour the natural ones.

Argentina produces 90% of the petroleum she consumes, that is why it is possible to predict a great development for the petrochemical industry, on which the synthetic fibers industry depends.

As an example of what is to come, in 1972 a plant started its production of dimethylterephthalate, raw material for polyester.

Recently "Petroquimica General Mosconi" has begun to produce caprolactam for polyamide 6.

There are also projects to produce the monomers for polyamide 6.6 (adipic acid and hexamethylene diamine) and acrylonitrile for acrylic fibers.

5. Research associations.

5.1. I.N.T.I.

In the field of industrial research, Argentina have one organization.

The National Institute of Industrial Technology (INTI) is a decentralized, autonomous agency within the State Secretariat for Industrial Development of the Economy Ministry. Its main function consists in fostering and carrying out applied research to improve the technical and economic development of industry; undertaking research and studies aimed at improving the processing of raw materials and manufacturing techniques, promoting the use of domestic or of more economical raw materials, and the exploitation of industrial byproducts.

INTI is directed and managed by a board of Directors consisting of a chairman and eight board members appointed by the Executive Branch of the federal government from a list of names proposed jointly by the State Secretariat for Industrial Development, the National Development Bank and the industrial sector.

The Board of Directors is assisted by a scientific and technical Advisory Committee made up of outstanding professionals in fields connected with the activities of the Institute.

To meet its wide and varied range of activities the officers of INTI have laid down the following basic guidelines:

- assisting domestic industry.
- contributing towards the improvement of its technology and upgrading its efficiency.

— reducing the extent to which the country is dependent of foreign technology.

— avoiding the overlapping of tasks and efforts at national level, by establishing close links with all research and development centers throughout the country.

INTI is funded primarily by a tax of 0.25% applied on all credits granted by banking institutions to industrial firms, and also from fees received for services provided by its laboratories to domestic industries.

The activities of INTI are channelled through two separate and distinct types of institutions:

— a group of central laboratories.

— a system of research centres.

INTI's central laboratories and some of the research centers are located in its Miguelete Technological Park, which occupies thirty hectares bordering the Federal Capital, in suburban Buenos Aires.

The Technological Park was set up in the early 1960's. Now its twenty six research centers, six departments and two special divisions take up about 20.000 sq. meters of buildings. They include a modern research complex, housing up-to-date equipment and instruments, in some cases unique in Latin America. It is supervised and operated by professionals and technicians trained both here and abroad.

The central laboratories consist of six department and their divisions and two special sections. The departments operate in the basic disciplines most often required by industry, and their various divisions are designed of specific tasks The disciplines covered are : Industrial Physics and Metrology, Chemistry, Construction, Mechanics, Food and Thermodynamics. The special sections are devoted to Computation and Data Processing, and Proyects and Prototypes.

The research centers are entities set up by INTI in conjunction with public organizations (National, Provincial, Municipal) or with one or more private companies to meet specific needs of industry. The Centers currently operate in the following areas : Acoustics and Lighting Engineering, Technical Assistance to Small and Medium-Size Industries, Marine Biology, Meat, Rubber, Electronic Components, Construction, Leather, Water-Desalinization, Industrial Design, Documentation, Fruits and Vegetables, Dairy Industry, Fish Industry, Environmental Engineering, Machine Tools, Materials, Minerals, Textiles and Wood.

5.2. C.I.T.

The Textile Research Center (CIT) established in 1967, by an agreement between the Argentine textile industry and the National Institute of Industrial Technology, is the only organization dedicated to research and give advice to the textile industry in regard to its raw materials and processes.

Its activities are divided in services, investigations, bibliographical information, organized courses and meetings.

CIT carries out work on natural and synthetic fibers, through all the processes : spinning, weaving, dyeing, finishing and garment making, on the treatment of liquial wastes and cotton dust.

The Center have physical and chemical laboratories and pilot plant with cotton microspinning system, open-end and self twist machines and pilot knitting machine.

It have 23 persons, with 8 professionals and 13 technicians.

Its plans in the future are to amplify its proceeding pilot plant with the object to make larger investigations in each field of the textil process.

Table N° 1

ANNUAL PRODUCTION (19

PRODUCTS	1971	1972	1973	1974
Cellulosic fibers				
Staple	5180	6574	8151	8430
	251	741	718	957
Cellulosic yarns				
Cellulose acetate	2288	1995	1927	2305
Tire-cord rayon	736	950	1011	913
Textile rayon	5353	5853	6009	5404
Synthetic fibers				
Acrylic	2500	4143	4967	6513
Polyamide	1215	1895	2281	1854
Polyester	5454	8344	11123	11708
Polypropylene	125	----	----	----
Synthetic yarns				
Industrial polyamide	6076	6243	6982	6841
Textile polyamide	13621	14271	16847	16227
Polyester	2518	2926	4082	3509
Polypropylene	1007	791	----	----
Industrial monofilament polyamide	----	28	35	37
Industrial polyester	----	----	----	----
Film				
Cellulosic	8032	8760	9024	9065

1980) (ton)

1975	1976	1977	1978	1979	1980
6195	4481	5315	3772	3700	1512
999	557	373	41	40	----
2179	1308	1213	955	850	624
933	940	1255	1137	1100	129
4205	3085	3054	2338	2250	1365
6654	6901	6825	7502	8066	8939
850	673	471	687	250	149
12242	9284	8553	8782	9241	4002
----	----	----	----	----	262
7387	6867	8503	6304	6451	6131
15884	135[illegible]1	13484	13004	12936	12796
2996	2774	2364	2814	2949	2337
----	----	----	----	----	----
27	24	22	24	13	8
----	----	----	----	----	----
9398	7345	8968	7775	8100	9024

Table N° 2

Wool world production (principals countries - tn - grease wool).

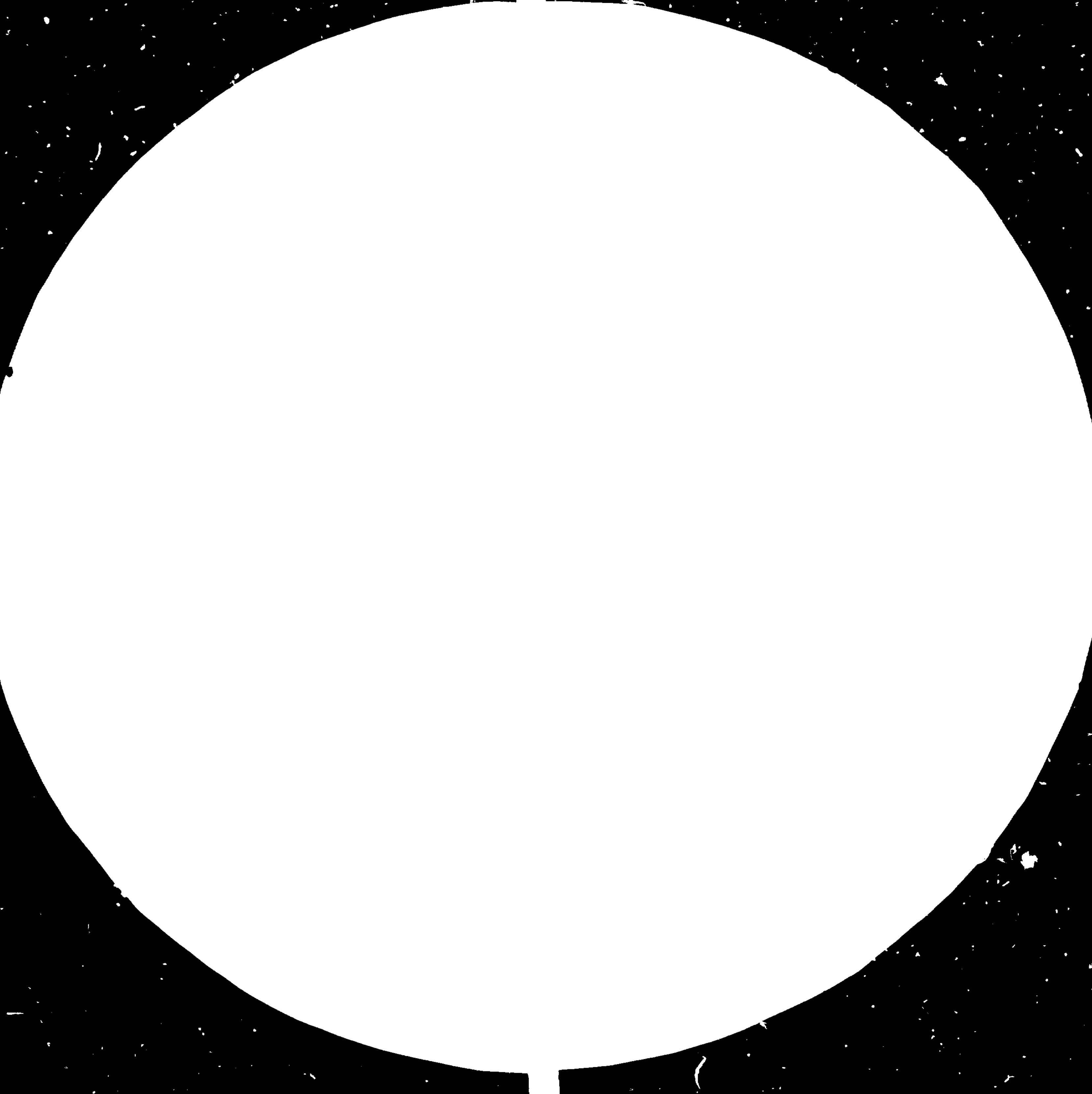
Years / Countries	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
South Africa	148.000	136.000	140.000	142.000	145.000	118.000	113.000	107.000	105.000	105.000	105.000	109.000
EE.UU.	109.000	107.000	103.000	96.000	88.000	83.000	82.000	79.094	80.000	72.000	65.000	57.000
Argentina	186.000	198.000	190.000	174.000	180.000	170.000	156.000	164.000	160.000	155.000	160.000	160.000
Rusia	357.000	371.000	394.000	415.000	390.000	419.000	429.000	420.000	415.000	428.000	458.000	460.000
Australia	754.000	794.000	803.000	870.000	908.000	872.000	861.000	725.000	701.000	789.000	747.000	752.000
N.Zeland	315.000	322.000	330.000	332.000	328.000	334.000	334.000	322.000	309.000	285.000	294.000	300.000
WORLD TOTAL	2.599.000	2.682.000	2.711.000	2.798.000	2.806.000	2.770.000	2.755.000	2.703.000	2.568.000	2.529.000	2.607.000	2.590.000

Sourse : FAO - 1976

Table No. 3

Argentinian textile mills — Situation in 1978

	Wool	Cotton
Spinning mills	50	60
Total spindles	348.000	1.170.000
Total workers	14.300	18.200
Production yarns and mixed with synthetic fibres (tn)	23.300	77.200
Total weaving mills	205	1.050
Total looms (woven and knitting)	5.845	22.200
Total workers in weaving mills	17.800	31.600
Production: woven and knitting fabrics (tn)	26.800	78.600




1.0
1.1
1.8
2.0
2.2
2.5
2.8
3.2


1.25
1.4
1.6

[illegible]

[illegible]

International Conference on
Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

HIGH SPEED SPINNING & TEXTURISING MACHINES

MR. UDO P. SCHWEIZER
BARMAG AG., Federal Republic of Germany

Sponsored by
UNIDO • GOVERNMENT OF INDIA • SASMIRA

MR. UDO P. SCHWEIZER graduated in 1965 from a College in Textile Engineering from Germany. Since then he worked entirely in the Synthetic Fibre Trade with special emphasis on Spinning & Texturising. He spent the beginning of his career for a few years in Australia with Fibremakers, an ICI based firbre plant. He then returned to his home country Germany where he worked for Enka AG. also a well known international fibre producer. For the last 9 years Mr. Schweizer worked for Barmag's United States subsidiary American Barmag Corporation as Service Manager. He was there in charge of the entire service organisation. During his time in America, Mr. Schweizer became a well known figure through the presentation of numerous papers on University campuses and his active involvement in the yarn texturing industry where he completed two terms as Vice-President and one term as President of the Textured Yarn Association of America.

He now has just moved into a new assignment in which he and his family took up permanent residence in Bombay and where he will look after Barmag's interest in India. Mr. Schweizer is employed with Mafatlal Engineering Industries Ltd.

Synopsis

The paper deals in general terms with high speed spinning and spin draw winding processes for textile and industrial yarns. Extrusion, quenching, take-up machines and automatic doffing are explained. The FK6 texturing machines are being outlined in their various cross sectional designs for false twist texturing. The air jet texturing machine with its newest possibility to produce spun like yarns with free fibre ends for novelty fabrics is also introduced.

HIGH SPEED SPINNING & TEXTURISING MACHINES

MR. UDO P. SCHWEIZER
BARMAG AG., Federal Republic of Germany

Barmag has undisputedly given significant impulses for the development of High Speed Spinning and Texturising machines. Take-up machines such as SW4S & SW46S or FK6 texturising machines are so well known by international fibre experts that they hardly need explaining. In this respect we are more than happy to note that especially to India Barmag has already supplied large machine orders of the most modern design.

Over the last 10-15 years we have seen a tremendous development take place with regard to the creation and development of newer and more economical processes. This is true for both machine types. Let us now concentrate first on the machines for High Speed Spinning.

Here we have to segregate between textile and industrial yarns. Whereas the majority of textile yarns are being spun as POY to be processed later on texturising machines to either stretch or set yarns, industrial yarns are being completed directly in a so called spin draw process — ready for the next processing step such as twisting.

Our first picture shows a typical spinning machines for Polyester POY. I wish to point out now the various main machine elements Starting with the extruder it should be noted that todays extruders are basically computer designed so that polymers can be carefully melted and perfect homogenisation can be achieved. The extruders come virtually in all sizes ranging from 25-250 mm dia. to accommodate every requirement with regard to out put. The extruder melts and pushes the polymer into the melt distribution manifold leading to the spinning beam.

Out put capacities of extruder have seen a large increase with the development of the LTM screw. The special feature of the LTM screw is that even in case of large through put in connection with the necessary screw geometry, no overheating of the melt temperature will occur. The excellent homogenisation quality of a LTM screw compared with a normal screw is also proven by the fact that almost no temperature difference will arise over the cross section of the melt stream.

The spinning beam consists of one or more spinning heads. Both melt distribution manifold and spinning head are dowtherm steam heated.

Spinning heads model SP 21, 22,23 & SP 31 & 33 are mainly provided for polyester and polyamide POY production lines. Our construction of spinning heads with their variable layouts allows the individual application to all specific requirements, for example production of 4 ends, 6 ends, 8 ends or 16 ends per position.

All parts of the spinning head, being in contact with the melt, are easily accessible and dismantable so that it is possible to produce for example 8 ends per position with a yarn count of 70 den. and 4 ends per position with a count of 150 den. with simple exchange of certain parts.

In the spinning head we find a value block on which the flow of polymer can be stopped in case of spinneret change. The valve block is connected to the pump block which distributes the polymer from the valve block to the various spinning pumps. The spinning pump meters the polymer most accurately to each spinneret. The spinning pump is a gear pump, made to the finest tolerances of specially hardened stainless steel.

The spinnerets themselves consist of filtration pack and the actual spinneret. The filtration pack can consist of either wire meshes, sintered metal or titania sand.

Below the spinneret some manufacturers prefer to form a layer of insert protective gas such as steam or nitrogen. This steam or gas can be superheated and applied either through the spinneret or externally.

We also find some customers requiring a monomer exhaust below the spinneret.

The still hot filaments have to be cooled now and this is done in the quenching chambers. Here a perpendicular air stream blows through the curtain of filaments. The quenching length is depending on the process 1-2 M long. Quenching starts approx. 40 mm below the spinneret. It must be noted that the yarn quality with regard to eveness is largely dependent on good and even quenching and quenching parameters such as air temperature and air volume have to be carefully maintained.

Let us discuss now the "heart" of a modern POY line, the take-up head respectively the take-up machines. The SW4S winder and all further winders of this group are suitable for all polymers, and they are today in operation for a production speed range from 2.500 m/min. Owing to their compact design and their modular construction shape they can be installed in narrow spacings and arranged in 2 decks.

This advantage was welcomed by those man-made fibre producers who had in mind to modernize their existing installations. Machinery makers were able to supply them with high-speed take-up machines matching their existing spinning machine.

All movements, such as the lifting and lowering of the traverse motion housing including groove and drive roller, breaking of bobbin chuck and setting of contact pressure towards the bobbin are made pneumatically.

The drive of the groove roller is made by means of an asynchronous outside rotor type motor. For the friction roller we are using a synchronous outside rotor type. Both motors are speed controlled by static inverters.

In particular, the development — traverse system being a combination between a conventional thread-guide traverse motion in connection with a groove roller — has brought a winding performance and safety for all kinds of applications that could not be reached by any winding technology.

This conception, using a thread guide with a weight of less than 1 gram is permitting extremely high traverse motion speeds, with low wear and tear rate and reduced noise level. Moreover, the retention time at the reversal point is extremely short due to a special geometry of the groove roller, thus avoiding bulge formation towards the sides of the package. The hardness is uniform all over the stroke length and particularly the package faces are very stable which is important for shipping.

All winders of the series SW4S are compensating the filament tension peaks which are provocated by the traverse motion triangle. This special effect is reached by a different depth of the groove in the groove roller, being more deep towards the outside as compared to the center. Largely this yarn tension compensation is contributing to a uniform yarn quality and perfect package formation.

Another advantage of the groove roller is its use for the purpose of influencing the filament tension towards the bobbin. As groove roller and friction roller have different drives, the circumferential speed of the groove roller may be set in such a way that there is a certin overfeed towards the winding speed, thus influencing the filament tension. BARMAG high-speed winders are therefore perfectly suitable for both, spinning-machines with or without godets.

One of the most heavily stressed machine elements is the bobbin chuck. In order to have still a reasonable long life time of the ball bearings, the design has been made in such a way that the bobbin chuck is running throughout the whole operation time in overcritical speed.

Moreover, the bobbin chuck is absolutely explosion-proof without any risk for the operator. Tubes are held on the chuck either mechanically or pneumatically.

All high speed winders should be equipped with a sequential controlled *three-step* contact pressure system. First high pressure in order to speed up the empty bobbin in the shortest possible time (step 1), low contact pressure during start-up with the aim to protect the first layers of filaments (2nd step) thus avoiding later uneveness in dyeing. After a certain time the contact pressure is automatically increased again to the normal value (step no. 3).

A further characteristic of high speed winders is the easy way of operation. The activation of a push-button will bring the upper winder part with traverse motion and friction roller into waiting position and the full bobbin is ejected by means of a push-out device on to a doffing device.

After placing the empty tube on to the bobbin chuck the friction roller is lowered down into contact position. For the string up procedure the transfer tail mechanism is placing the ends automatically on the paper tube.

For this purpose, the operator is first separating the number of ends by positioning them on to the thread guides of a swivel arm, using the string-up gun. He then is pressing a push-button which will generate a rotation of the swivel arm by about 180°. During this movement the filaments are caught by the paper tube, simultaneously a transfer tail is made.

The first high-speed winder SW4S was designed for a stroke length of 250 mm and a maximum package diameter of 260 mm. It was a one-package winder. Inspired by the man-made fiber producers requesting bigger weights and multiple package winders. We then developed the models SW4SL and SW4SLD and later their models SW4SSL and SW4SSD in superlong design. These winders are good for 2 ppackages of 250 mm stroke each, respectively 3 or 4 packages with corresponding stroke length.

Apart from the above feature the maximum package diameter was increased to 435 mm. As you may take from the shown chart the package weights have been increased by the factor 6 since the original model SW4S.

Especially for fine denier polyamide the machinery makers recognised in a very early stage that significant advantages with regard to quality improvement can be reached in connection with friction draw texturing if the take-up speed of the winding machine is higher than 4,000 m/min. In addition to the afore-mentioned SW4S series, BARMAG therefore has developed their model SW46S, suitable for a take-up speed upto 6,000 m/min.

All advantages which were described earlier are all the same in both series, for example the combination of thread guide traverse motion in connection with a groove roller, the fully-automatic transfer tail device as well as the wide range of winder configuration with regard to dimensions and number of packages per head.

A significant feature of the winder series for 6,000 m/min. is the start-up assistance of the bobbin chuck. By means of an air turbine the bobbin chuck is accelerated within a relatively short time to the high velocity which is required.

High-speed winders for upto 6000 m/min have been working under production conditions for quite some years. A large number of our customers decide for this model, even if for the time being they cannot make use of the full speed potential due to process reasons. They may thus run the winders with speeds lower than 4,000 mmin. at this moment, but they have the mechanical potential for a later speed increase. In such cases, certain machine components, for example start-up turbine and oil mist lubrication may not be incorporated at the beginning but can later be added when the full speed is requiured.

In addition BARMAG is offering different kinds of semi-or fully-automatic doffer-systems.

Independent from the material to be processed, either polyester or nylon, there are 4 main application areas of high speed winders as listed on this slide :

1. **High speed spinning** is a process, which is run with speeds of 3000 to 4500 m/min. for polyester and 3500 to 5500 m/min for polyamide.
2. **Super high-speed spinning** is applied for take-up speeds of 3500 - 6000 m/min. to obtain flat yarn.
3. **Spin drawing with godets** is a process in a speed range of 3500 - 4200 m/min. to produce fully drawn yarns, however in one process step.

4. **High speed spin drawing** with spinning speeds upto 4000 m/min is already in operation and the filaments are drawn in one step with take-up speeds of 5000 - 6000 m/min.

As mentioned in the beginning we differentiate between processes for textile and industrial yarn.

Industrial yarns are yarns which are being used in tyres, conveyor belts, safetly belts, tents but also sewing threads, which are of a much finer yarn count, belong to this product group. There are always certain sdyarn physical requirements for industrial yarns such as high tenacity or low shrinkage.

The extruder screws needed for this process differ significantly from the normal spinning extruder screws because the viscosity of the polymers used is much higher than for normal textile end use yarns. Care must be taken that frictional heat is reduced so that not excessive melt temperatures will occur. LTM screws are exclusively used for these processes.

Spinning head and spinning pumps have been adapted for the special requirements. High viscosity means also particular high melt pressure sometime upto 1000 bars.

Below the quenching chambers is the inter floor tube. The yarn carries a still high amount of heat down into this tube. Because the heat should not reach the take up area we find at the end of the tube only a small opening through which the yarn travels. The hot air has now the tendency to rise again in the inter floor tube and this flow will negatively affect the yarn quality. Therefore provision has been made to exhaust the hot air at the lower end of the inter floor tube.

Under high speed process for the industrial yarn we understand a spin draw process which is a single step process It has to be mentioned that at the moment a large proportion of all industrial fibres are produced using the conventional 2 step process whereby the first step consists of spinning and take-up and the second step the final drawing either on a heavy draw twister or on a multiple and drawing frame.

For the single step process we are using today again a Kiss roll spin finish applicator. This also in combination with a spin finish metering pump. The filaments are led in a ribbon formation over this roller and this ensures that spin finish is applied onto all filaments. In a metered finish application via a nozzle this is not always the case and segments with low or no finish might occur which would lead to filament breaks during the next process step, the drawing process.

The drawing is done over heated godets. Here Barmag has a speciality to offer which is the product of years of research. The vapotherm godet. An extremely even temperature profile across the total length is obtained by having a double shell which is inductively heated. Between the walls of the double shell we have a heating medium which works on the vapour condensation principle — therefore the high temperature evenness.

This godet has an extremely high heating capacity and therefore in many cases we only need one godet plus separator roll compared to our competitors who still have to use two godets. Godet dia. is 180 mm with our standard length of 200 + 300 mm.

Because the denier is usually high and therefore the doffing time is short we are using for the take-up here our SW4R Take-up heads for wasteless doffing. This already highly efficient system can be complemented by an additional automatic doffer system. The full packages are being transferred to the doffer and subsequently new tubes are being pushed onto the chuck automatically. Then the full packages are being transferred to a creel like trolley. This is our AD4 system.

A different system is the PID (Position integrated Doffer) where we have a trolley system which moves around the spinning take-up machine. The full packages again are being doffed and empty tubes replaced on the chuck.

Advantages of fully automatic doffing systems are that they requires less operators, increase the quality because the full packages are not being handled by people and are not being touched.

We now turn to Draw Texturising machines. Here clearly we can observe that the combination of drawing and texturing has been implemented on a world wide scale. It is questionable if friction texturing would ever have penetrated the market as quickly as it did if POY would not have been available. Undrawn as well as fully drawn yarns present certain problems in high speed friction texturing. These problems are broken filaments and irregular dye up-take with undrawn yarn due to the very short shelve life of the yarn and a draw twister barre as well as take off tension related problems at higher speeds with fully drawn yarns. The marriage of POY and Friction Twisting is perfect. POY having a long shelve life and a high yarn stability together with very even tensions in the friction twisting zone will only positively influence the texturing process. The conversion efficiency has over the years increased and today we see a large number of mills running lets say 150 den. Yarn at 750 m/min with a break rate of less than 0.02 breaks per Kg. textured yarn.

The quality of the final product, machine efficiency, actual production cost per Kg., ease of operability and last not least maintenance cost are of paramount importance.

The machinery makers have developed over the years machines for every world market. From highest speed potential machines for the very best POY to machines which are specifically laid out to process on friction false twisting even moderate to low oriented yarns which are still being produced in large quantities.

From yarns for commodity items to highly specialised yarns for fabrics of the finest texture as we find them specifically in the Asian market, the art is to find the right machine cross section in the combination with specialised friction discs and friction surface.

Our texturing machine is generally called *FK6*. This type of machine is now split into the various machine cross section such as FK6, FK6U, FK6M & FK6L and the ai8r jet texturing machine FK6T80.

Let us examine now what it takes to get to a high speed texturing process. We should understand that high speed for a low oriented Polyester might be 500 m/min., high speed for a 150 den. POY might be 800 m/min. and high speed for a 20 den. Nylon might be 1000 m/min. commercial speed. Naturally we cannot expect that only one machine cross section respectively machine element arrangement will cater to all the different yarns. Therefore large series of different machine cross sections was developed.

Today we differentiate basically between 3 false twisting machine types, the Lower Speed potential machines with a maximum operating speed of 700 m/min., the medium range with 900 m/min. and the high speed machines with 1200 m/min. maximum speed.

As machine cross section we offer our latest development the M configuration in which both, primary heater and cooling rail are slanted. This results in a greatly optimised yarn path giving us the best combined features of the former U & L version. This configuration lends itself primarily for high speed texturing of POY yarns. For the texturing of undrawn Nylon yarns below 30 den. and certain low oriented Polyester yarn we found that optimum fibre properties could only be obtained with a straight yarn path as we have it on the FK6.

Texturing machines for Polyamide & Polyester for fine deniers LOY are generally equipped with a predraw attachments without respectively with draw pin.

In order to texturize yarn at highest speeds all machine components must be adequately layed out for the various requirements. Heater length as well as furface and heat profile need to be of the best the industry can offer. Here the dowtherm heated Block heaters are the only answer to ensure the most even dyeing results in the textured yarns. On double heater machines of course both heaters should be executed as dowtherm heaters because only dowtherm will offer the quckest heat recovery after the temperature was lowered as it happens during the threading with a suction gun.

The heart of the texturing machine is of course still the friction unit. Our customers prefer today the sturdy execution of the fixed centre aggregate. As mentioned earlier, friction surfaces are now available to even meet the most stringent yarn requirements. On friction discs our customers do still prefer hard discs over soft ones because of the lasting surface and the high speed potential of the hard discs. Soft discs such as Polyurethane have a tendancy to deteriorate at high yarn speeds in an unpredictable manner. This will lead to costly renewal of discs in short intervals to ensure controlled quality.

The big advantages that the soft discs offer are however higher twist level and tenacity as well as no snow deposits on the texturing machine.

We are seeing today however that friction disc texturing still does not fulfill some of the requirements and wishes of the throwsters. Disadvantages, etc. are—

One cannot predict the exact twist which will result from a certain machine setting.

Texturing yarn with supr high twist at the highest yarn speeds is not possible.

Texturing of high denier yarns with high twist is not possible.

Production of specially/fancy yarns are not easily obtained.

The high amount of snow.

To solve this problem Barmag has developed already for some time a cross belt texturing friction unit which we call Beltex. This unit can be retrofitted into any F K machine. Because of the high speed potential of this system the most logical machine would be the 1200 m/min speed potential machine.

For this kind of friction texturing a totally new design for the twist insertion was invented. We call it the NCV — Nip controlled vector drive. This drive has the ability to choose any crossing angle and enable us to actually accurately predict the yarn twist. The denier range for this system is very large from 40-600 den. So far we have not seen any snow formation which means that down time during the cleaning cycle due to removal of snow has been eliminated. The unit also offers the possibility of producing novelty type yarns. The most important factor however is that we do not require any lubricant such as water between the yarn contact surfaces. thus we achieve a high eveness from position to position and there are no environmental problems, one of the biggest disadvantages of other cross belt texturing units.

In our final view on texturing machines I would like now to talk briefly about air jet texturing. Barmags FK6T80 was first introduced to the public at the ITMA in 1979 in Hanover, Germany. Since then further developments took place which resulted in a machine which gives the throwsters facinating possibilities to create spun like yarns for entirely new kind of fabrics. The 'T' in Fk6T stands for Taslan, a Du Pont trademark for yarns produced w3ith the Du Pont developed Taslan jet. The Customer has however prerogative to choose the jet from the manufacturer of his choice.

The reason for the apparent success of the air jet texturing machine lies certainly in the spun like yarns which can be achieved with this process. In many of its properties the yarn resembles a spun yarn. If you examine a spun yarn under a microscope, you will find that it is not predominantly the free fibre ends which are sticking out of the yarn bundle which contribute to the bulk of the yarn but more the loops which are formed by the individual filaments. And this is where the taslan yarns do resemble conventional spun yarns. The many small loops formed during the texturing process are in fact the main contributing factor to the bulk of the yarns and later of the fabrics. In spun yarns we find that also the free fibre ends will positively contribute to the hand of a fabric. So our research activities were guided into the direction to also achieve a taslan yarn with free fibre ends. Today we can say that our research into this direction was a success and an in line process with the texturising process has now been developed. Fabrics yielded from this process do not only resemble but in many cases surpass spun yarn fabrics on appearance and evenness.

Let us quickly examine now the machine elements of a typical FK6T80. Before and after the entry box we have delivery units with which we can overfeed one or more ends into the jet. Prior to the yarn entering the jet it is wetted with water.

The air consumption at 125 psi pressure is approx. 8.5 cfm per jet with textile deniers. As the next stage we find a cold stabilization zone, which is located above the operator aisle. This stabilization zone is a special feature of our machine. It will contribute to the formation of very small sized loops and to a high yarn stability. In the following heat setting zone the loop sizes are further reduced and the boiling water shrinkage of the yarn is lowered. This is important for certain weaving or knitting constructions.

The effect of the stabilization and heat setting has one further advantage. The yarn which is finally wound onto a cylindrical package will very easily unwind off the package. No further winding process is necessary as it used to be with conventional taslan yarns.

The air texturizing process is remarkably flexible and allows a variety of different products to be made. Deniers in the range of 50-1000 can be textured. The individual denier per filament ought to be lower than 2.5 and is often as low as 1 dpf.

We have the impression that textile industry again discovered the air texturing process as an economic process for an area of wide applications.

This paper has presented a general over view of the industries latest innovations in spinning and texturing machines. The time did unfortunately not allow us to go into much detail. Also interesting side products such as non-stop filters and 3D-Mixers for spinning or tangle jets, twist-stop-rollers and micro process-or controlled machine elements could not be covered. Inline texturing with spinning as it is done for carpet yarns could unfortunately also not be covered.

I hope however that you were able to see that even todays technology will not be tomorrows. The developments will continue with their search for increased production, lower energy and production costs and high production flexibility.

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TEXTILE DENIER POLYESTER FILAMENT— WORLD SUPPLY AND DEMAND PROSPECTS

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MR. ROBERT M. DILLON has been engaged in textile marketing research for the last twenty-three years. A native New Yorker, Mr. Dillon obtained his undergraduate and M.B.A. Degrees from New York University. After his education, he joined International Statistical Bureau, Inc., an organisation specialised in the textile fibre and fabric markets and during his ten years service with this organisation, he worked as a Senior Market Analyst and Director of Market Research. For three years, he worked as a market analyst with Monsanto Textiles Company Inc. From 1969 to 1979, he was President of his own firm, Dillon & Dillon Inc. which carried out number of market research projects. The market studies carried out by his company have been utilised by most of the leading fibre manufacturers of different countries. He has published number of articles in various journals all over the world. Mr. Dillon joined Chemtex Inc. in November 1979 to direct corporate marketing research in identifying man-made fibre needs in developing countries and at the beginning of 1982, he was appointed Vice-President of Marketing.

Synopsis

The basic theme of this paper is that developing countries are in an excellent position to take advantage of all the technological developments which have characterized textured polyester in the past decade, while being equally well-situated to avoid the negati [illegible] - essentially marketing — factors which have contributed to adve [illegible] for textured polyester in the United States and Western Eur [illegible] ..ie past several years.

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Introduction

From 1973 to 1978 world polyester filament capacity rose by 10.6 per cent per year with projects initiated in response to the rapid rise in the demand of double knit fabrics beginning in the late 1960's and early 1970's. The excellent performance and the favourable economics, characteristic of polyester filament, supported unrestrained optimism until consumers decided in 1975 that they wanted a change from the domination of double-knits in outerwear. Demand dropped sharply even as new capacity came on stream resulting in a huge over-capacity which, in turn, led to price wars principally in 150 denier. Notwithstanding, world polyester filament consumption still rose by 5.9% per year as filament yarns were adopted in woven fabrics, and interest in lower denier filament yarns increased. Despite this continued strong interest in polyester, it was not enough to absorb the excess capacity and adjustments by the industry, which are now being implemented, were required to bring the capacity/demand ratio into an acceptable balance.

The increased consumer demand in fine denier is supported by the fact that since 1975 the average denier in the United States has fallen by over 15 per cent. In Japan, which is more influenced by exports to developing countries whose people use lighter weight fabrics, the average denier has fallen by about 25%.

This change in demand for lower deniers has a significant influence on the capacity situation.

Most older plants were designed to produce only 150 denier. The capacity of such plants is a function of the denier produced. When lower deniers are manufactured, the capacity is reduced accordingly. Unless other technology is employed, the production rate of 75 denier is only half that of 150 denier. Lower denier products from such plants cannot compete with similar products from new plants which were designed to produce lower deniers efficiently. Yet the older plants with non-competitive capacities contribute to the over-capacity until they are permanently closed. Such closings have occurred and are continuing.

The closure of older technology plants in developed countries the reduction in the denier pattern of production, and the continued growth in demand for polyester filament in woven fabrics have been reducing over capacity. If non-competitive facilities are excluded, the demand/supply balance is now approaching traditional healthy values (e.g., 90% of capacity utilized). Based on the past historical over-capacity experience and the absence of large projects to install additional capacity as existed in the mid-1970's, we believe the demand/capacity ratio in the world picture for polyester filament will be healthy throughout the rest of the 1980's.

Pricing of polyester filament yarn is primarily dominated by supply and demand as companies compete for market share. Despite rising crude oil prices, large price reductions occurred during periods of over-capacity even though the price of crude oil is an important element in the cost of raw materials and intermediates. However, as supply and demand come into balance, prices of filament are increasingly influenced by manufacturing costs with the cost of raw materials a major factor. Assuming a reasonable supply/demand balance, price projections were therefore derived based on anticipated price increases in crude oil. Other non-energy related costs generally follow inflation. Price projections were therefore made based on constant 1980 dollars, and the assumption that oil prices will rise at an average of 2.8%/year. On this basis we project that the world price for 150 denier polyester feeder yarns in 1990 on a constant 1980 dollar base will range from $1.23/lb (break-even price) to $1.63/lb (includes a reasonable return on investment). Historically, the price of 75 denier feeder yarns have been nominally 20 to 30% higher than 150 denier which reflects supply/demand relative to 150 denier.

Production and Demand Trends

During the initial phase of polyester filament growth in the early 1960's, most of the yarn was fully drawn (i.e., flat yarn) and used for blouse fabrics, curtains, sail cloth, sewing thread, and the like. However, with the advent of textured polyester in the mid-1960's coupled with increasing consumer demand for garments with easy care properties and good crease recovery, very rapid growth in the production of textured polyester double-knits occurred. The number of manufacturers of such fabrics increased during the period 1967 to 1973 by a factor of 6 and the number of knitting machines grew from some 3,000 units to an estimated 25,000. The dramatic growth in consumption of polyester during this period catalyzed several important technological advances. For example, double heater texturing machines were developed, spinning and texturing speeds were dramatically increased and high speed spinning of partially oriented (POY) feeder yarns was introduced.

The substantial expansion of polyester filament production capacity in the United States is shown in Figure 1, and was directly related to the rise in demand for double-knits. The number of U.S. fibre producers increased, total domestic capacity expanded rapidly in the early 1970's and capacity utilization was high. However, demand remained higher than production and consequently Western European producers expanded their capacity in order to increase exports to the United States.

The situation in the early 1970's was characterized by an under-capacity of filament production as a result of the rapid increased demand in total mill consumption. U. S. polyester filament producers therefore geared up for increased production as a result of the apparent sky-rocketing demand for double-knits. Meanwhile, European producers enjoyed a healthy export market so there was little incentive for them to improve their facilities with the rapidly developing advanced technology that was being incorporated in many of the new facilities being constructed in the United States and Far East. Western Europe was then left with outmoded equipment in the face of increased capacity with modern facilities in the United States and Far East.

Because of the high demand for 150 denier yarns for double-knits, product development for alternative outlets was not promoted. This left filament producers ill-prepared for the sudden decline in the double-knit business in the mid-1970's. This effect was further compounded in Western Europe which was already suffering from both a decline in utilization as a result of new U.S. capacity coming on stream, as well as the burden of older technology. Filament demand and capacity utilization were clearly seriously affected by the double-knit recession as shown on Figures 2 and 3, with Western Europe being affected more seriously. When analyzing this situation, consideration must be given to the time lag (minimum 2 - 3 years) to expand or construct plants following authorization of a project. There is also a tendency to delay decisions to shut down plants because of hopes that the market will turn around. Many of the companies that added capacity when they saw the boom in then late 1960's and early 1970's are no longer in the polyester filament business. This includes such companies as Rohm and Haas, Phillips Fibres, C. L. Meyers, and Monsanto among others. In 1975 there were 15 producers of polyester filament in the United States and now there are only 5. The remaining facilities are those which are more efficient because of their more sophisticated technology. The Europeans have not reacted as quickly as the United States in reducing total capacity as fibre demand declined.

Following the decline in demand for round cross-section 150 denier polyester textured yarn, producers attempted to diversify their product range through the introduction of finer deniers and modified cross-sections as well as to stimulate the trend toward woven fabrics. Figure 4 shows the trend in average deniers of polyester feeder yarn for the United States and Japan. The Japanese producers exported much of their production so their decreasing trend in average denier is representative of many developing countries where there is a demand for fine denier yarns for light weight fabrics. In fact, throughout the mid-1970 recession, the capacity utilization of Japan was maintained at a much higher rate than either the U.S. or Europe (see Figure 3). The average denier of European producers is even higher than that for the United States. This reflects their inability to respond to this fine denier trend because their plants were installed early in the growth of polyester filament and were mainly designed for 150 denier yarns.

The over-all world trends in capacity and demand for total polyester (staple and filament) and for polyester filament only are shown in Figures 5 and 6. Capacity utilization began to recover from a low point in 1975. A closer examination of this trend, given in Figure 7, shows that the growth in demand has remained relatively high (5.9%/yr) despite the double-knit fiasco. By contrast the growth in capacity for the past years has been very low. This indicates that a balance between supply and demand (i.e., at 90% of capacity) should occur by the mid-1980's. In fact, published capacity figures may well overstate the true position because production capability is usually expressed as a function of 150 denier whereas the trend to finer deniers implies a lower capacity. This is because plants are traditionally quoted in tons per day or thousands of tons per year and are assumed to be based on the production of 150 denier yarns if the denier is not otherwise specified. Unless the plant was designed for low deniers or other technology is employed, the productive capacity of the plant decreases in direct proportion to the reduction in denier with a compounding increase in production cost.

The fact that European plants are not able to respond to the demand for fine deniers and that they are based on older, less economical technology, may partially account for their slower capacity utilization recovery. The results also suggest that much of the European capacity is not competitively viable and should be discounted in the world picture. The fact that a number of European fibre producers have recently announced that they are closing plants or going out of the polyester filament business supports this analysis.

By contrast, many of the filament plants in the Far East and those surviving in the U.S. were built using newer technology and are not penalized when they produce lower deniers. The Far East countries, who built their plants for export markets, many of which required lighter weight fabrics, are therefore particularly well suited to produce lower denier products without penalties.

Projection of Polyester Filament Prices

Prices of fibre are extremely sensitive to supply and demand as can be seen from the lack of apparent corelation between the price history of polyester filament yarn compared to the price history of oil and the price history of intermediates from which it is derived. However, as we shall see, selling prices become increasingly sensitive to raw material costs once supply and demand are in balance. Furthermore, in the previous section we have shown that a reasonable supply/demand balance for polyester filament yarn can be expected by the mid-1980's. Thus the price of oil and the intermediates used to produce polyester become very important in projecting the price of polyester filament yarn in the future.

Historical Price Movements

In Figure 8 we have illustrated the price movement of polyester feeder yarn, the hydrocarbons used to produce intermediates and intermediates used to produce polyester, and the changes in oil prices for the past decade. The prices reflect the proportions of components necessary to produce polyester. The hydrocarbons used to produce the intermediates, TPA and ethylene glycol, are para-xylene and ethylene respectively. Rapid, apparently inconsistent changes in the curves can be identified with particular events. For example, dramatic rise in the cost of intermediates in 1979 can be related to the combined effects of an anticipated large increase in available ethylene glycol plant capacity (Oxirane 800 MM lbs) which did not materialize and a plant fire which temporarily reduced total capacity (Calcasieu 200 MM lbs).

It is clear from Figure 8 that the cost of intermediates does not change in a direct relationship with crude oil price movements. While oil price is certainly an element of the cost structure, market influences, such as the supply and demand for fibre, are also an important factor.

The price of crude oil increased during the 1970 to 1980 period by approximately 1100% in current dollars (590% in terms of 1980 dollars) while the U.S. market price of 150 denier polyester feeder yarn declined in real terms by about 66%. In terms of 1980 dollars, the price of oil increased by 340% during the 1974 to 1976 period while the cost of intermediates during the period rose about 1/9th as fast at 38%. Clearly, the price increases could not be passed on from oil, hydrocarbons and intermediates to fibre sales prices when supply and demand were grossly out of balance.

In fact the decline in filament prices resulted from a complex combination of factors related not only to demand and capacity, but also because of end-use applications and employed technology—even though primary raw materials and energy costs were increasing. The net result of these effect was that profitability of fiber manufacture was reduced during the period to below a break-even line. Adjustments were required and, in the United States, for example, many plants were closed.

As capacity became more in balance with demand, a dramatic increase in prices began in 1978 (before the 1979 increase in oil prices) and continued to rise even though oil prices stabilized after 1979. With the reduction in capacity and the continuing future increase in consumption, the question, therefore, is how fiber price movements related to a balanced demand/supply will reflect oil cost increases.

Crude Oil, Fibre Intermediates and Polyester Filament Price Forecasts

As pointed out previously, during the period 1970 to 1980, crude oil prices rose dramatically from under $3 a barrel to over $30 a barrel or approximately 590% in terms of 1980 dollars. Oil price movements to 1990 have been variously projected in constant 1980 dollars at compound rates of between a high of 4.7% per annum and a low of 0.3% with a medium rate at 2.8% (Figure 9) which is in accordance with the World Bank projection stated in "World Development Report — 1980".

With strong evidence that as supply and demand come into balance (i.e., at or greater than 90% capacity utilization) in the early 1980's, the rate of oil price increases will be more directly reflected in prices for intermediates and polyester yarn. In our analysis we have used world oil prices and U.S. prices for hydrocarbons, intermediates and fibres. These are considered to approximate world prices since the U.S. is the major consumer of imported petroleum in the world (domestic oil has been decontrolled), and in recent years the major exporter of polyester fiber (but not fabrics and garments). Any advantage the U.S. may have had because of price controls for domestic oil has now largely disappeared. However, it does support our approach for developing projections from the latest prices available. Under such a scenario the rate of price increases for intermediates is expected to change at 1/2 to 1 times the rate of increase in oil price. Since the price of oil in constant 1980 dollars is expected to rise about 2.8%, the price of intermediates can be expected to increase at between 1.4% and 2.8% per annum.

Even though the prices of crude oil, hydrocarbons and intermediates increased during the 1970 to 1980 period, the market price of 150 denier polyester feeder yarn showed a steady decline until 1976. This is shown in Figure 10 together with intermediates cost expressed as a percentage of fibre price which moved from between 10 to 20% to over 40% during 1970 to 1980. The high percentage in 1979 is a reflection of the sharp and anomalous increase in ethylene glycol price.

When the prices of polyester filament yarn and the cost of the fiber intermediates are related to the conversion cost of fiber and the profitability of fiber manufacturers during the period, a break-even profit position occurs about when the percentage of intermediates is around 40% and a profitable position is established at around 30% of the sales price.

A projected fiber price for 1990 expressed in constant 1980 dollars would thus be between 2.5 to 3.3 times the projected price of intermediates. On this basis, with a median projection of intermediates price increasing at 2% per annum in constant dollars, the 1990 fiber price would expected to be in the range $1.63/lb in constant 1980 dollars (Figure 11). Acceptable profitability would probably not occur until the prices are above the mid-point or between $ 1.43 to $1.63/lb.

The major product deniers to be produced by most developing nations will be finer than 150 denier as used in our analysis. We, therefore, developed a historical relationship between the price of 150 denier and 75 denier yarns. Since Japan produces a lower average denier than the U.S. and has historically based much of its exports on lower deniers, we used the Japanese prices to support estimates for the differential price for 75 versus 150 denier feeder yarns. The ratios of these prices are shown on Figure 12 which shows that while the finer deniers also respond to their own supply/demand pressures, the prices for 75 denier are approximately 20 to 30% higher than those for 150 denier.

A tabulation of the prices of polyester filament feeder yarns compared to texturized yarns is given in Table 1. Both feeder yarn prices and textured yarn prices for 150 denier in Japan and the U.S. are shown. However, information on 75 denier is limited to Japan with reliable data on texturized yarn prices only available for the past few years. As indicated earlier, production of 75 denier is relatively small in the U. S. and useful price information accordingly limited.

The difference in prices between feeder yarn and texturized yarn is given in Table 2 for 150 denier in both Japan and the U.S. Reliable information regarding the differential for 75 denier is limited to Japan.

As a means of relating the price of textured yarn to its feeder yarn component, we have calculated the textured yarn/feeder yarn price ratio for 150 denier polyester yarn. The results shown on Figure 13 show that the price ratio has been fairly constant in Japan based on local prices. The ratio in the U.S. was considerably higher than for Japan a few years ago but has steadily declined so that the two are now comparable. Limited data for 75 denier are also included.

In summary, as supply and demand come into balance, prices of filament are increasingly influenced by manufacturing costs with the cost of raw materials as a major factor. Assuming a reasonable supply/demand balance, price projections can be derived based on the constant dollar concept which incorporate independent anticipated price increases in crude oil.

Table 1
POLYESTER FEEDER YARN/TEXTURED YARN
Prices ($/1b)

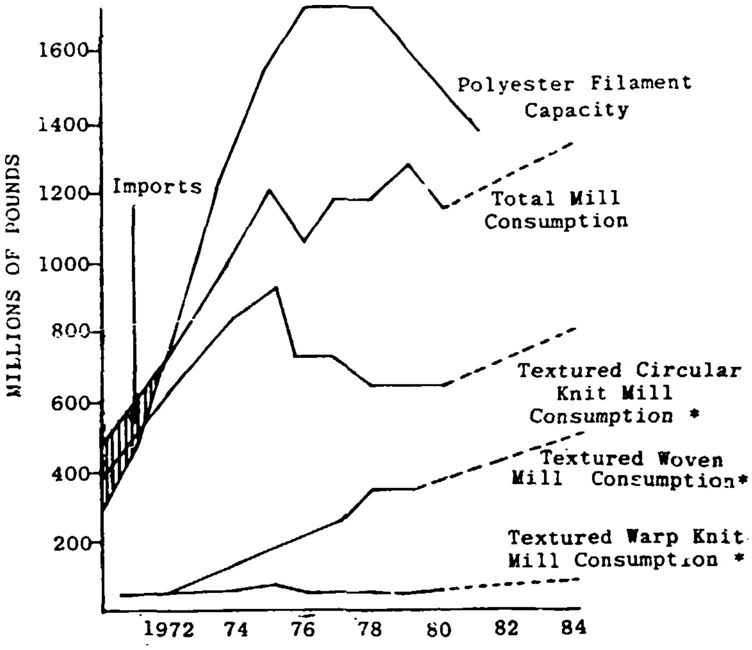
		Japan (Local)				U. S. A.		
		75d		150d		75d	150d	
Year	Quarter	Feeder	Textured	Feeder	Textured		Feeder	Textured
1979	1	1.41	na	1.04	1.20	not available	na	na
	2	1.33	na	0.99	1.18		0.75	1.01
	3	1.34	na	1.05	1.18		0.75	0.93
	4	1.27	na	0.98	1.13		0.73	0.93
1980	1	1.30	na	0.99	1.16		0.74	0.96
	2	1.54	na	1.24	1.41		0.74	1.03
	3	1.51	1.75	1.25	1.40		0.79	0.99
	4	1.47	1.69	1.24	1.37		0.79	1.00
1981	1	1.62	1.88	1.38	1.54		0.90	1.11
	2	1.54	1.90	1.30	1.52		1.03	1.22
	3	1.52	1.88	1.28	1.51		1.03	1.23
	4	1.53	1.90	1.30	1.51		1.02	1.17

Table 2
POLYESTER
Differentials between Textured Yarn Prices and Feeder Yarn Prices

		Japan (Local Prices)			U. S. A.	
		Differentials $/1b			Differentials $/1b	
Year	Quarter	75 d	150 d	75d/150d	75 d	150 d
1979	1	na	0.16	—	not available	na
	2	na	0.19	—		0.26
	3	na	0.13	—		0.18
	4	na	0.15	—		0.20
1980	1	na	0.17	—		0.22
	2	na	0.17	—		0.29
	3	0.24	0.15	1.6		0.20
	4	0.22	0.13	1.7		0.21
1981	1	0.26	0.16	1.6		0.21
	2	0.36	0.22	1.6		0.19
	3	0.36	0.23	1.6		0.20
	4	0.37	0.21	1.8		0.15

Figure 1

U.S. POLYESTER FILAMENT HISTORY

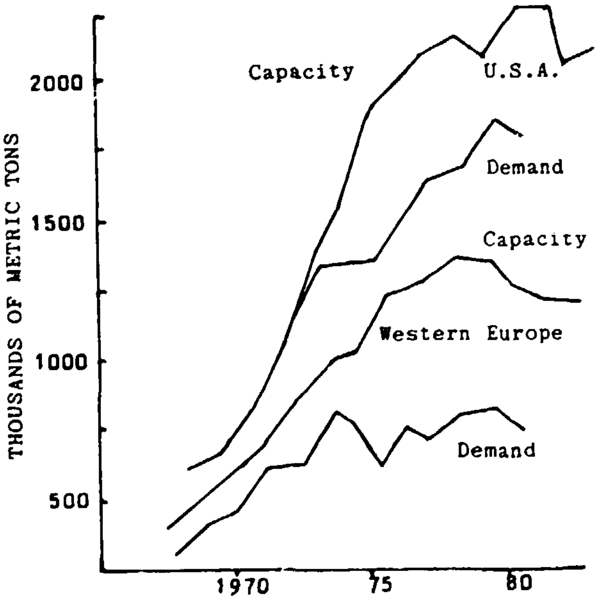


* These are independent curves and are not cumulative

Figure 2

POLYESTER (STAPLE AND FILAMENT) CAPACITY AND DEMAND

U.S.A. AND WESTERN EUROPE

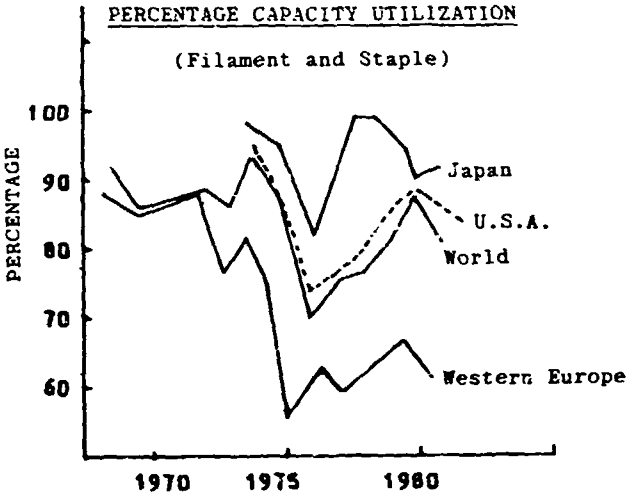


Source: Textile Organon

Figure 3

PERCENTAGE CAPACITY UTILIZATION

(Filament and Staple)



Source: Textile Organon

Figure 4

TREND IN AVERAGE DENIER OF TEXTILE POLYESTER FILAMENT

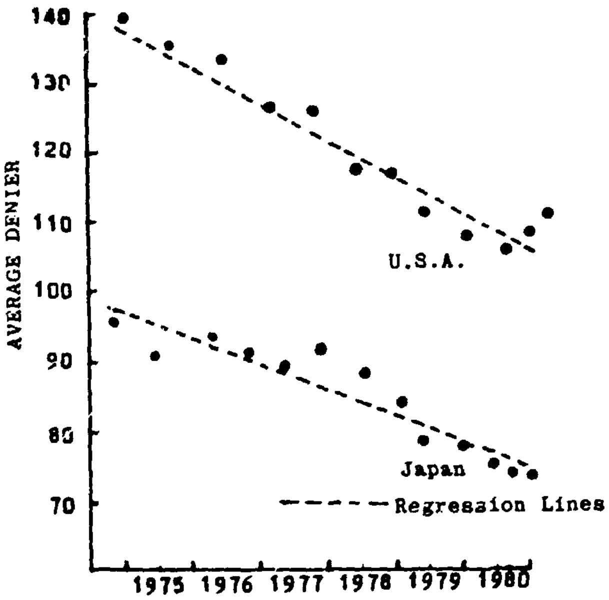
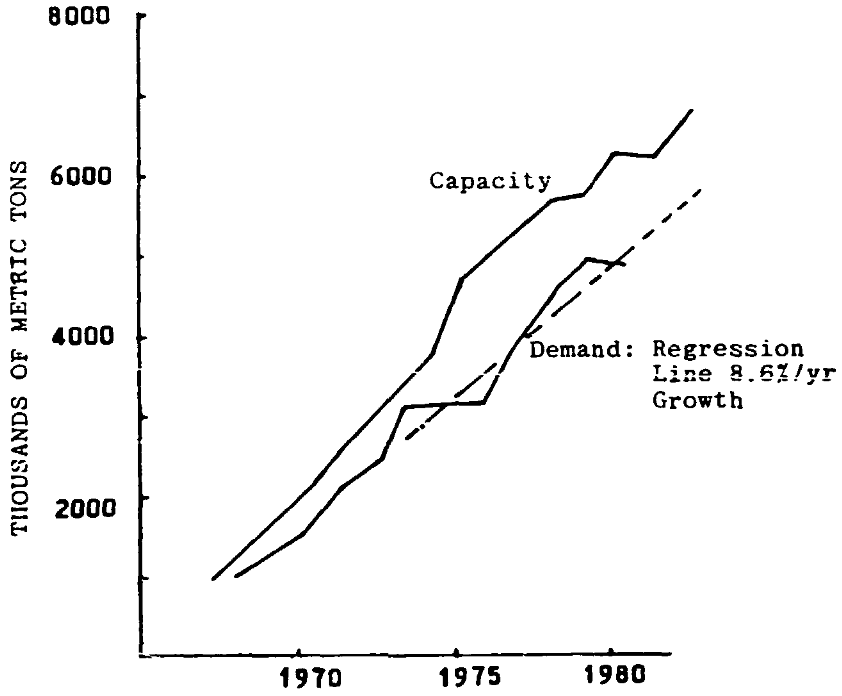


Figure 5

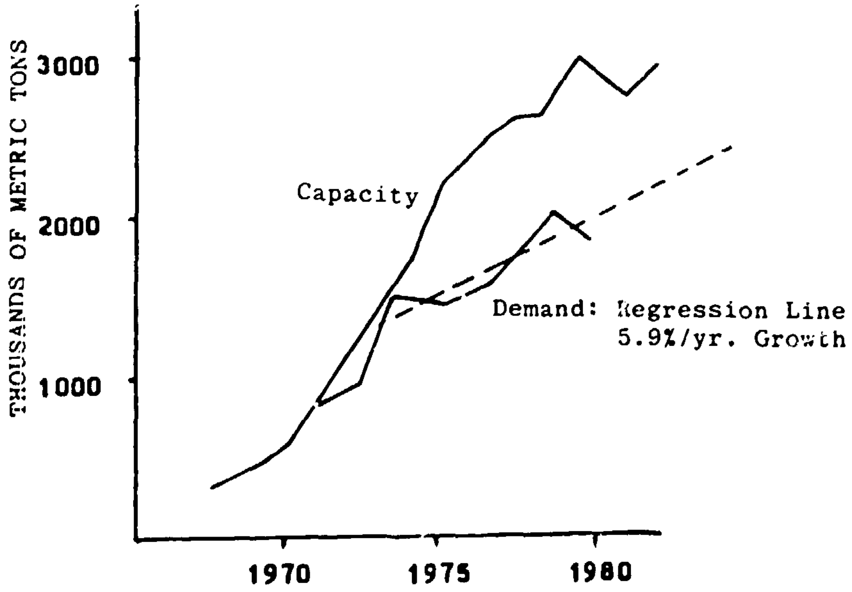
WORLD POLYESTER (STAPLE AND FILAMENT) CAPACITY AND DEMAND



Source: Textile Organon

Figure 6

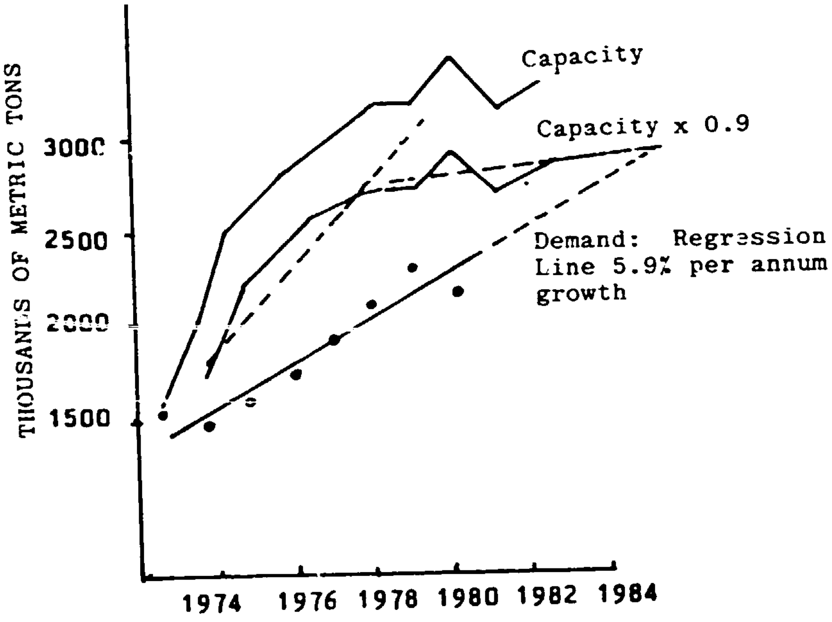
WORLD FILAMENT POLYESTER DEMAND AND CAPACITY



Source: Textile Organon

Figure 7

FILAMENT POLYESTER : WORLD CAPACITY AND DEMAND



Source: Textile Organon

Figure 8

CURRENT $ PRICE MOVEMENTS

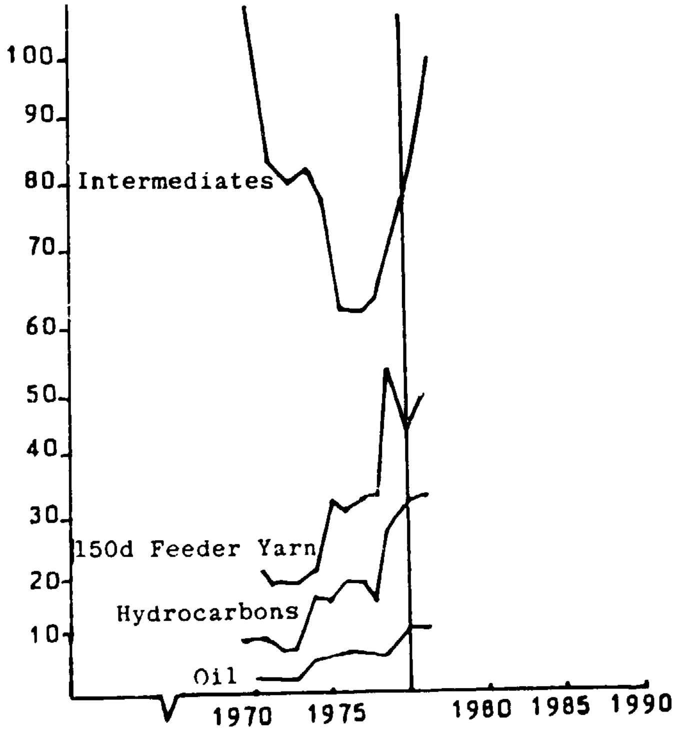


Figure 9

OIL PRICE MOVEMENTS

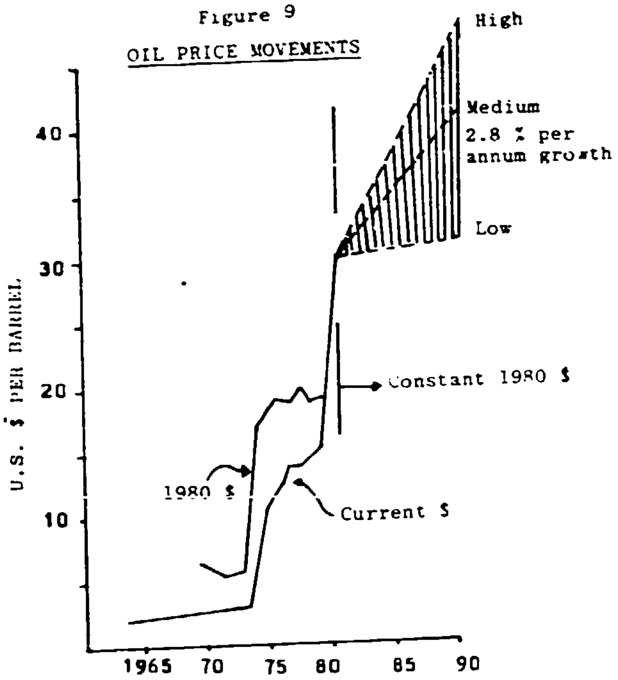
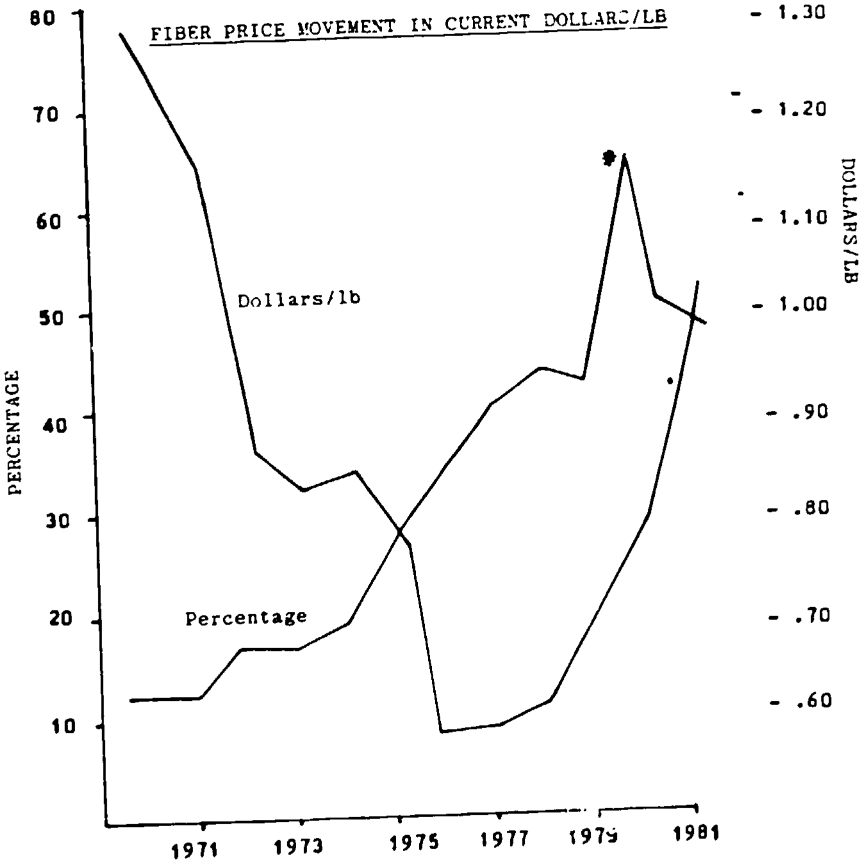


Figure 10

INTERMEDIATE COST AS A PERCENTAGE OF FIBER PRICE



* Anomalous Price - see text

Figure 11

PRICE TRENDS IN CONSTANT 1980 DOLLARS

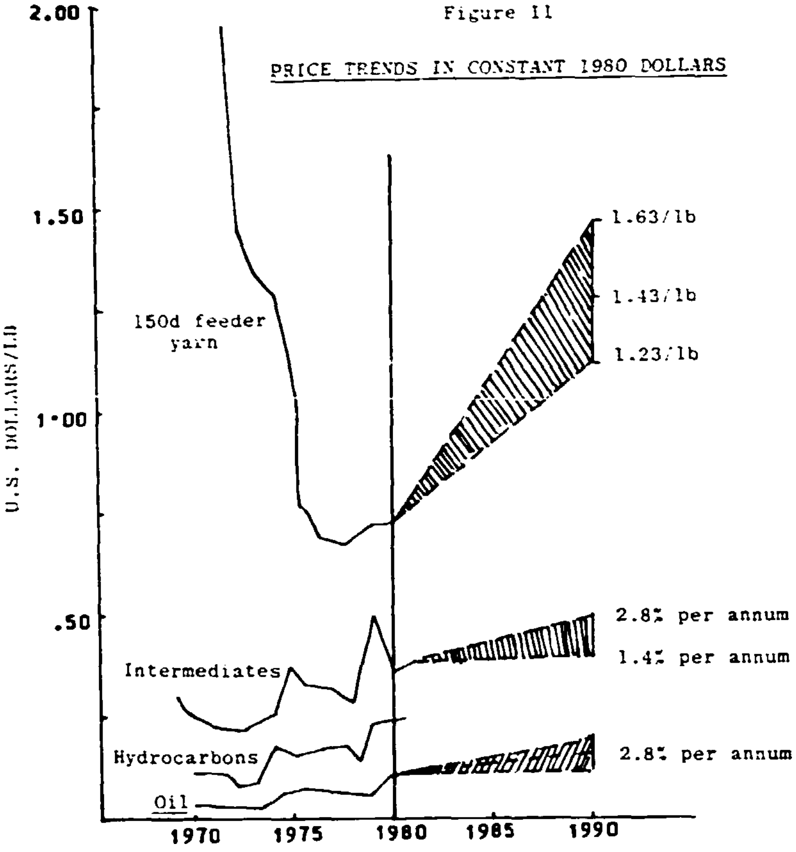
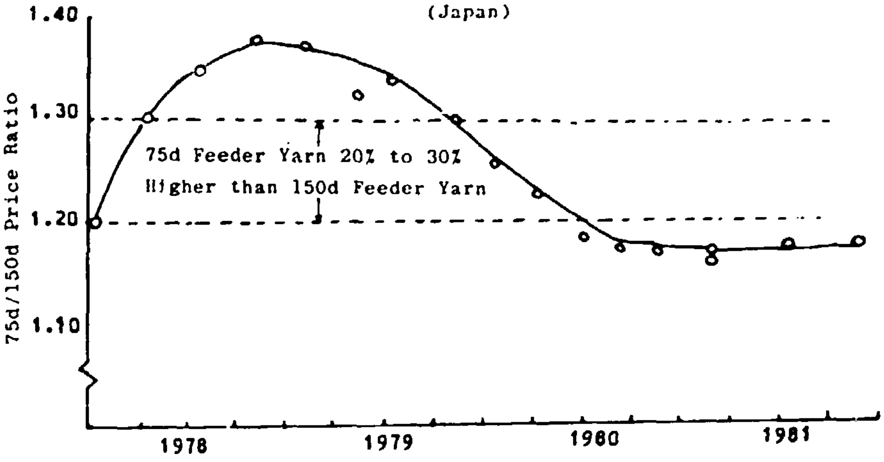


Figure 12

RATIO OF 75d/150d POLYESTER FEEDER YARN PRICES

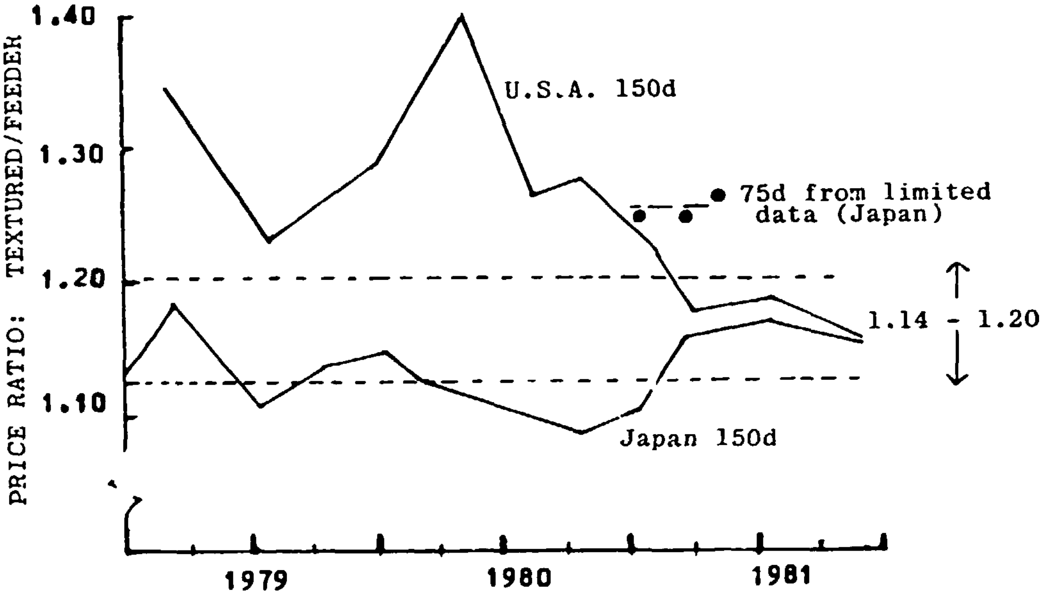
(Japan)



SOURCE: Asian Textile Record

Figure 13 TEXTURED YARN/FEEDER YARN PRICE RATIO

Polyester



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International Conference on
Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

SIGNIFICANCE OF DEMONSTRATION PLANT PROJECTS FOR TRAINING IN INDIA AND DEVELOPING COUNTRIES

M. C. VERGHESE
Former Head, Chemical Industries, UNIDO & Consultant Chemical Engineer

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MR. M. C. VERGHESE, born in Kerala on October 16, 1916, had his early education there. However, he had his graduation from the Madras University as well as Indian Institute of Sugar Technology and Post-graduation in Chemical Engineering from the Massachusetts Institute of Technology, U.S.A. in 1946. Subsequently he joined FACT, Kerala, as Deputy General Manager. He also held several positions in different organisations in India prior to joining the United Nations Industrial Development Organisation (UNIDO). Vienna, in 1967. He retired as the Head, Chemical Industries Section, UNIDO. He has to his credit several published articles in leading scientific periodicals. During his tenure with UNIDO, he assisted several developing countries in setting up various projects including the Demonstration Plant Project at Sasmira, in India.

Synopsis

The paper explains the guidelines formulated by the United Nations Development Programme for the setting up of Pilot Demonstration Plants as well as guidance for assistance. It also enlists some of the projects assisted by UNDP on the models of the Demonstration Plant Project at Sasmira, in Kuwait, Vietnam, Rwanda and other Developing Countires.

The 'dual purpose' plant at Sasmira should serve as a training centre for local personnel as well as those in the Developing Countries. It also emphasis the possibility of effective transfer of technology and cooperation between developing countries.

SIGNIFICANCE OF DEMONSTRATION PLANT PROJECTS FOR TRAINING IN INDIA AND DEVELOPING COUNTRIES

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United Nations Development Programme (UNDP) had formulated written guidelines for establishment of Pilot Demonstration Plants in the member countries for guidance for countries requesting assistance from the U. N. system as well as the specialized agencies. There are also unwritten understandings of the objectives, scope, magnitude and locations of such projects. The encouragement for setting up such projects was maximum during the 1970's but has decreased during the 1980's for various reasons.

The guidelines stipulate that the Pilot Demonstration Project should try to demonstrate a process or scheme for industry so far not fully commercialized or to improve an existing process and to prove its viability for establishing commercial plants. The know-how should be open to all member countries. The other objectives should be training of personnel from local, regional and inter-regional areas in production, quality control, product end use, use of local raw materials, adaptations of process and products for the country or the area etc. The scope of such projects is not to have commercial production or to compete with established or future private or public sector enterprises but have sufficient capacity of products for experimentation, seed marketing and end product adaptation. The magnitude of such projects can be production of a few hundred kilograms per day to few tonnes per day in a continuous semi-continuous or batch process. UNDP or other bilateral inputs could be anywhere between 1 million to 10 million U.S. Dollars. In addition, provision of technical personnel, equipment, process, 'know-how' technology transfer and other inputs such as training abroad etc. could be provided. "Buy Back" Schemes are also envisaged; Location of such projects could be in one country where raw materials are available, Industries to benefit are close-by or where the products can be demonstrated. The project could be in a region or could be inter-regional.

UNIDO's first pilot project in the Chemical Industry field was in Rwanda, a Central African land locked LDC which established a pilot plant for extracting pyrethrins from pyrethreum flowers making a crude extract (3,000 kilograms per year). The product is a harmless pesticide to animals and humans. Another pilot project you will visit is in SASMIRA for making

500 kilograms per day of polyamide or 500 kilograms per day of polyester fibres. It is a "multi-purpose" unit. The 'Sponge-iron' project in India of UNDP is a very large and interesting project making sponge-iron using coal for iron-ore reduction.

Some of the new possible pilot project ideas which were on the anvil during 1975 are as follows :—

1. A pilot project like in SASMIRA in the Arabian Gulf Region possibly Kuwait for producing polyester fibre and determine the man-made fibre/cotton mix for making Arab dress to benefit countries of the Gulf.
2. DDT in Vietnam.
3. Methane gas from lake Kivu to benefit countries around the lake — Rwanda, Zaire and Uganda and make use of the renewable source of energy.
4. A project for use of plastics in Agriculture in India.
5. A project similar to the Central Institute for Plastic Engineering and Tools (CIPET) in India f [illegible] he ASEAN Region.

The significance of such projects is in initiating countries into industrial development for improving standards and quality of life, training, use of indigeneous raw materials and demonstration of products of use by the majority of population and ultimately import substitution. The possibility of training of personnel in such projects in countries where they exist, should be fully exploited and utilized by neighbouring countries. Truly, transfer of Technology and Co-operation between developing countries (TCDC) can then become effective.

The demonstration pilot plants such as the 'Dual Purpose' plant in SASMIRA could and should serve as training centres not only for local personnel but also those of developing countries in the region. SASMIRA and the demonstration pilot plant and the Fibre Research Laboratory are ideally suited for such training. The inputs to SASMIRA and particularly the pilot plant are from the Industry; the Government of India, the UNDP and the Federal Republic of Germany. The trainees will naturally widen their knowledge not only in production, quality control and use of fibres but will come in contact with distinguished scientists who are engaged in fibre research and development. This could open up possibilities of setting up viable commercial production as joint ventures of suitable fibres in many countries. Some countries particularly in the tropics have gone into production of fibres sometimes unsuitable for local climate and customs.

The significance of training in a pilot plant is to largely eliminate such costly mistakes.

A word of caution in training, transfer of technology and 'know-how' from certain developing countries to others particularly the least developed, land locked or island countries is necessary. Some countries complained in the past of the "closed-shop" policies of "multinational" or "trans-national" companies such as restrictions to visit their facilities, secretiveness in R & D, transfer of outmoded technologies etc. The same developing countries have sometimes adopted the same policies of 'multinationals' or 'trans-nationals' towards other developing countries. Statements have been heard to the effect "we have developed this process or technology by ourselves in the face of utter non-cooperation from "trans-nationals" spending much money and effort. Why should we transfer such 'know-how' to others easily". Such attitudes are deterimental to co-operation and advancement of all developing countries.

A typical instance can be quoted which occurred in a UNDP sponsored European Development Fund assisted project. The country concerned in Africa refused to supply few kilos of seeds to Nepal to develop an agriculture based industry. In turn, the neighbouring countries in Africa refused permission for trainees to visit or study existing commercial plants. These are short- sighted policies which do more harm than protect a country's interest. The significance of an 'open' demonstration plant for training is also in avoiding such problems.

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PHYSICAL YARN STRUCTURE AS RELATED TO PROCESS CONDITIONS AND PROPERTIES OF POLY (ETHYLENETEREPHTHALATE) AND NYLON 6 YARNS

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ROELOF HUISMAN, born in 1938, studied Inorganic Chemistry at the University of Groningen, Netherlands. In 1969, he graduated on a thesis titled 'Investigations on Tantalum Selenides' wherein a study on the relations between the crystal structure of several polymorphic tantalum selenides and their magnetic and electrical properties was carried out. Since 1973, he is associated with the Meltspinning Department of the ENKA Research Institute in Arnhem, Netherlands, where he is at present working on the structural characterisation of synthetic fibres and the integration in process and product development with the co-authors.

Synopsis

In the paper, several aspects of the physical structure of synthetic yarns will be discussed. The emphasis is almost completely on poly (ethyleneterephthalate) yarns, but some attention will also be paid to nylon 6. The physical structure can be regarded as an intermediate between yarn process and yarn properties; correlations between this structure on the one hand, and process conditions and yarn properties on the other, will therefore be given in the presentation.

After an introduction, and a discussion of the structural characterization methods, the effect of winding speed during high speed spinning on the physical structure of PET will be treated. In the second lecture, thermal yarn properties, dyeing behaviour and mechanical yarn properties will be discussed in terms of the parameters of the physical structure.

PHYSICAL YARN STRUCTURE AS RELATED TO PROCESS CONDITIONS AND PROPERTIES OF POLY (ETHYLENETERE-PHTHALATE) AND NYLON 6 YARNS

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Introduction

In the last few years there has been a growing interest in the study of the physical fibre structure. This may be ascribed to an increased need for high-quality fibres and the aim to produce these fibres with high economic efficiency. This may call for extreme process conditions; one of the ways to meet the requirement of high efficiency is to apply drastically increased process speeds. In this field of process extrapolations, an advanced structural know-how about the response of the polymer to extreme process conditions has proved very helpful. The lectures to be presented will deal with several aspects of the molecular-physical structure of synthetic fibres, with a strong emphasis on poly (ethyleneterephthalate) yarns. The characterization of the structure will be presented, after which some results and applications will be discussed.

Before entering into the details of these subjects, however, the papers will pay some attention to the philosophy underlying the structural investigation.

Therefore, three items will be discussed in the lectures, viz:

I. The philosophy underlying the structural investigations.

II. The methods used in the structural characterization of yarns.

III. Results and applications of the study on yarn structures with respect to a) process conditions and
b) thermal and mechanical yarn properties.

I. Philosophy

A synthetic yarn process essentially is a succession of yarn treatments using combinations of temperature, tension and residence time. Almost all process conditions can be translated into these three variables. For a given polymer the combination of process conditions completely determines the thermal and mechanical properties of the yarns produced. The way in which process conditions influence the yarn properties, so the relation between the two, is highly relevant with respect to process control or process development.

If for a given end use a yarn with a particular combination of properties is required, knowledge of the relations just mentioned permits the translation of these product requirements into a set of appropriate process conditions. In this way this knowledge can guide the process development effectively. Moreover, for subsequent process control it will prove to be of high practical importance.

The relation just mentioned, however, generally is not a simple one. All separate steps have their own (mostly interdependent) conditions. Relating the yarn properties to this set of process conditions makes relationships of this kind often obscure and very complicated.

In this situation a good insight into the physical yarn structure is helpful. The physical structure can be regarded as an intermediate between yarn process and yarn properties. This is illustrated schematically in Fig. 1. A set of process conditions results in a physical yarn structure, that is responsible for the intrinsic yarn properties. With respect to the physical structure, two types of relation can therefore be distinguished, viz.:

a) relations between process conditions and physical yarn structure;

b) relations between structure and yarn properties.

In this way the relations observed can be interpreted in physical terms. This improves not only their own reliability, but also the reliability of process extrapolations. Another advantage is that via the physical structure the coherence between the yarn properties is more easily recognized and better understood.

II. Methods used in the structural characterization of yarns

In this part a more substantial discussion about the investigation of the yarn structure and the different characterization methods will be given. This will be introduced on the basis of a general structural model of drawn yarns given in Fig. 2. As can be seen from this picture, ordered (crystalline) regions alternate with less ordered (amorphous) domains. The picture also shows that a separate molecule can run through several crystalline and amorphous regions.

Besides, there is the possibility that a molecule folds back on the surface of a crystal to reenter it.

Depending upon the process conditions the polymer molecules are more or less oriented along the fibre axis. In this way so-called fibrils are formed, i.e. structural units in which the coherence of amorphous and crystalline domains is found, predominantly in longitudinal direction. However, these fibriis also have a lateral extension, as can be seen from Fig. 2.

For an impression of the relative magnitudes of the various structural component in PET yarns, the following values may be useful:

The distance between two neighbouring molecules in the unit cell (= the repeating unit in the crystal) is about 5 A^0 (=5 x 10^{-10} m); the length of a monomeric unit of ethyleneterephthalate (= height of the unit cell) is about 10 A^0. The total length of a PET molecule is depending on its application 1000 - 1500 A^0. The lateral size of a crystal is about 70 A^0, the height about 100 A^0; the dimensions of the amorphous domains are of the same order. This makes it clear that a molecule can run through successive crystalline and amorphous regions.

The dimensions mentioned are in the order of ^{0}Angstroms. The wave length of X-rays is of the same order, so it is not surprising that X-ray diffraction is an important method for structure characterization. If this method is to be applied for process development at least two requirements must be met:

1. the information must be accurate and quantitative in order to permit a comparison between data of different yarns;
2. the method must be quick in order to establish in that process development a rapid feedback from yarn structure to process conditions.

Both requirements can be met by means of a highly automated X-ray procedure in which curve resolution is applied on experimental diffractometer scans (1,2). An example of such a scan is given in Fig. 3, showing an equatorial X-ray trace of a polyester yarn. As can be seen, this scan is composed of three rather sharp crystalline reflections and one broad line, brought about by the scattering of the amorphous regions. The peak positions of the crystalline reflections give information about the distances between the molecules in the crystalline lattice. The halfwidth of these peaks is inversely proportional to the dimensions of the crystal. As already mentioned, the accurate determination of the peak positions and halfwidths is performed by means of curve resolution. The experimental profile is fitted to the sum of four symmetrical bell-shaped lines. For such lines the so-called Pearson VII function is used. A representation of this type of functon is given in Fig. 4.

The Pearson VII line is governed by the combination of four parameters, i.e. peak height, peak position and two parameters describing the halfwidth and the shape of the peak at the tail. This latter effect is shown in the figure where plots of the function are given for different values of the shape parameter, at the same halfwidth. In this way the most important advantage of the Pearson VII function is shown: the halfwidth and the tail of the distribution can be varied independently, a property not possessed by more conventional functions, often applied in this field, such as Gauss and Lorentz. These latter two curves are as a matter of fact special cases of the Pearson VII curve with the m values being resp. infinite or 1.

From the peak positions the packing of the molecules in the crystals can be deduced. In this way they can be used to calculated the density of the crystalline regions. We found this crystalline density to be highly dependent on the process conditions. A high process temperature leads to a high value of the crystalline density; densities over 1500 kg/m^3 have been found (3,4). This value is substantially higher than the crystalline density $d_c = 1455$ kg/m^3, which is often used in the literature, based on investigations of Bunn and coworkers (5). The choice of the crystalline density has a considerable consequence for the calculation of the crystallinity. For a system consisting of a crystalline and an amorphous phase the overall density can be expressed as :

$$d = V_c d_c + (1 - V_c) d_a,$$

where V_c is the volume fraction of crystalline material.

The overall density of the yarn can be determined accurately in a density gradient column. If in first approximation the density of the amorphous regions is taken as a constant, the crystallinity can be calculated as:

$$V_c = \frac{d - d_a}{d_c - d_a}$$

A higher value of the crystalline density results in a lower value of the crystallinity. Indeed, in the literature values of V_c in the order of 0.60 are reported for PET. It is our experience that the crystallinity does not surpass $V_c = 0.40$.

A key concept in describing the morphology of the yarn is the orientation in the crystalline as well as in the amorphous regions. The orientation is generally represented by the orientation factor f, defined in such a way that f = 0 for the isotropic case, and f = 1 in the case of ideal orientation. The orientation of the crystals can be determined directly by means of azimuthal scanning of the X-ray reflection. The orientation in the amorphous regions is much more difficult to determine with a sufficient degree of accuracy. An indirect method is proposed in the literature formally illustrated in Fig. 5.

By means of pulse propagation the sonic modulus of the yarn is determined. The value of this modulus is representative of the overall orientation of the yarns, so both crystalline and amorphous orientation are involved in the sonic modulus value. Samuels (6, 7) developed a theory which was based on ideas from Ward (8, 9) and Moseley (10), where the sonic modulus is related to crystalline and amorphous orientation and crystallinity as given in the first formula of Fig. 5. The quantities $E^0_{t,c}$ and $E^0_{t,a}$ are transverse moduli. The longitudinal moduli, which are much greater than the transverse ones can be omitted in the calculation because of the fact that they appear in the formula as compliances and therefore are very small. Dumbleton (11) determined the values of $E^0_{t,c}$ and $E^0_{t,a}$, the values are given in Fig. 5.

So, if the sonic modulus, the crystallinity and the crystalline orientation factor are known, the value of the amorphous orientation factor can be calculated.

At this point a refinement in the calculation of the crystallinity can be made. In first approximation the amorphous density was assumed to be constant. It was established experimentally, however, that the amorphous density depends on the amorphous orientation. The relation observed is given in Fig. 5. The so calculated amorphous density is used for calculating the crystallinity.

The last component of the structural morphology of a yarn, the characterization of which will be discussed, is the size of the crystals. Information about the crystal size can be found in the radial halfwidth of the X-ray reflection. In this way, for PET, information can be obtained about the lateral and longitudinal crystal size. Accurate values of the halfwidth can be obtained by means of the aforementioned curve resolution of the experimental X-ray profiles. An example of the dependence of the crystal size on the applied process temperature is given in Fig. 6.

The size of a PET crystal in two lateral directions is plotted in this picture. There is an exchange between the PET molecules via the dipoles of the ester groups running in the direction [010]. From Fig. 6 it can be seen that a bigger crystal is formed at the higher process temperature. It is also evident that the crystal growth of PET is preferably in the 010 direction, i.e. the direction of the strongest interaction. This is physically well conceivable; the crystal growth is strongest in that direction where the crystallizing system can lower its energy in the most effective way.

Summarizing this part of the presentation: by means of X-ray diffraction, pulse propagation and density measurements one can characterize the physical yarn structure in terms of volume fraction of crystalline material, crystal size in different directions and crystalline and amorphous orientation.

Finally some thermal analysis techniques may be mentioned. By means of Differential Scanning Calorimetry the thermal transition points can be studied with respect to temperature and heat of transition. In this technique the heat flow to a polymer sample is compared with that of a reference. If e.g. the polymer undergoes an endothermic transition, more energy has to be transported to the sample in order to keep sample temperature and reference temperature equal. Fig. 7 shows the heating trace of an amorphous PET sample, with the glass transition, crystallization and finally melting of the sample.

Thermomechanical Analysis plots the contraction of a yarn as a function of a continuously increasing temperature. An example of this technique will be given in the next section.

III. Results and Applications of the study of the Yarn Structures

III. a. Relation between physical structure and process conditions

As an example of this kind of relations, the effect of the winding speed on the physical structure of as-spun PET yarns will be discussed. By way of illustration, the behaviour of some practical properties will be shown as a function of the winding speed, which was varied between 2000 and 6000 meters per minute. The elongation at break gradually decreases with the winding speed, as indicated in Fig. 8. This points to an increase of orientation and so it is not surprising to find that the modulus increases with the speed as shown in Fig. 9. Much more fascinating is the behaviour of the boiling water shrinkage. Fig. 10 shows a rather sudden decrease in shrinkage, which drops to low values at the highest winding speed. To study this phenomenon the as-spun yarns have been examined quite extensively with the combination of techniques described before.

The first quantity determined is the overall density d_4^{23}. The results of these measurements are presented in Fig. 11 where the density is shown as a function of the winding speed. At a speed of 3500 m/min. the beginning of a sharp increase of the overall density can be seen. At the highest winding speeds a tendency towards saturation is observed. By this sharp increase a change from amorphous to partly crystalline material is suggested.

In Fig. 12 the DSC diagrams are given. First the two extreme situations of 2000 and 6000 m/min. are considered. For the lower winding speed the glass transition can be seen at about 76°C, followed by the crystallization exotherm with a peak temperature near 132°C and after that a melting endotherm with its minimum at about 253°C. From this DSC trace it can be concluded that the original fibre wound at 2000 m/min. is largely amorphous because the crystalline material that melts finally has formed during the DSC run as indicated by the crystallization peak. In sharp contrast to this DSC trace is the one brought about by the yarn wound at 6000 m/min. This curve only shows a melting endotherm indicating that this material originally is already partially crystalline. The situations in between these two extremes show a gradual change. The glass transition is found at a constant temperature of 76°C up to winding speeds of about 4000 m/min. Also the cystallization exotherm is shown by the same group of yarns. Between 4000 and 5000 m/min., however, a sharp distinction between glass transition and crystallization exotherm can no longer be made. This is caused by the fact that the crystallization peak shifts gradually to lower temperatures at increasing winding speeds. At speeds about 5000 m/min. no transition is observed any longer in the DSC diagrams except melting. Concerning the melting peaks it can be seen that at about 4000 m/min. the shape of the melting peak starts to change. The rather broad peak found for the yarns wound at low speeds converts via mixed situations to a sharp one as found for the yarns taken up at the highest speeds. Summarizing, it can be concluded from DSC measurements that the physical structure of as-spun PET fibres changes from amorphous to semi-crystalline within the range of winding speeds investigated. However, quantitative conclusions about the amount of crystallinities cannot be obtained in this simple way.

For a qualitative impression of the crystalline structures of the as-spun fibres involved, Astbury pictures were made. The most relevant photographs are shown in Fig. 13. In the region of the lowest winding speeds only an amorphous halo can be seen. At increasing speeds this halo gradually concentrates towards the equator indicating an improved orientation of the molecules in the predominantly amorphous samples. The first indications of some very poorly developed crystalline material are visible in the picture of the yarn wound at 4500 m/min. The Astbury photographs of the yarns wound at even higher speeds show increasingly sharper spots pointing to a further developed crystalline material.

To obtain more detailed quantitative information various types of diffractometer scan have been made of the semi-crystalline samples.

In Fig. 14 the equatorial X-ray diffraction traces are given for the situations ranging from 4500 m/min. to 6000 m/min. The traces illustrate quite evidently the immense influence the winding speed has on the crystalline structure. For the yarns wound at high winding speeds well resolved patterns are found. The yarns taken up at lower speeds only give rise to broad unresolved traces. As, according to Scherrer's formula, narrow peaks are related to crystals which are large in the direction perpendicular to the crystal plane involved, it can be concluded that the lateral dimensions of the crystals in the yarns wound at high speeds are relatively well developed. The fact that the intensity of the profiles increases with the winding speed does not provide additional information. This phenomenon may be caused by an improved orientation and/or a decrease of the halfwidths of the peaks. To derive quantitative information from the traces presented, the profiles have been simulated, as discussed in the preceding section. This way of elaboration proved to provide accurate information about peak positions, halfwidths and intensities. Also the radial diffractometer scans of the $\bar{1}05$ reflections, giving information in longitudinal direction, were made and computer fittings with one Pearson VII line calculated. The resulting peak positions were combined with the values obtained from the equatorial scans to calculate the axes of the unit cell. For these calculations the angles of the triclinic unit cell were assumed to be constant having the values $\alpha = 100.1^{0}$, $\beta = 117.9^{0}$ and $\gamma = 110.7^{0}$ (12). Those results, which could be obtained with sufficient reliability, are given in Table 1, together with the crystal sizes calculated from the observed halfwidths of the peaks. The indications a and b refer to the axes of the basal plane of the unit cell as depicted in Fig. 15. The height of the unit cell is indicated by c. The symbol $\Lambda 010$ stands for the crystal thickness perpendicular to the a-axis, $\Lambda 100$ for the thickness perpendicular to the b-axis and $\Lambda_{\bar{1}05}$ for the height of the crystal, all three quantities not being corrected for paracrystalline distorsions. From the unit cell dimensions also the crystalline densities were calculated and reported in Table 1. From this table it can be seen that in general the lengths of the axes decrease at increasing winding speed. This fact has not only been found in this series but was confirmed in many other analogous investigations. The closer stacking of the molecules in the crystals of yarns taken up at higher speeds is most evidently illustrated by the behaviour of the a-axis and the crystalline density. There is a physical reason for the observation that the a-axis is the most sensitive one. This axis is along the exchange interaction between the π-electrons, whereas the b-axis mainly in the direction of the stronger dipole-dipole interaction. According to the other experiments (12) apparantely the interaction energy along the a-axis is of that order of magnitude that the temperature, at which the crystal forms, influences the stacking of the molecules in the direction of the a-axis. This finding has been used to estimate crystallization temperatures from the tabulated values of the a-axis for the various winding speeds. The estimated temperatures have been given in Table I. Concerning the crystal sizes it can be concluded that in all three dimensions the crystals are larger when formed at a higher winding speed. In contrast to experience obtained in an investigation on thermal annealing, the growth in the direction of the strong dipole-dipole interaction, $A_{010'}$ is not much more pronounced than in the other direction. This suggests another mechanism of crystallization than the diffusion controlled lateral growth (taking place during heat treatments).

TABLE I

Results from quantitative elaboration of WAXS experiments

Winding speed		Unit cell		Apparent crystal sizes			Crystal-line density	Estimated crystalli-zation tempera-ture
	basal	plane	height	lateral		height		
	a	b	c	A_{010}	A_{100}	$A_{\text{-}105}$	d_c	
(m/min)	(A^0)	(A^0)	(A^0)	(A^0)	(A^0)	(A^0)	(kg/m^3)	(^0C)
4750	4.504	5.90	10.72	24	29	54	1488	186
5000	4.495	5.88	10.72	29	34	57	1495	198
5500	4.485	5.88	10.71	41	41	76	1499	212
6000	4.480	5.88	10.71	51	49	84	1501	218

TABLE II

Physical quantities related to orientation

Winding Speed (m/min)	Sonic modulus GPa	Crystalline orientation factor fc	Amorphous orientation factor fa	Volume fraction crystallinity
2000	3.01	—	0.093	0
2500	3.23	—	0.155	0
3000	3.62	—	0.246	0
3500	4.31	—	0.367	0
4000	5.43	—		
4250	6.00			
4500	6.91	0.76	(0.589)	(0.056)
4750	7.63	0.965	0.602	0.106
5000	8.57	0.972	0.626	0.155
5500	9.78	0.976	0.650	0.209
6000	11.60	0.979	0.693	0.242

By makings WAXS-azimuthal scans the crystalline orientation was determined. For PET the most suitable reflection for this purpose is the $\bar{1}05$. Basically these azimuthal traces consist of two identical $\bar{1}05$ peaks and two minor 024 peaks on the wings. The four contributions can nicely be seen separately in the patterns brought about by the yarns wound at the highest speeds as illustrated in Fig. 16. The patterns shown were fitted with four Pearson VII lines, taking into account that both $\bar{1}05$ peaks and both $0\bar{2}4$ peaks have to be identical, with the centres of both pairs coinciding. In this way also for the unresolved profiles, related to the yarns taken up at low speeds, good fittings and reliable parameter values could be obtained. From the resulting parameters of the $\bar{1}05$ line the crystalline orientation factor f_c is calculated according to the method of Hermans at al. (13). The results are listed in Table II. It has to be noticed that already at the winding speed of 4750 m/min. a very high nearly saturated value is obtained.

To get an insight into the orientation of the molecules in the amorphous regions, these crystalline orientation factors have to be combined with pulse propagation measurements. This technique provides the propagation velocity of longitudinal waves (freq. 10 kc/s) in the yarns. The values so obtained are listed in Table II and plotted in Fig. 17 vs. the winding speed. It can be seen that extrapolation to a winding speed of zero agrees with the value of 0.273×10^{10} N/m^2 = 2.73 GPa determined by Dumbleton (11) for unoriented amorphous samples.

To obtain amorphous orientation factors f_a these sonic moduli values have been combined with the crystalline orientation factors f_c, using the method proposed by Samuels (6) and elaborated by Dumbleton (11). In order to use this method, values for the volume fraction of crystalline material, V_c, were needed. This quantity was calculated from the measured overall density d_4^{23} , the crystalline density d_c as calculated from X-ray diffraction measurements, and the amorphous density d_a, as discussed before. The results are reported in Table II.

In Fig. 18 the volume fraction of crystalline material is plotted versus the winding speed. It clearly shows that above a winding speed of 4000 m/min^{-1} the first crystallization can be observed.

Fig. 19 gives the crystalline and amorphous orientation factors as a function of the winding speed.

Striking is the rapid saturation of the crystalline orientation and the gradual course of the amorphous orientation.

As a kind of qualitative summary of the findings presented before a rough picture of the structures of the as-spun fibres can be made, as presented in Fig. 20. At the winding speed of 2000 m/min. a fibre is produced consisting of molecules with low orientation which have not crystallized. An increase of the windng speed up till 3500 m/min. only results in an increased orientation without any indication of crystallization. At higher winding speeds some crystallization becomes apparent, while at speeds of 5000 m/min. and higher very well developed crystals are detected.

These models can nicely account for the extreme differences in mechanical properties in this series of as-spun fibres as illustrated by the contraction measurements shown in Fig. 21. For the yarn wound at 2000 m/min. only contraction in the glass transition region is found, pointing to a disorientation process in the amorphous material leading to an increased entropy. With further increase in temperature the modulus of the soft amorphous substance becomes so low that only elongation can take place. At 2500 m/min. the amorphous material is better oriented, resulting in a higher contraction during disorientation after passing the glass transition temperature. In this case during the subsequent elongation some crystallization can already take place. This is in accordance with the DSC-diagrams of Fig. 12, which show that at higher winding speeds the crystallization shifts to lower temperatures. This crystallization process, taking place during the TMA measurement, provides some physical crosslinks preventing a further elongation. The same effect can be seen at a further increase of the winding speed: Increasing contraction at the glass transition temperature caused by an increased orientation of the amorphous material, and a decreasing softening caused by the fact that the crystallization process comes closer to the glass transition region. At 4000 m/min. the first decrease of contraction during the glass transition is observed. This can be ascribed to the forthcoming crystallization in the as-spun yarns as revealed in Figs. 11 and 18. The increase of the crystallinity, as present in the original samples produces a very pronounced decrease of the glass transition contraction as illustrated by the TMA traces of samples wound at higher speeds. For these situations another contraction peak arises, viz. in the melting region. In this region the well oriented crystalline domains melt and the released molecules will disorient in order to reach an increase in entropy.

Now also the observation shown at the very beginning of the presentation on this subject, that the boiling water shrinkage drops very suddenly as a function of winding speed can be understood. This can be regarded as a cross section through the TMA pictures shown in Fig. 21 at the boiling water temperature.

So it is clear that the steep decrease of shrinkage is caused by the crystallization process taking place during winding at higher speeds.

Based on the picture just developed, a trial will now be made to understand the origin of the crystalline structures found.

First of all it is very clear that the crystallization process during spinning at high winding speeds as described before is many decades faster than that found for PET crystallizing from the isotropic melt. This is in agreement with all findings of crystallization under conditions of molecular orientation. This fact is attributed generally to the reduced entropy gain during the melting of crystals under orientational conditions (14). Consequently, the melting point increases when the released molecules are more restricted in their mobility. Considering a spinning fibre as a cooling melt, this implies that the super-cooling at a given temperature is higher when more molecular orientation exists, or in other words, when the fibre is taken up at a higher winding speed. According to Peterlin (15) the critical size of the primary crystalization nucleus decreases and the crystallization rate increases exponentially with supercooling. From the first phenomenon it has to be expected that the use of a high winding speed, producing high orientation, results in a crystal structure formed at a high temperature. This is in accordance with the finding that the a-axis of the elementary cell is shorter for higher winding speeds indicating higher crystallization temperatures, as can be seen from Table I. The effect of the different degrees of supercooling on the crystallization rate accounts for the finding that the crystallinity increases with the take-up velocity above 4000 m/min. Below this winding speed no crystalline structure at all could be detected.

As already mentioned before it is thought that the molecular orientation is responsible for the spectacular change in crystallization behaviour of spinning fibres when the take-up velocity is varied. Hence, said velocity is not the only spinning variable to influence this crystallization process. Other spinning conditions which may affect molecular orientation can also be used to direct the crystallization process. So Liska (16) already found a first indication of the influence of the viscosity on the crystallization of PET at a winding speed of 4000 m/min.

This is also shown in Fig. 22 where the boiling water shrinkage is plotted versus the winding speed for two different molecular weights (i.e. viscosities). It is clear that the drop in shrinkage occurs at much lower winding speeds in the case of the high molecular weight. According to the model just presented this must be ascribed to a crystallization taking place at a lower winding speed in the fibres with high molecular weight. Fig. 23 shows the density of the same yarns; this picture indeed shows the easier onset of orientation-induced crystallization in the fibre with the high molecular weight. Fig. 24, finally, shows similar effects but now with the draw-down as a parameter. At the same winding speed, the yarn produced at the high draw-down has the lowest shrinkage and the highest density, in accordance with the idea of orientation-induced crystallization during spinning.

III. b. Relation between physical structure and yarn properties

In a preceding part, the characterization of the physical structure has been introduced, based on the two-phase model of synthetic yarns. These two phases behave quite differently with respect to their physical properties. Therefore they have their own specific contribution to the physical yarn properties. In one group of properties the crystalline part plays an important role, in another mostly the amorphous part is involved. This will be illustrated in the present lecture; a description of some yarn properties will be given in terms of structural parameters. Three classes of properties will be discussed, viz.:

1. thermal properties;
2. dyeing behaviour;
3. mechanical properties.

III. b. 1. Thermal properties

In a discussion of the thermal properties of a yarn, the melting point plays an important role. This melting point should be attributed to the crystalline part; only the ordered part can lose its order. It is known in polymer physics that the melting point is size-dependent, a smaller crystal having lower melting points. In small crystals the surface contributes relatively much energy to the system, resulting in a lowering of the melting point. So a polymer does not have a fixed melting point. The reason why always the same melting temperature is observed for a particular polymer, e.g. 226°C for nylon 6, is the low heating rate. In general the heating rate (for DSC about 10°/min.) is low with respect to the quick recrystallization process. If a small crystal melts at not too high temperature it will recrystalline into a bigger one with a higher melting point. In this way during a DSC trace the endothermic effect of melting is compensated by the exothermic effect of (re)crystallization. Final melting of the material is observed if the heating rate "overtakes" the recrystallization rate.

The effect of the crystal size on the melting temperature can be demonstrated if the recrystallization during heating can be prevented. This can be done by crosslinking the molecules in the amorphous regions. For the chemically inert PET this is not easy; for nylon 6, however, the methoxy methylation method of Arakawa (17) offers such an opportunity. By means of this method the molecular segments in the amorphous domains are blocked and the real melting point of a crystal can be determined. On the other hand, the size of the crystals can be determined by X-ray diffraction.

In Fig. 25 the relation between the two is given. As can be seen, even melting points below 200°C are found! In fact only averaged values are plotted in this figure; in reality a distribution of crystal sizes exists, consequently also a distribution in melting points.

Knowledge of this kind can be utilized in a model for understanding and guiding texturizing processes. In general, texturizing can be described as changing the external shape of a flat yarn into a crimped one. The crimps, actually present or latent, have to be stable with respect to certain aftertreatments. To crimp a yarn it is generally subjected to deformation forces at high temperatures. The optimum texturing temperature depends on the structure of the original yarn. At this point it is useful to realize that in texturing processes heating rates in general are very high. If the texturizing temperature is higher than the melting point of the crystals, which is governed by their size, the crystals will melt, resulting in sticking of the filaments. Therefore this situation is not workable.

Optimal texturizing is performed at a temperature where partial melting takes place. All the crystals that have melting points below the texturizing temperature will melt. In this situation, orientation differences over the cross-sections of the filaments, brought about by the deformation force in the texturizing process, are supposed to vanish extremely fast (fluid-like behaviour). By the recrystallization process the new crimped shape is fixed in new larger crystallites. This is schematically illustrated in Fig. 26. When this yarn is straightened, as during winding of the textured yarn, orientation differences over the cross-section of the filaments are generated in the places where the bends were formed during texturizing (Fig. 26). The crimp has now become latent, i.e. the outer shape is rather flat and the crimps originally present manifest themselves as orientation differences like those given in Fig. 26.

To develop the latent crimp into an actual one a tensionless heattreatment above the glass transition temperature is sufficient because this induces shrinkage differences, due to orientation differences, over the cross-sections just where deformation had taken place during texturizing.

If crimp development is hindered by e.g. tension (as is the case in almost all dyeing processes) it is extremely important that the crystal structure in which the orientation differences had been fixed remains unchanged. If during the such treatments the crystals weaken or even melt, the orientation differences disappear and the latent crimp is lost. So it can be concluded that for a general purpose yarn it is an absolute requirement that the crystal size, as obtained during texturizing, is large enough to be stable during dyeing. In Fig. 27 the change in crystal size during dyeing is plotted vs. the original crystal size. This picture demonstrates very clearly the substantial change in crystal size if the original crystal size is small.

Based on the considerations just presented a relation can be expected between the thermal crimp stability and the crystal size of the crimped yarn. Fig. 28 shows the loss of crimp for different crystal sizes. The figure convincingly shows the relatively high crimp stability of the texturized yarn with a large crystal size, i.e. a high melting point.

III. b. 2.Dyeing behaviour

For polyethyleneterephthalate dyeing with disperse dyestuffs is by far the most important way. In the process of dyeing with disperse dyestuffs four steps can be distinguished :

1. dissolution of the dyestuff;
2. transport of the dye through the bath to the fibre surface;
3. adsorption onto the fibre surface;
4. diffusion of the dyestuff molecules into the fibre.

Polyester has a relatively poor accessibility to dyestuffs in comparison with e.g. nylon 6. To get at least somewhat acceptable dyeing rates, high temperatures have to be applied (HT dyeing) or the accessibility must be increased by adding carriers to the system. Therefore it can be assumed that the last step, the diffusion of the dye molecules into the fibre is the rate-determining one. The mass transfer within a fibre strongly depends on the underlying molecular physical structure, so it appears to be sensible to relate the dyeing behaviour to this structure. In Fig. 29 the dyeing results are plotted for a series of polyester yarns annealed at different temperatures (given on the abscissa) and afterwards dyed simultaneously under the same conditions. To give some more details about the dyeing procedure: dyeing was carried out with 2% dyestuff calculated on weight of fibre. The process was started at 60ºC, the temperature was raised to 125ºC in 45 min. At this temperature the HT dyeing process was continued for one hour. In the example given, the dyestuff used was Palanilibrillantrred BEL. C.I. Disperse Red 92.

As can be seen from the figure, there is a minimum in the curve at about 200ºC. This is well known for PET, it was first reported years ago by Marvin (18). The next few minutes will be devoted to a description of the dyeing results just mentioned in terms of the structural parameters.

Fig. 30 shows the structure of two different yarns heattreated at low and elevated temperature, respectively. The models are representative of a general experience in studying PET fibres: fibres annealed at a low temperature show a low crystallinity build up of many small crystals, fibres annealed at a high temperature have a high crystallinity and are composed of fewer large crystals together with large adjacent amorphous regions. The effect of heating a PET fibre can be described as a coarsening of the structure.

With respect of dye diffusion, the crystalls can be considered to be completely inaccessible to the dye molecules. These molecules will only be taken up in the amorphous phase. Therefore the total volume of the amorphous regions, the value of 1-Vc, must be one of the factors governing the dye uptake of a fibre.

Another controlling factor will be the accessibility already introduced. In view of the considerations just presented it is clear that only the accessibility of the amorphous regions is involved. The accessibility is directly coupled to the mobility of the molecular segments in the amorphous regions. In a structural sense this mobility can be related to two aspects :

1. the structural morphology, i.e. the coarseness of the structure;
2. the amorphous orientation.

First the effect of the coarseness of the structure will be discussed. If the crystallites are considered as physical crosslinks decreasing the segmental mobility, many small crystals have a greater crosslinking effect that fewer bigger ones. In this sense the accessibility of the amorphous regions can be supposed to be related to their volume. Therefore, the coarseness of the structure, as introduced before, will have consequences for the dyeing behaviour. Fig. 31 shows the volume of the individual amorphous regions for the yarns studied, which were annealed at different temperatures. This value can be calculated by using X-ray data and the volume fraction of crystalline material. Especially at high temperatures a large increase in amorphous volume, i.e. coarseness, is found. Accordingly the accessibility to the dye molecule will be relatively great for these coarse structures. An indication of the increased segmental mobility in this kind of fibres is found in the work of Statton et al (19) who observed in wide-line NMR signals an increased fluid-like mobility in the yarns annealed at elevated temperatures.

In the model presented the effect of increasing the annealing temperature is made up of two opposite factors, i.e. a decrease in the amorphous content reducing the dye absorption and an increase in the accessibility facilitating the diffusion of the dyestuff. The balance of these two effects can account for the observed minimum in dye uptake in Fig. 29 A schematic picture of the dyeing model is given in Fig. 32 where values for the amorphous content, 1-Vc, and the volumes of the individual amorphous regions in the fibrils are given.

The model also accounts qualitatively for the size of the dye molecule. With a small dyestuff molecule the accessibility of the amorphous regions will be a less important factor in the control of the dyeing process. Consequently it may be expected that in this case the minimum will be less pronounced. Fig. 33 shows the dye uptake for the same yarns dyed with Foron Blue E-BL, C.I. Disperse blue 56, a dye with a much smaller molecule than Palanilibrilliant Red. The less pronounced minimum is evident, and in complete agreement with the considerations just given.

As said before, also the amorphous orientation contributes to the accessibility. It may be expected on physical grounds that the diffusion rate will be higher in a less oriented medium. Fig. 34 gives dye uptake curves as a function of the volume of amorphous regions for different amorphous orientations. (In this picture highly stabilized yarns are used, therefore only the high temperature side of the dyeing picture is involved). The picture clearly shows the effect of orientation.

The effect of orientation can be expressed in a factor, with limiting value zero for perfect amorphous orientation and vice versa. This picture, where both the volume and the orientation of the amorphous regions are involved, is given in Fig. 35.

Concluding: it is very well possible to describe the dyeing behaviour of a PET fibre in terms of the total volume of amorphous material, the volume of the individual amorphous regions and the orientation of the molecules in these amorphous domains.

III. b. 3. Mechanical yarn properties

Before relating yarn properties to physical structure parameters it is useful to make at this point a distinction between intrinsic and extensive yarn properties. The intrinsic properties are completely determined by the underlying physical structure. Such properties are e.g. modules and shrinkage. Other properties also depend on macroscopic factors as yarn damage and denier unevenness: they are called extensive yarn properties. Yarn tenacity and elongation at break are illustrative of this type of properties. If, for example, the draw ration is too high damage may occur to the yarn, resulting in a reduced tenacity and elongation at break. In our experience in such cases the decrease of tenacity *and* elongation is not accompanied by a corresponding decrease of modulus, the latter being an intrinsic property. It will not be surprising that in the first instance a description of the intrinsic properties, viz. shrinkage and modulus, will be given in terms of the physical structure. In a later stage also some aspects of tenacity and elongation at break will be discussed.

Starting with the shrinkage: the driving force behind yarn contraction is of entropic nature. Above the glass transition temperature, the polymer molecules in the amorphous parts have sufficient mobility to obtain their most probable configuration, which means that they will tend to coil up. The higher the temperature, the more pronounced this process will be. In most cases, at least where the industrial yarns are concerned, the crystals may be regarded to behave as rigid blocks during the thermal shrinkage. Based on these arguments, the contraction should be proportional to the amount of amorphous material, to be described by the factor ($1-V_c$).

The second factor governing the yarn shrinkage is the orientation of the molecular segments in the amorphous domains. In the unstrained condition a well-oriented molecular segment is a configuration of low statistical probability. Therefore, it will have a high tendency to coil up, which means that a high amorphous orientation will give rise to a large disorientation, resulting in a high shrinkage.

A combination of both arguments provides the factor ($1-V_c$) f_a, which can be used for describing the shrinkage behaviour of a yarn. Fig. 36 shows the hot air shrinkage at 160°C versus this factor. A fairly good correlation is found. So, it can be concluded that the yarn shrinkage can be influenced by variations in V_c and/or f_a. A lower shrinkage is obtained at a higher crystallinity or at a lower amorphous orientation. In process terms this can be effected by increasing either the annealing temperature or e.g. the amount of overfeed.

Passing over now to a description of the modulus it must first be concluded that such a description in terms of the underlying structure has certainly not been fully established. Only a qualitative discussion is possible at the moment.

The impact of an external stress on a yarn will first result in an elastic yarn response. At this stage, at small deformations, the molecules will be uncoiled and valence angles will be deformed. At higher elongations also a viscous response of the yarn occurs. In this process, apart from the phenomena just mentioned, bond rupture may take place, depending on the type of molecule; also microfibrils may slide along one another. Contributions in the literature on this subject are given by Station (20), Prevorsek (21) and by the Zhurkov group in Leningrad (22). It will be clear from these considerations that only the first part of the stress-strain curve is accessible to a first attempt to make a description in terms of the physical structure.

As a first approximation it is assumed that a high orientation results in a high modulus. This means that in the case of high orientation a deformation to a certain elongation will require a relatively high stress. In stressing the yarn both the amorphous and crystalline regions are involved. So, a useful parameter is the overall orientation factor, i.e. the crystalline and amorphous orientation factor weighed by the crystallinity.

$f_o = V_c f_c = (1-V_c) f_a$.

This means that modulus values can be plotted versus this factor. The question in which modulus.

A useful way to describe the tensile yarn behaviour is by plotting the modulus-strain curve, i.e. the first derivative of the stress-strain curve.

An example of a stress-strain curve and its corresponding modulus-strain analogue is given in Fig. 37. Two peaks can be distinguished in the modulus-strain curve, the position and peak height of which change with the process conditions. The first peak occurs at very low elongations (1%). In Fig. 38 the height of this first peak is plotted versus the overall orientation factor just mentioned. A good correlation is found: a low overall orientation results in a low modulus and vice versa. In practice mostly the load at five per cent elongation is used. Fig. 39 gives this load as a function of the overall orientation. Although the fit is poorer than in the preceding figure, there still is a clear relationship. Evidently, the physical structure in the unstrained state defines, to a large extent, the structure after 5% elongation.

Finally, concerning modulus, two remarks can be made:

1. Fig. 38 shows a sharp increase in modulus at high values of the overall orientation. This can be understood in realizing that for a completely, perfectly aligned, crystalline material the factor $V_c f_c + (1-V_c) f_a = 1$; for that case the longitudinal crystalline modulus E cryst. 10,000 cN/dtex is reported (23, 24).
2. In Fig. 40 the overall orientation factor is differentiated mathematically to V_c and f_a. The first derivative to V_c is always positive. So, an increase in crystallinity at constant amorphous orientation results in a higher modulus. This is physically well conceivable because at higher V_c more rigidity is added to the yarn.

Also the derivative to f_a is positive. So, a higher amorphous orientation yields a higher modulus.

III. b. 3. 1. Consequences

In the last part of this lecture on mechanical yarn properties some consequences will be discussed of the ideas developed in this part of the presentation.

Many yarn applications require a high modulus combined with a low shrinkage. For instance, in the production of a coated fabric or a tire the yarn construction is subjected to high temperatures. Under these circumstances a low yarn contraction is required. At the same time the yarn construction should add rigidity to the composite material, which asks for a high modulus.

A usual way to describe the combination of modulus and shrinkage is by applying the modulus-shrinkage ratio. Based on the arguments discussed before, this ratio can be described by the factor

$$F = \frac{V_c f_c + (1-V_c) f_a}{(1-V_c) f_a}$$

(Fig. 41)

In Fig. 42 the ratio between LASE 5 and the shrinkage at 160° C is plotted versus the factor just mentioned. Apart from a high scatter (the high modulus-shrinkage values are based on low shrinkage values, which are relatively inaccurate) there is a clear correlation.

In Fig. 43 the behaviour of the function F is given as a function of the variation of V_c and f_a . The first derivative to V_c is always positive, the other always negative. This is schematically illustrated in Fig. 43. Hence, an increase in V_c or a decrease of f_a will result in an increased modulus-shrinkage ratio. This is shown in Fig. 44, where for clearness' sake, only some average values of the modulus-shrinkage ratio are given. An increase in V_c at constant f_a results in an increased modulus shrinkage ratio. The same effect is found for a decrease of f_a at constant V_c. However, a decreased f_a results as such in a reduced modulus, Therefore, increasing the crystallinity is a much more attractive way to increase the modulus-shrinkage ratio.

The increase in crystallinity can be performed in two ways:

1. by increasing the process temperature, which has already been discussed;
2. by decreasing the viscosity (= molecular weight). The lower the viscosity the higher the chain mobility. So, if all the other variables are kept constant, the diffusion of molecular segments towards a crystalline lattice will be easier for the more mobile molecule, i.e. the molecule with the lower molecular weight.

The effect of temperature and viscosity is shown in Fig. 45, showing the results obtained in an investigation where temperature, viscosity and draw ratio have been varied systematically. For the data in Fig. 45 the draw ratio has been kept constant. From the figure it can easily be seen that at constant viscosity, a high temperature leads to a high crystallinity, whereas at constant temperature a decreased viscosity results in an increased crystallinity. The effect on the ratio of modulus and shrinkage is given in Fig. 46. It is clear that the highest modulus-shrinkage ratio is found for the yarn which has the lowest viscosity and was subjected to the highest temperature. This is completely in line with the ideas just discussed.

Another important yarn property, however, is its tenacity. According to current ideas the intrinsic part of tenacity is associated in a complicated way with the amount, orientation and length distribution of the tie-molecules. These are molecules connecting - via the amorphous domains - successive crystalline regions. At the moment is is not yet possible to characterize these molecules in a proper way. Nevertheless, the macroscopic behaviour of the tenacity, provides sufficient information for use in this evaluation.

Fig. 47 shows the tenacity of the afore-mentioned yarns as a function of the draw ratio applied at three different viscosities and process temperatures. Apart from the fact that a higher draw ratio results in a higher tenacity (and a lower elongation at break), there is a pronounced influence of the viscosity. At the same draw ratio a higher yarn viscosity yields a yarn with a higher tenacity. This can physically be understood by realizing that a higher viscosity, i.e. a longer molecule, has a higher probability of bridging an amorphous domain. Therefore, the number of tie-molecules is expected to be higher. Moreover, it can be seen from the figure that the highest temperature, at the same viscosity and draw ratio, results in the lowest tenacity. So, the conditions to produce a yarn with a high modulus-shrinkage ratio conflict with those for the production of a high-tenacity yarn. For the latter yarn moderate temperatures are required in combination with a high yarn viscosity, the reverse holds for the yarn with a high modulus-shrinkage ratio.

In this presentation the effect of different process conditions has been discussed: temperature, yarn tension and the molecular weight. In the conflict just mentioned between the modulus-shrinkage ratio and the tenacity, another process condition not mentioned so far has to be discussed, viz. the residence time at high temperature. The effect of this parameter is illustrated in Fig. 48 where the modulus-shrinkage ratio is plotted versus the yarn tenacity for two different processes: the steamdrawing process and the spindrawwinding process. It is clear e.g. for steamdrawing that an increase in modulus-shrinkage ratio is accompanied by a decrease of tenacity. However, the course for steamdrawing is quite different from that for spindrawwinding. The figure shows that a given tenacity can in principle be obtained in both processes. However, if at a certain tenacity a high modulus-shrinkage ratio is required, i.e. a high crystallinity, sufficient residence time is needed. In the spindrawwinding process the residence time on the hot godet is of the order of 0.1 sec. The residence time in the steambox for steamdrawing is of the order of seconds. Therefore, if a rather long residence time is required, this is available only in the steamdrawing process.

The figure can also be interpreted from another point of view. If a certain modulus-shrinkage ratio is required, the corresponding tenacity will generally be higher for the steamdrawing process. In the case of a high modulus-shrinkage ratio, a high crystallinity is required. In the spindrawwinding process this crystallinity has to be obtained in a very short time. The only possible way to achieve this is by using extremely high godet temperatures. But such high temperatures are detrimental with respect to the yarn tenacity. If more time is available to reach such a high crystallinity, as in the case of the steamdrawing process, such extreme yarn temperatures are not required, resulting in a yarn with a higher tenacity. This is clearly shown in Fig. 48, where the difference between both curves is biggest at the high modulus-shrinkage ratios and the relatively low tenacities.

In other other case, if not too high modulus-shrinkage ratios are required, both curves coincide. Here also the spindrawwinding process can make use of moderate temperatures, avoiding too big tenacity reductions. This is in agreement with a general experience, that the yarn tenacities do not break down below a certain critical temperature.

In practice this means that with respect to tire yarns, with not too high a modulus-shrinkage ratio, both the steamdrawing process and the spindrawwinding process can yield yarns with the same combination of mechanical properties. If, however, a high modulus-shrinkage ratio is required, the spindrawwinding process, because of its short residence time for annealing, cannot yield a yarn with the same combination of properties as the steamdrawing process.

Concluding, we hope to have shown you that studying the molecular physical structure not only gives much pleasure to the investigator but also contributes to the solution of practical problems. It enables to understand the relations between process and properties, and the mutual relations between the properties as such. Furthermore it provides an understanding of the limitations and possibilities of the various yarn processes.

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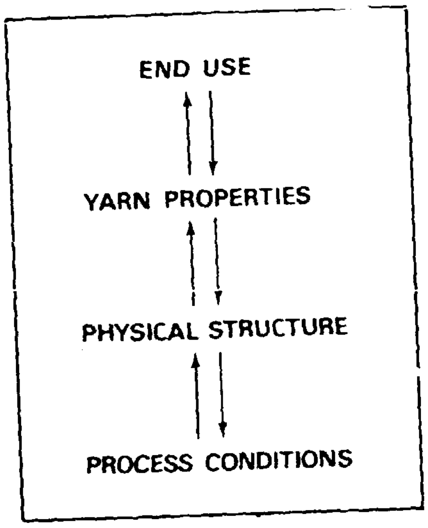


Fig. 1. Intermediate-position of the physical yarn structure.

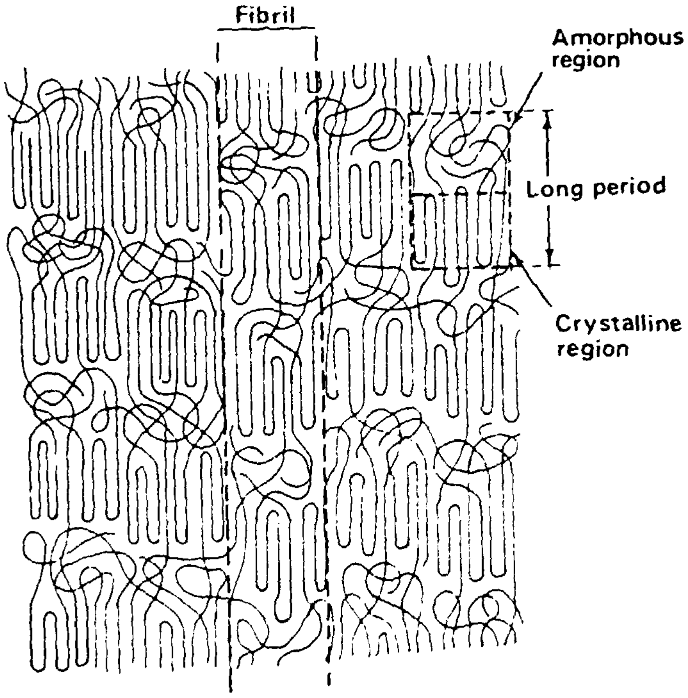


Fig. 2. Structural model of drawn yarn.

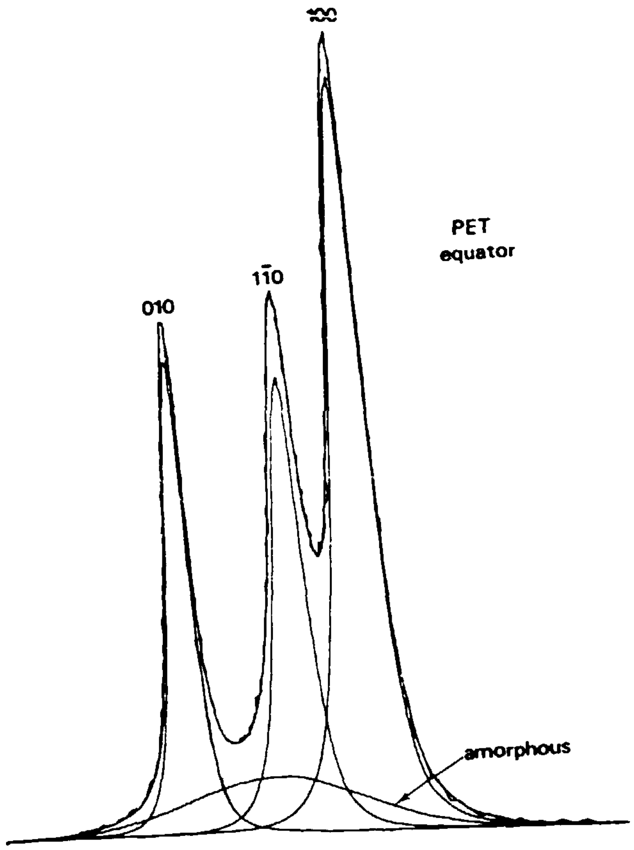


Fig. 3. Profile and deconvolution of an equatorial scan of PET.

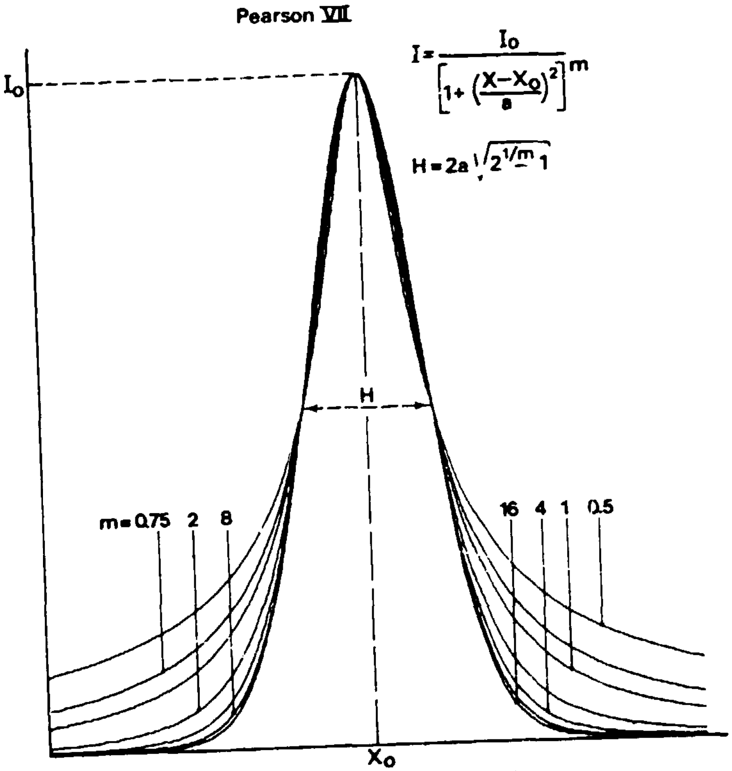


Fig. 4. Properties of the Pearson VII function.

$$\frac{3}{2E_{son}} = \frac{V_c(1-f_c)}{E^o_{t,c}} + \frac{(1-V_c)(1-f_a)}{E^o_{t,a}}$$

$$E^o_{t,c} = 3.68 \text{ GPa}$$

$$E^o_{t,a} = 1.82 \text{ GPa}$$

$$V_c = \frac{d-d_a}{d_c-d_a}$$

$$d_a = 1336 + 9.4 f_a$$

Fig. 5. Schematic presentation of Samuels theory.

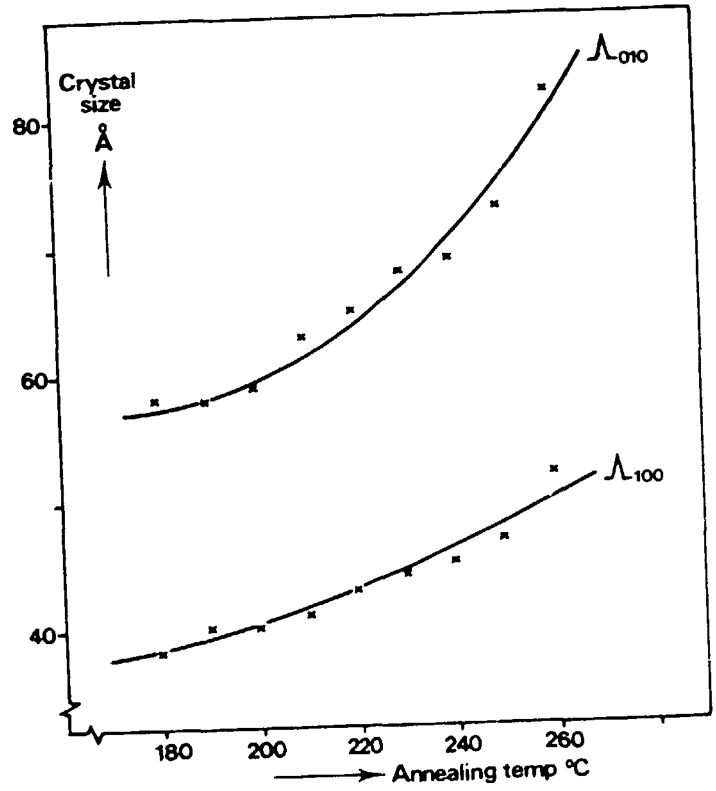


Fig. 6. Effect of annealing temperature on two lateral crystal sizes.

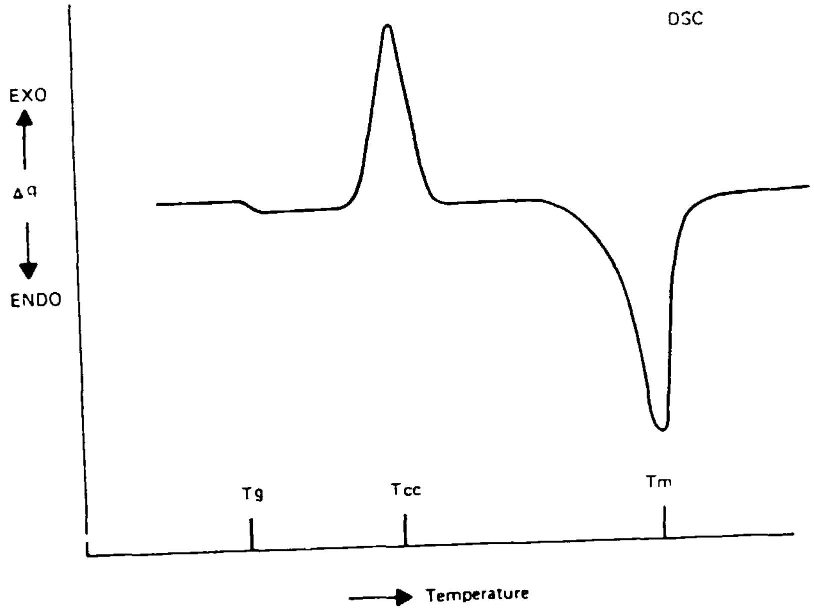


Fig. 7. DSC trace of as-spun PET.

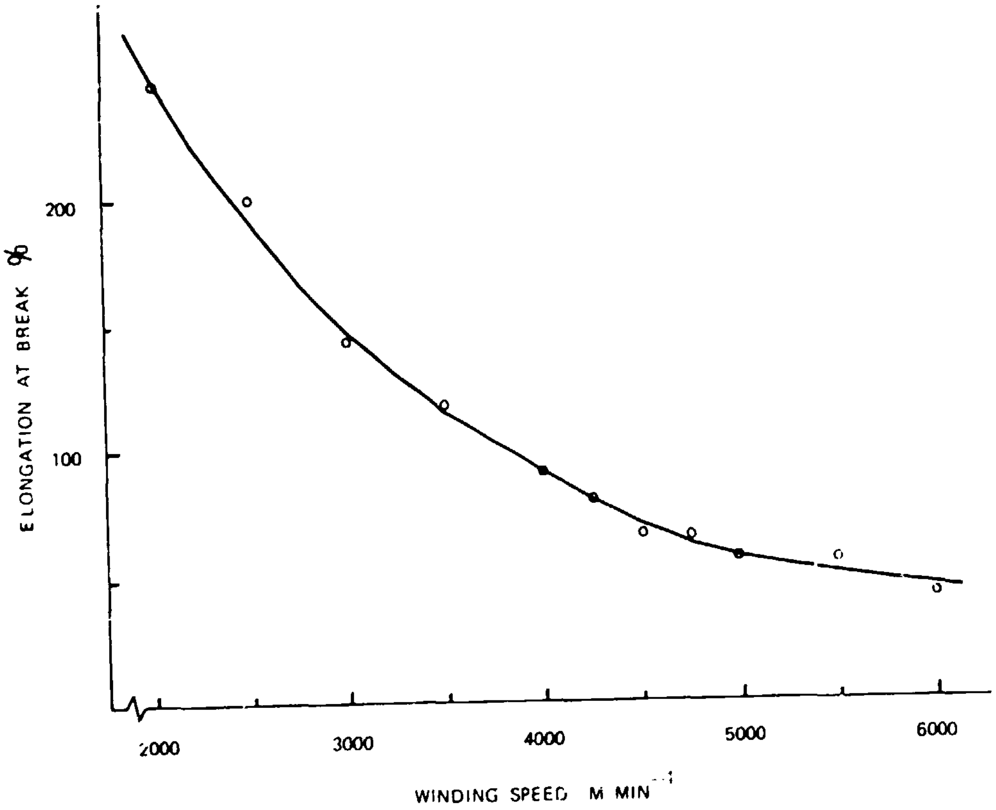


Fig. 8. Elongation at break for PET yarns wound at different speeds.

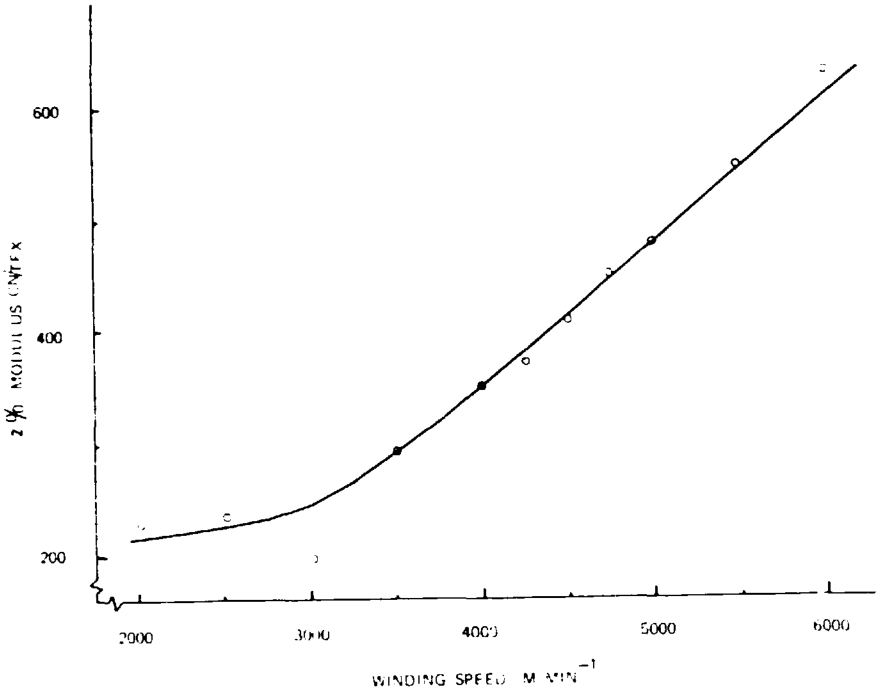


Fig. 9. 2% tangential modulus vs. winding speed.

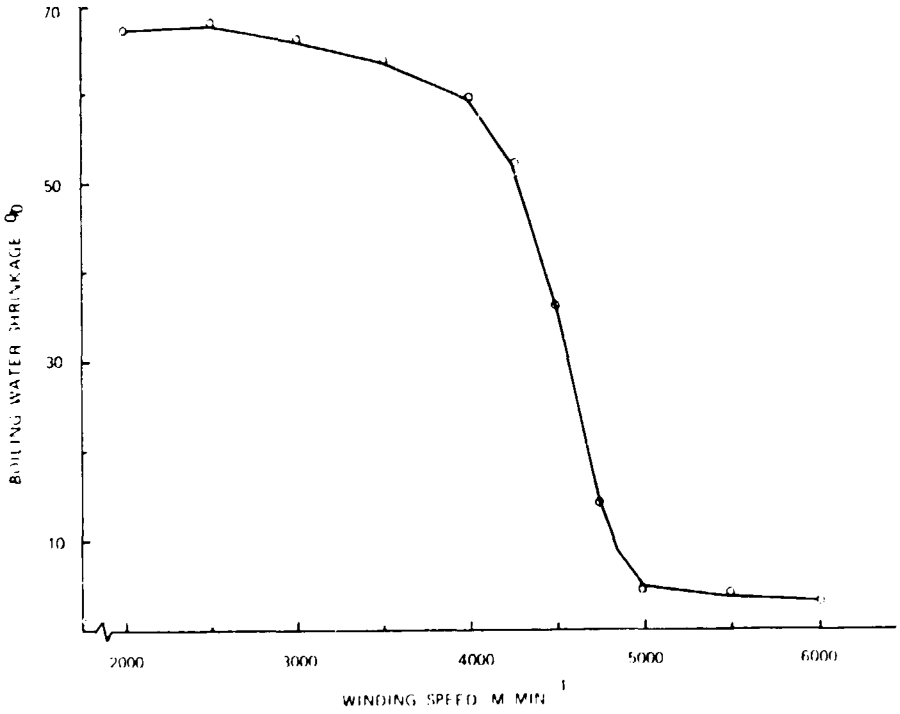


Fig. 10. Boiling water shrinkage for PET yarns wound at different speeds.

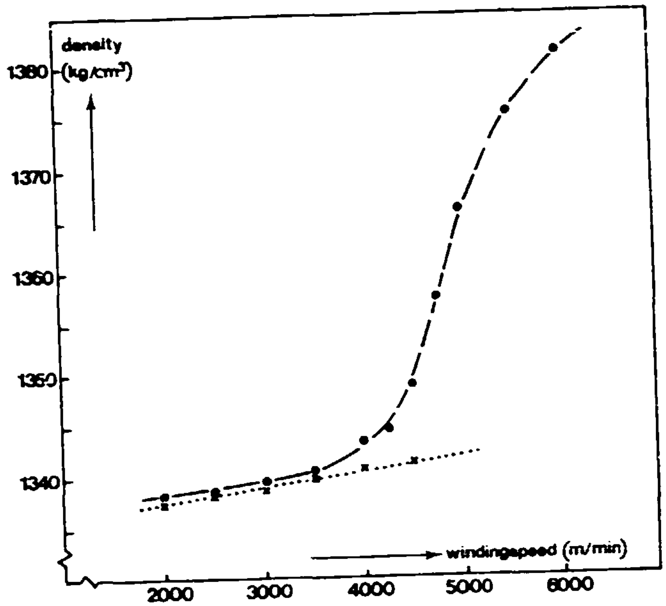


Fig. 11. Experimental density of PET as function of winding speed.

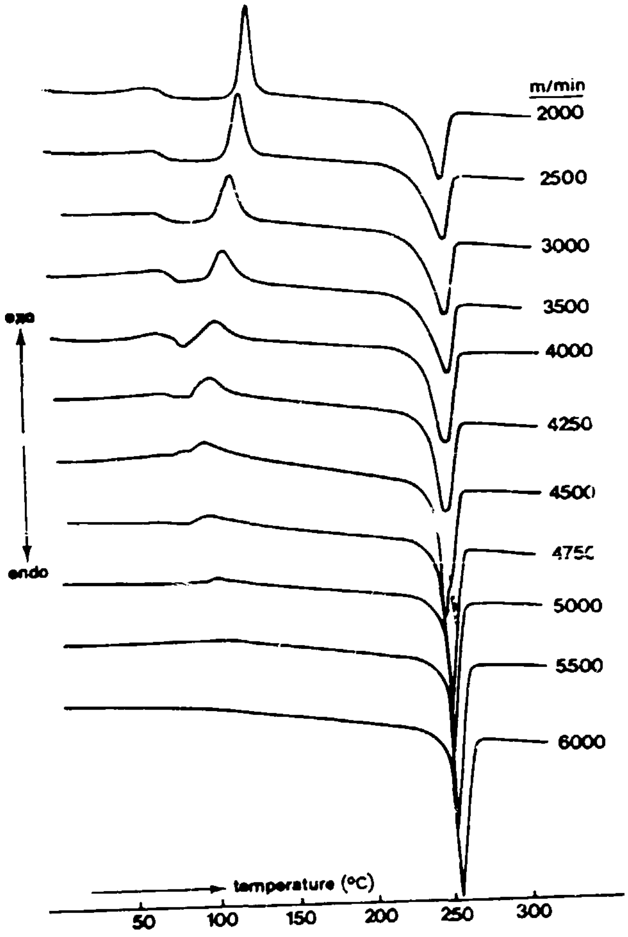


Fig. 12. DSC traces of as-spun yarns wound at the indicated velocities.

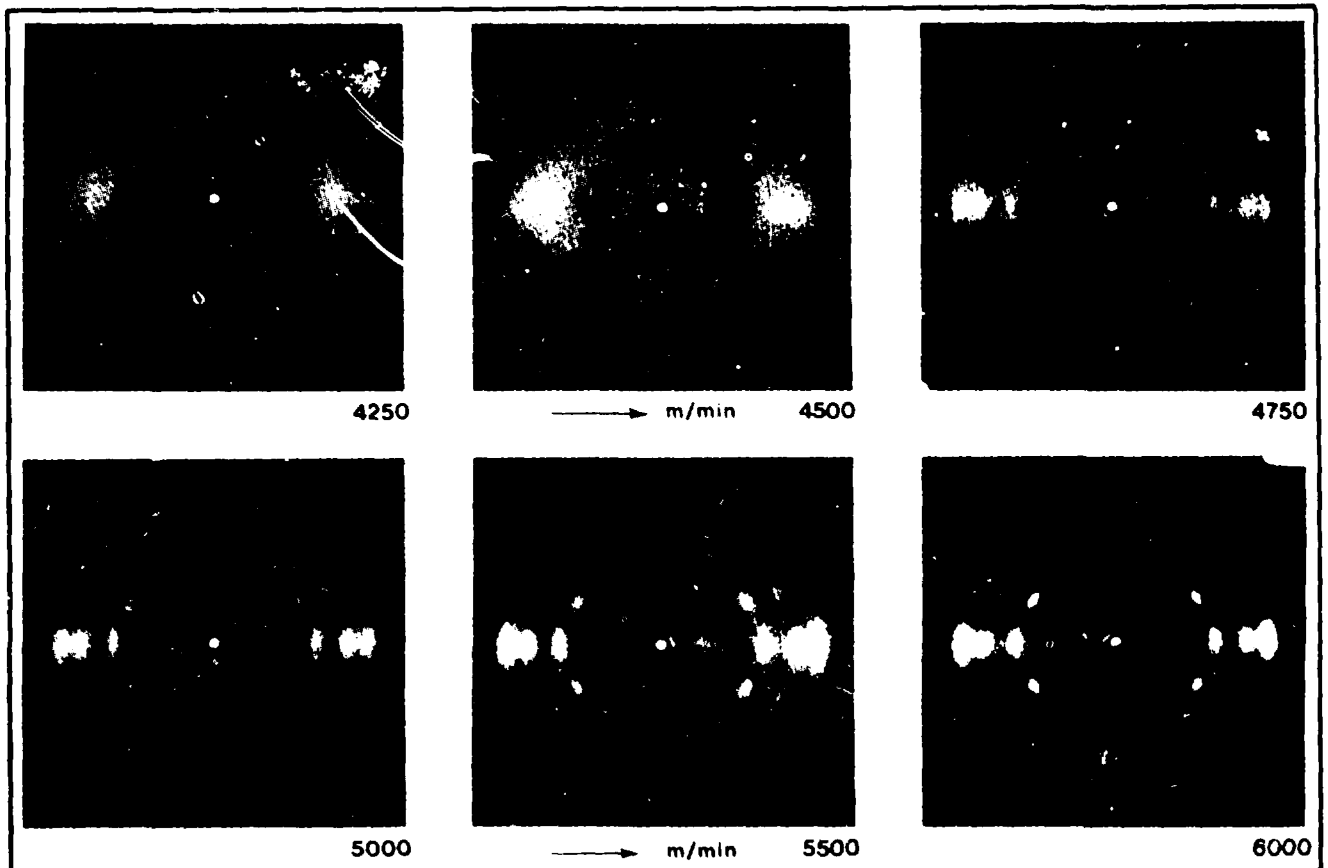


Fig. 13. Astbury pictures.

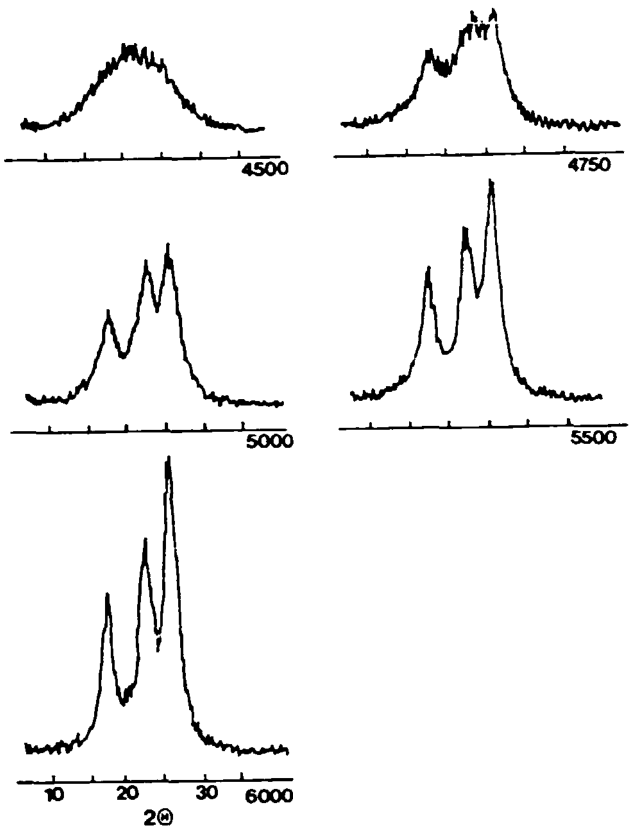


Fig. 14. Equatorial X-ray diffractometer scans.

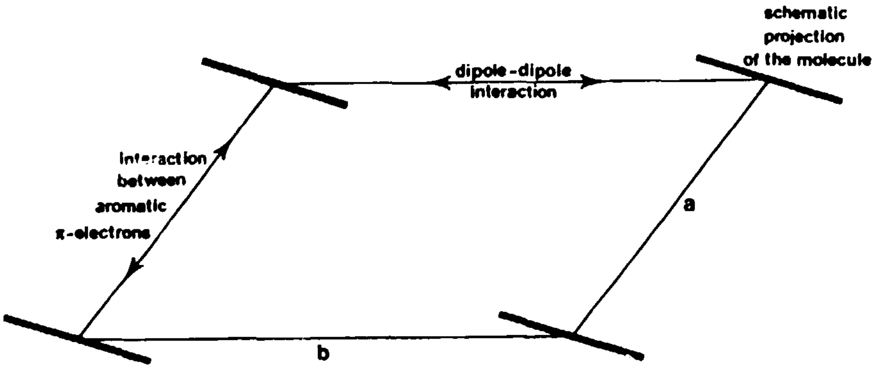


Fig. 15. Schematic basal plane of unit cell of PET and representation of intermolecular interactions.

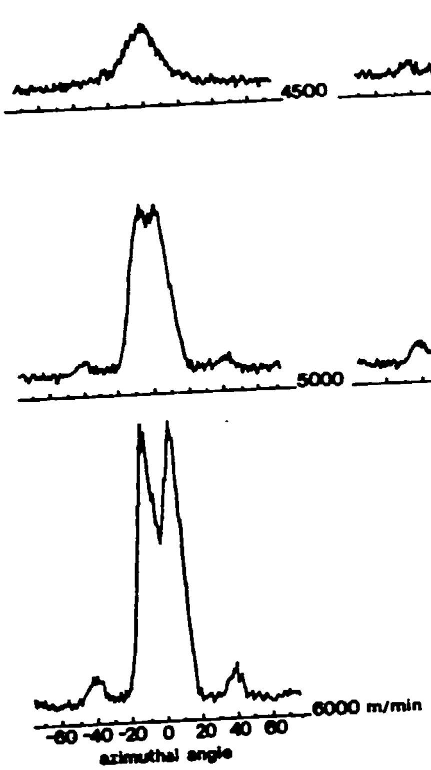


Fig. 16. Azimuthal X-ray diffractimeter scans over the $\bar{1}05$ reflection.

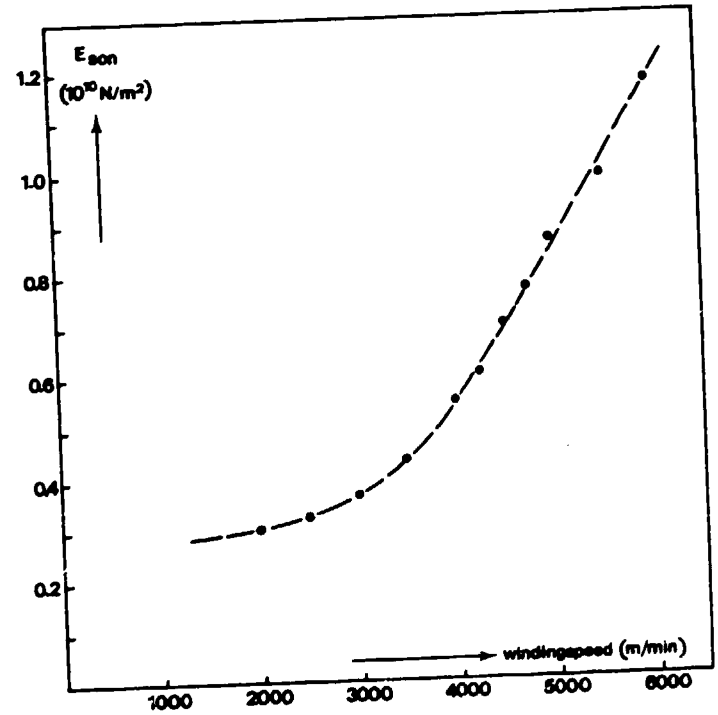


Fig. 17. Sonic modulus as function of winding speed.

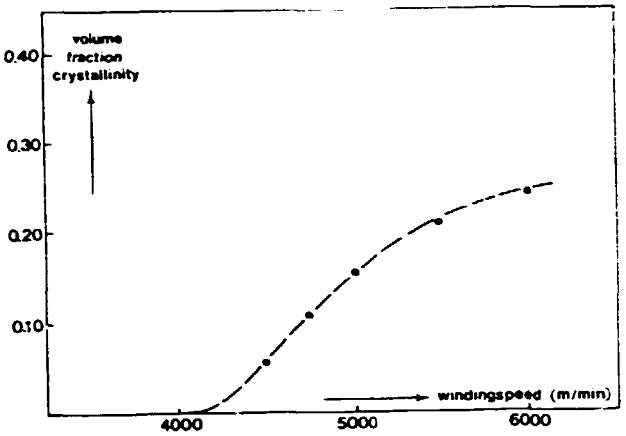


Fig. 18. Volume fraction crystalline material vs. winding speed.

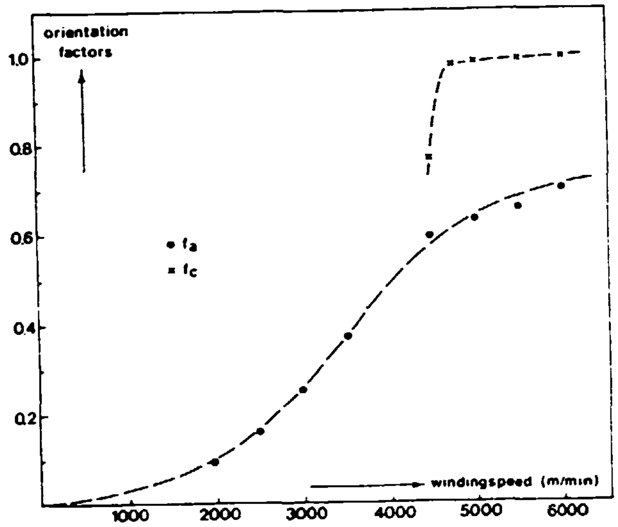


Fig. 19. Orientation factors vs. winding speed .

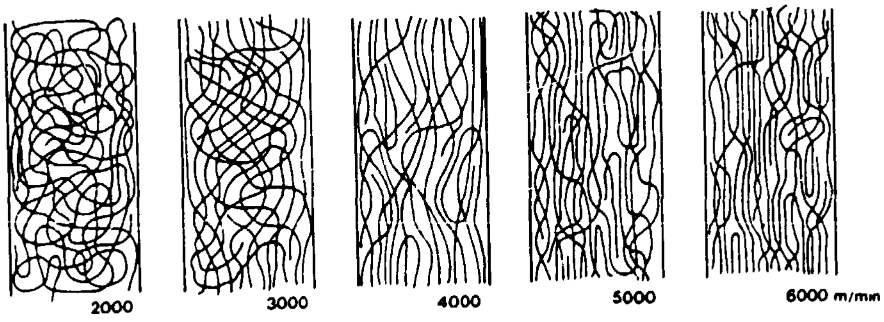


Fig. 20. Proposed molecular arrangements in yarns wound at various speeds.

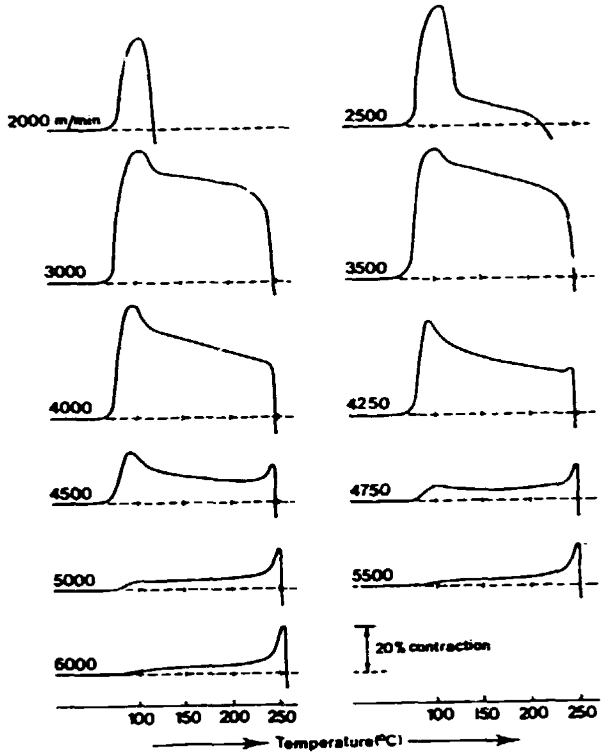


Fig. 21. Contraction as function of increasing temperature for yarns taken up at the indicated speeds.

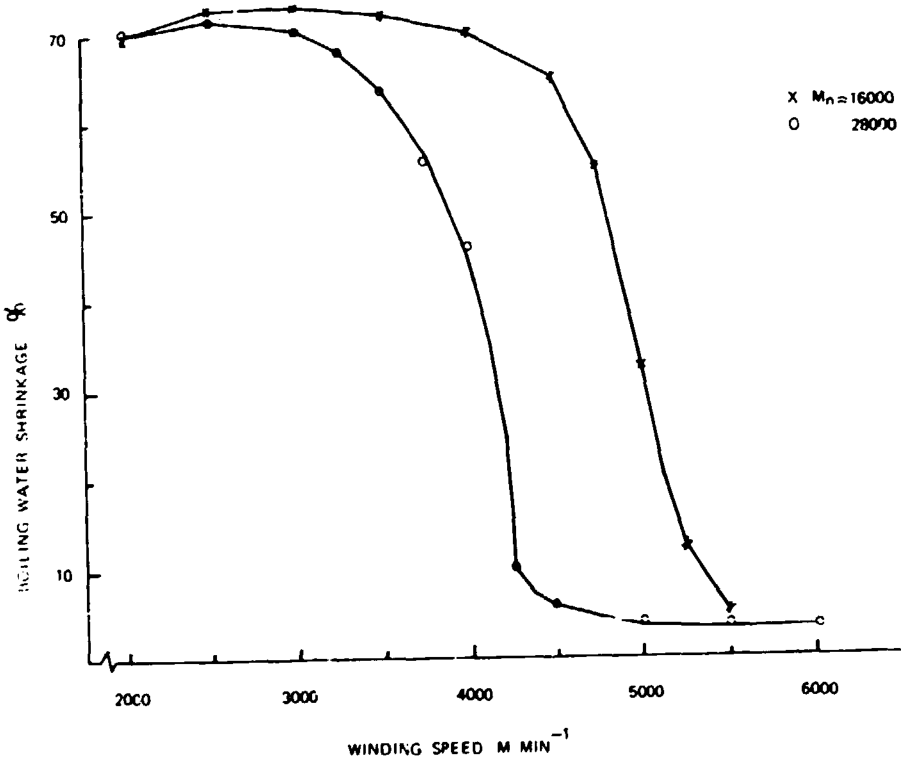


Fig. 22. Boiling water shrinkage vs. winding speed for two different molecular weights.

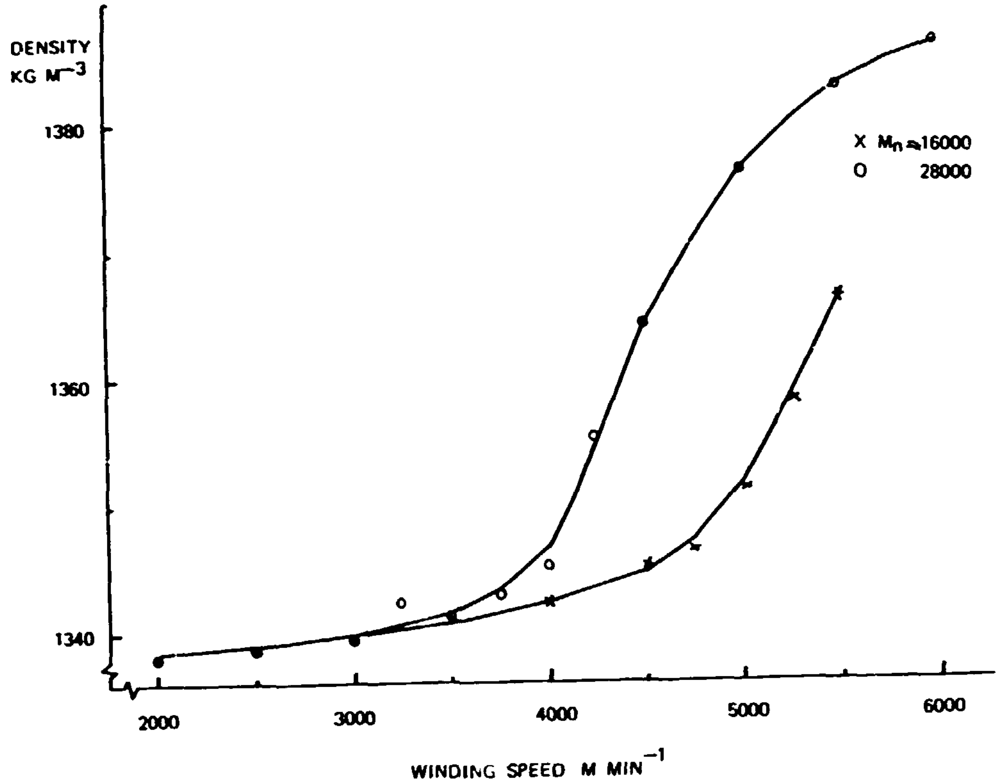


Fig. 23. Density vs. winding speed for two different molecular weights.

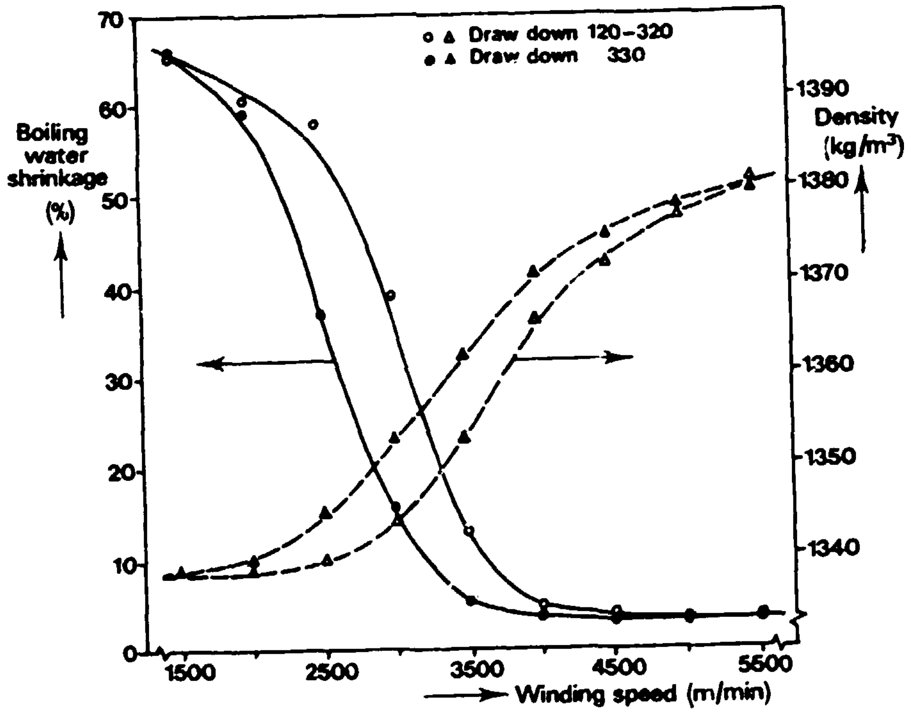


Fig. 24. Boiling water shrinkage and density vs. winding speed for yarns taken up with different draw-down.

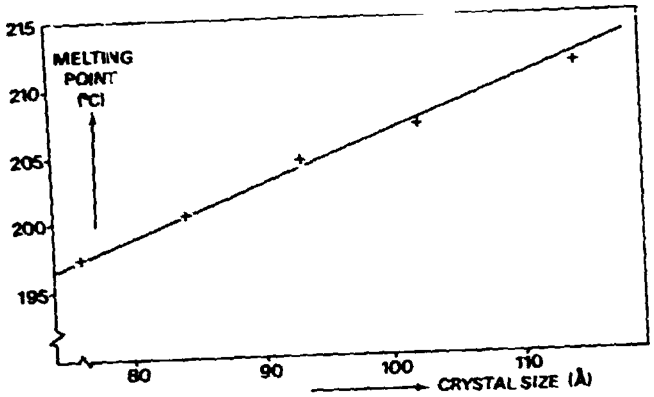


Fig. 25. Melting point vs. crystal size for nylon 6 yarns.

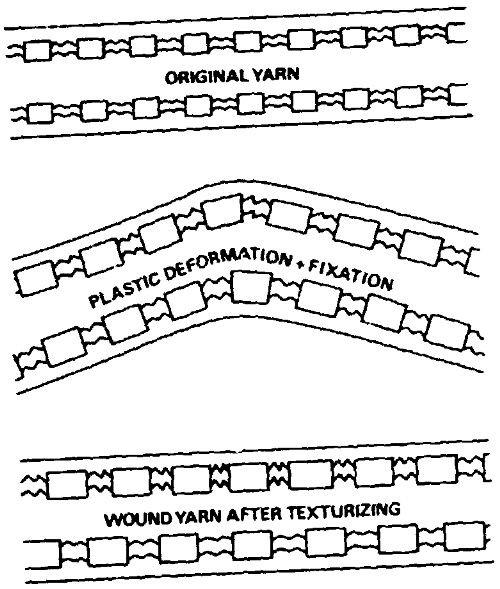


Fig. 26. Proposed physical structure of feeder yarn, yarn during texturizing and wound yarn after the crimp process.

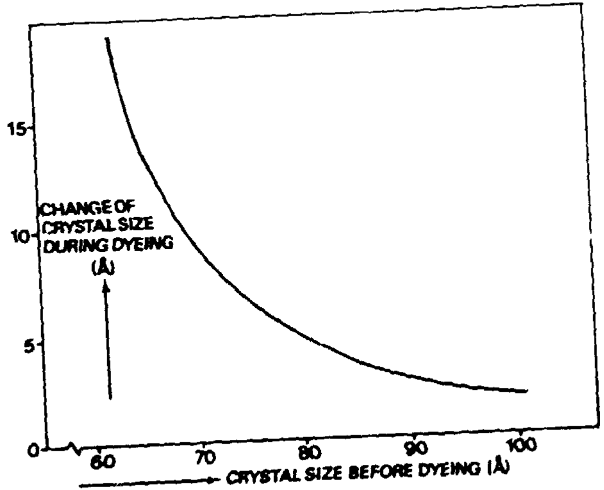


Fig. 27. Change of crystal size during dyeing as a function of the original crystal size for nylon 6 yarns.

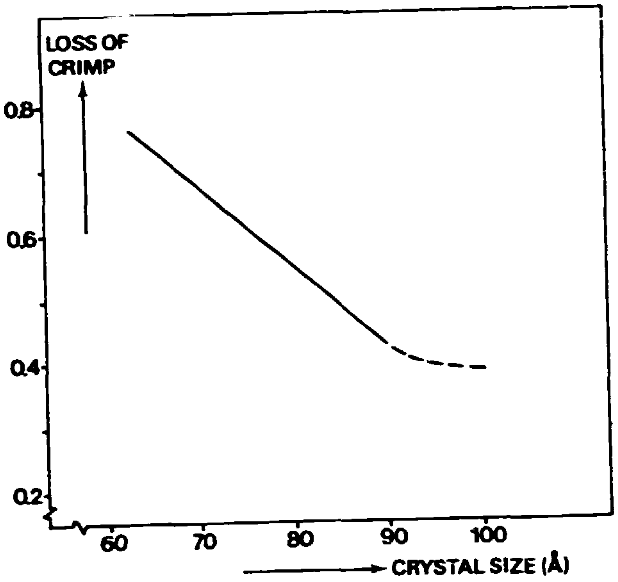


Fig. 28. Loss of crimp vs. crystal size of crimped nylon 6 yarn.

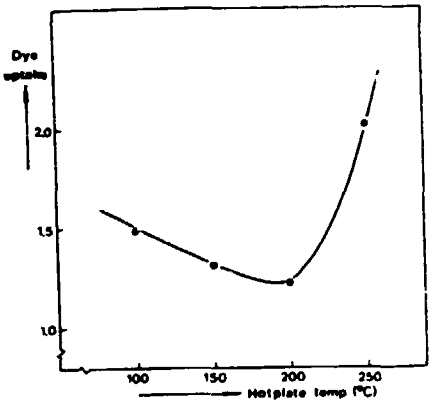


Fig. 29. Uptake of Palanilbrilliant red of yarns heattreated at different temperatures.

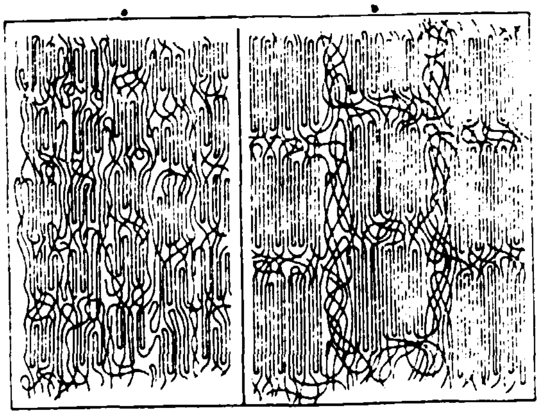


Fig. 30. Comparison of different yarn structures formed:

a. at low temperature;

b. at elevated temperature.

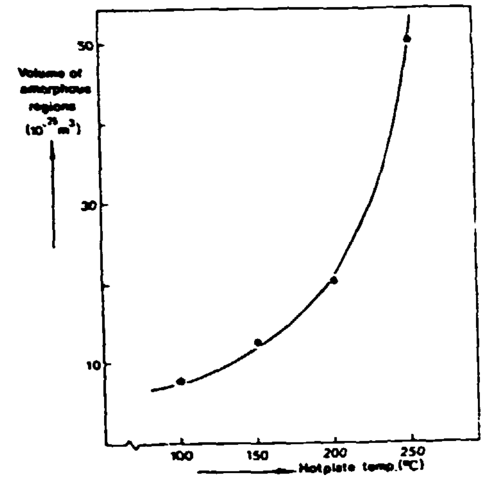


Fig. 31. Volume of the individual amorphous regions vs. annealing temperature.

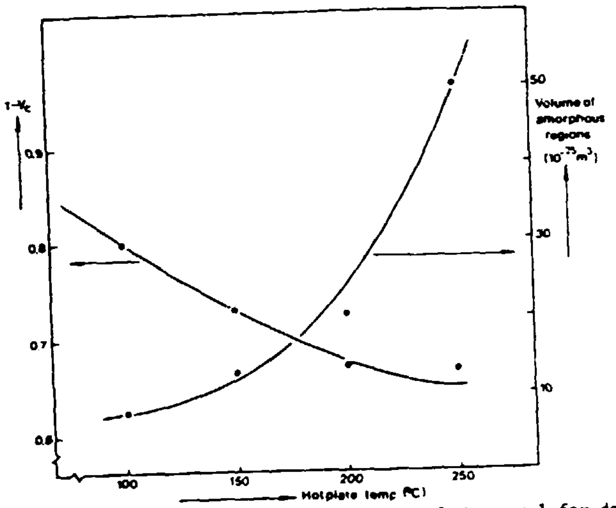


Fig. 32. Schematic representation of the model for description of dye uptake of PET yarns.

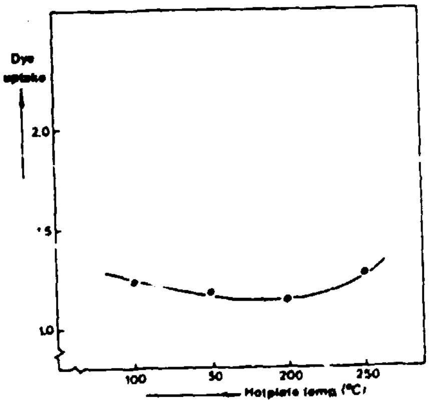


Fig. 33. Uptake of Foronblue of yarns heat-treated at different temperatures.

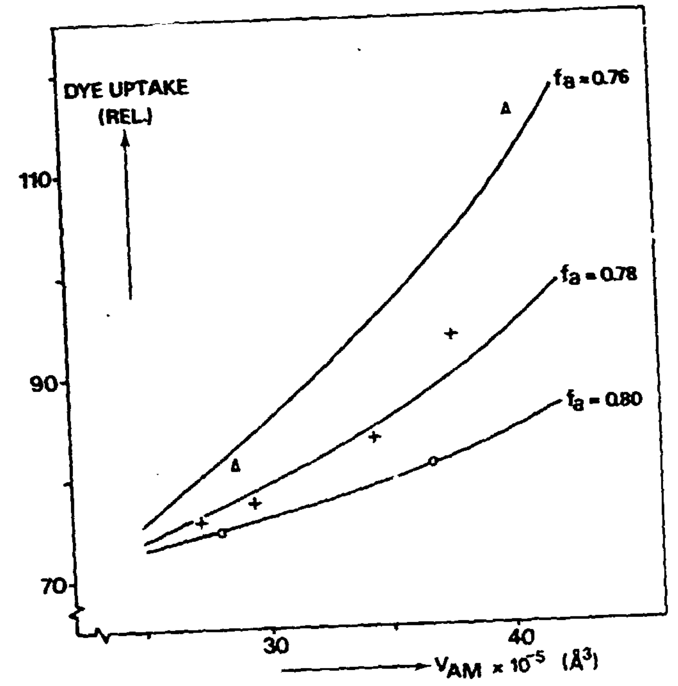
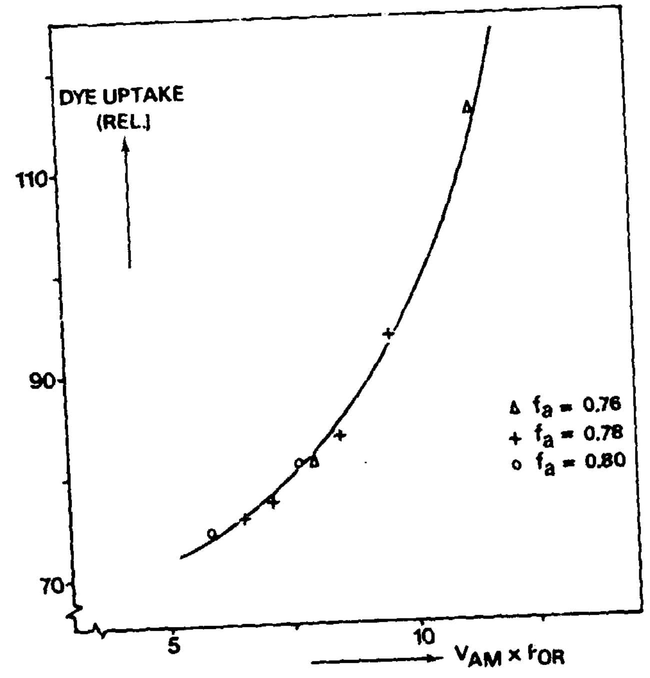


Fig. 34. Dye uptake for PET yarns vs. the volume of the individual amorphous regions for different levels of amorphous orientation.



$$V_{AM} = \frac{1-V_c}{V_c} \times \Lambda_{010} \times \Lambda_{100} \times \Lambda_{\bar{1}05}$$

$$f_{OR} = 1-e^{-\left(\frac{1-f_a}{f_a}\right)}$$

Fig. 35. Dye uptake of PET yarns in terms of crystalline morphology and amorphous orientation.

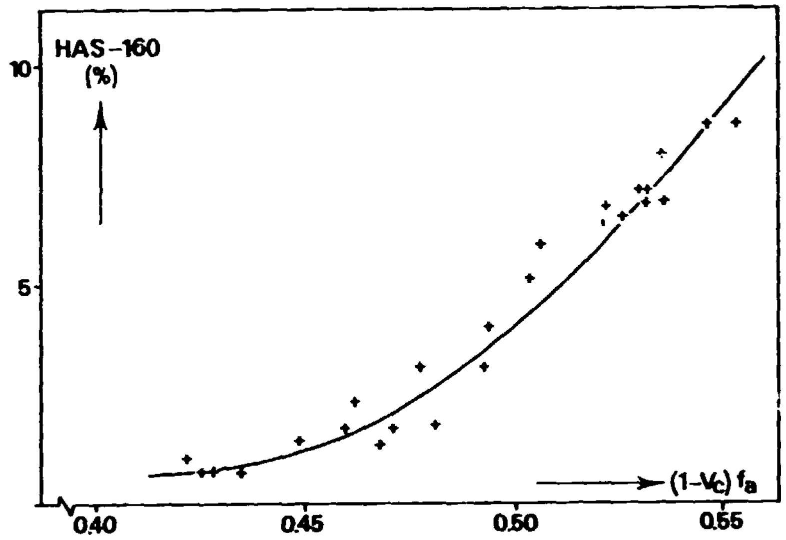


Fig. 36. Hot air shrinkage at 160°C vs. (1-V_c) f_a.

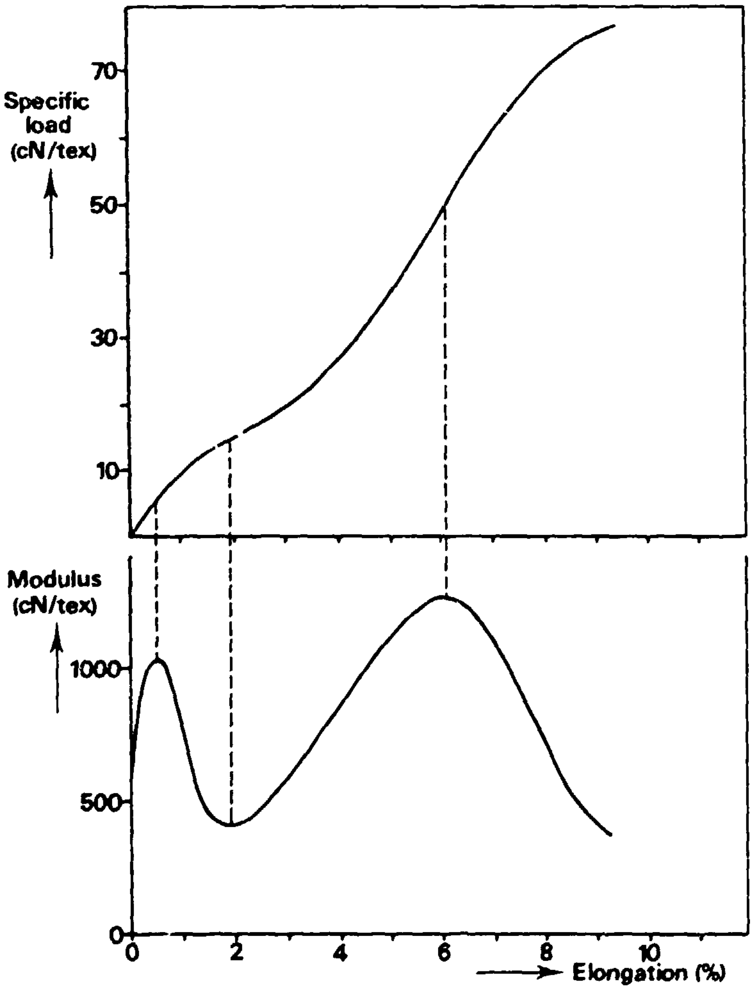


Fig. 37. Stress-strain and corresponding modulus-strain curve.

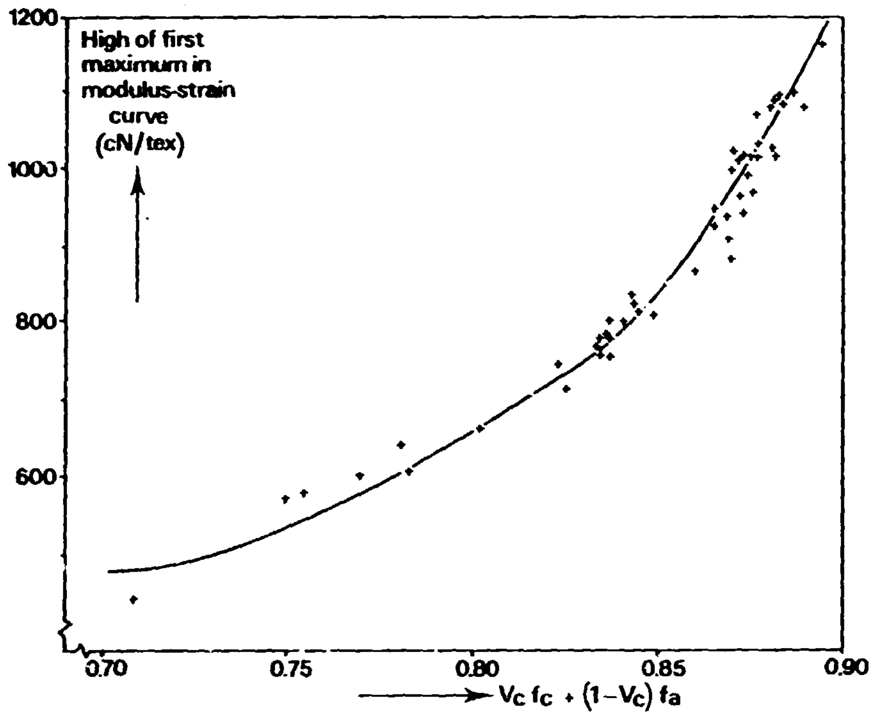


Fig. 38. Height of first maximum in modulus-strain curve as a function of the overall orientation.

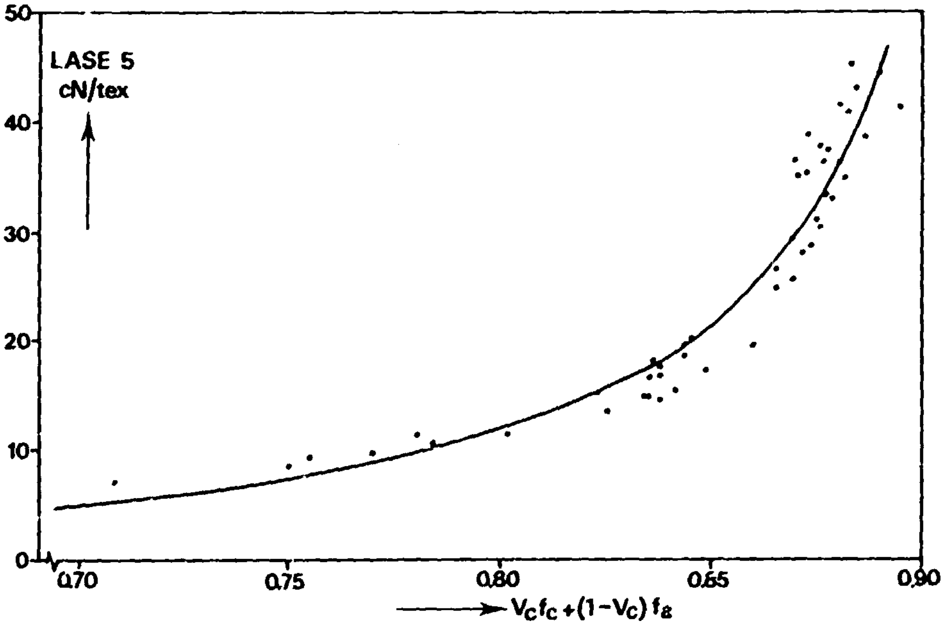


Fig. 39. Load at 5% elongation vs. overall orientation.

Modulus (:) $V_c f_c + (1-V_c) f_a$

$$\begin{aligned} & V_c f_c + (1-V_c) f_a \\ & \qquad \parallel \\ & V_c(f_c - f_a) + f_a \equiv f \end{aligned}$$

$$\frac{\partial f}{\partial V_c} = f_c - f_a \quad > 0$$

$$\frac{\partial f}{\partial f_a} = (1 - V_c) \quad > 0$$

Higher crystallinity → higher modulus

Lower amorphous orientation → lower modulus

Fig. 40. Effect of crystallinity and amorphous orientation on modulus.

MODULUS (:) $V_c f_c + (1-V_c) f_a$

SHRINKAGE (:) $(1-V_c) f_a$

$$\frac{\text{MODULUS}}{\text{SHRINKAGE}} \; (:) \; \frac{V_c f_c + (1-V_c) f_a}{(1-V_c) f_a}$$

Fig. 41. Structural description of modulus-shrinkage ratio.

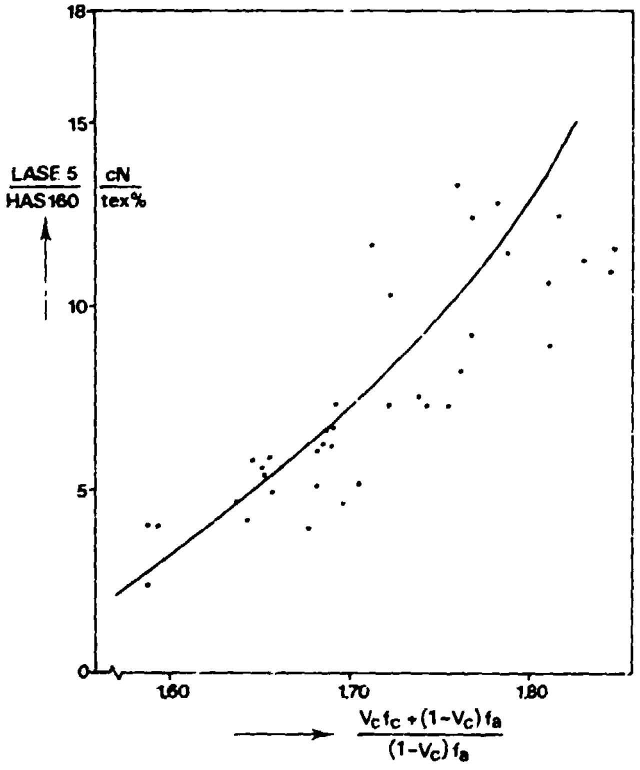


Fig. 42. Experimental modulus-shrinkage ratio vs. the "model value".

$$\frac{\text{MODULUS}}{\text{SHRINKAGE}} \propto \frac{V_c f_c + (1-V_c) f_a}{(1-V_c) f_a} = F$$

$$\frac{\partial F}{\partial V_c} = \frac{f_c}{(1-V_c)^2 f_a} > 0$$

$$\frac{\partial F}{\partial f_a} = \frac{-V_c f_c}{(1-V_c) f_a^2} < 0$$

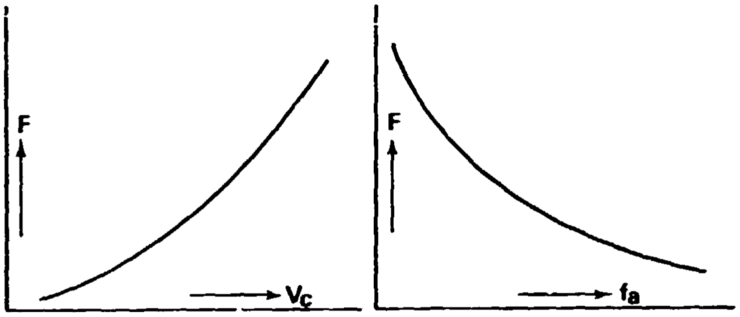


Fig. 43. Effect of crystallinity and amorphous orientation on modulus-shrinkage ratio.

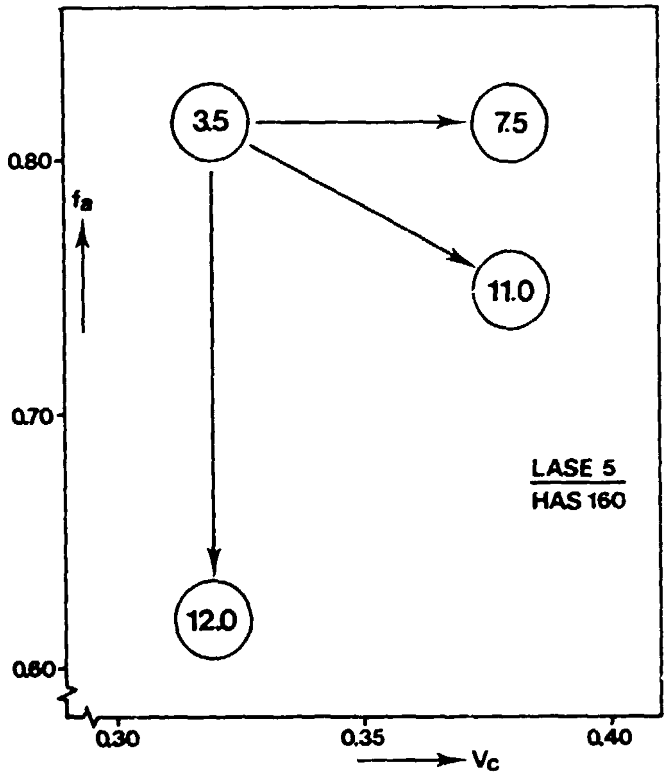


Fig. 44. Experimentally observed effect of V_c and f_a on the ratio of LASE 5 and HAS 160.

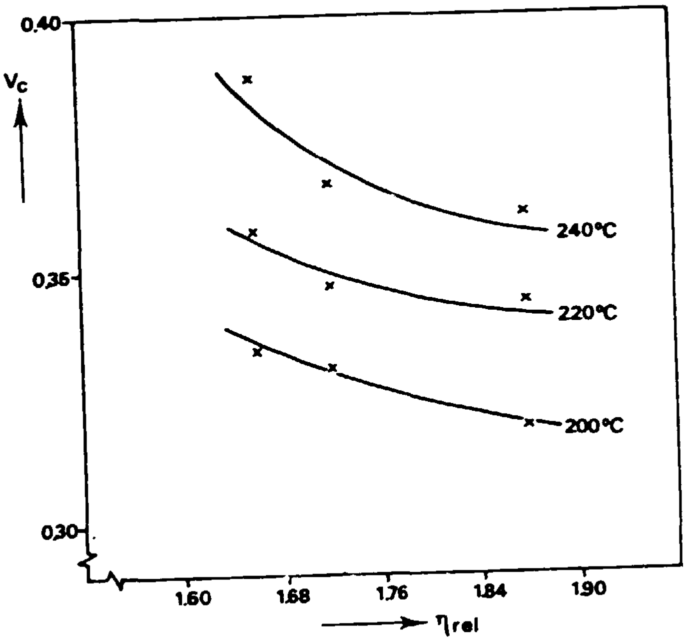


Fig. 45. Effect of temperature and viscosity on yarn crystailinity.

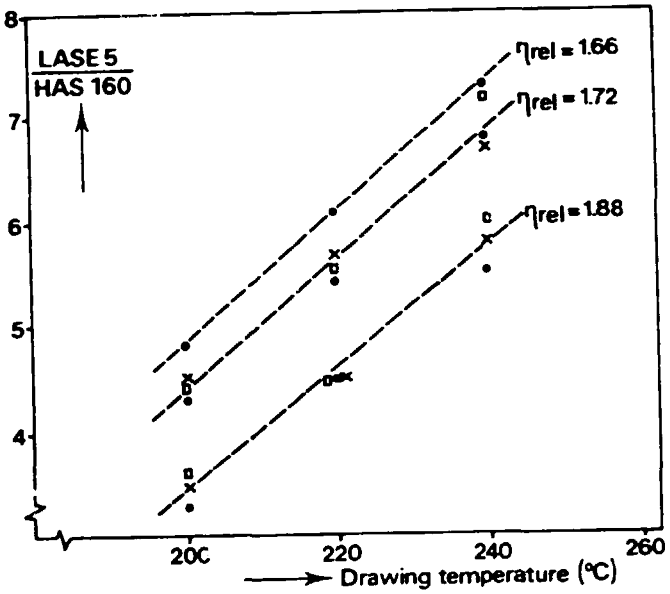


Fig. 46. Experimentally observed effect of temperature and viscosity on modulus-shrinkage ratio.

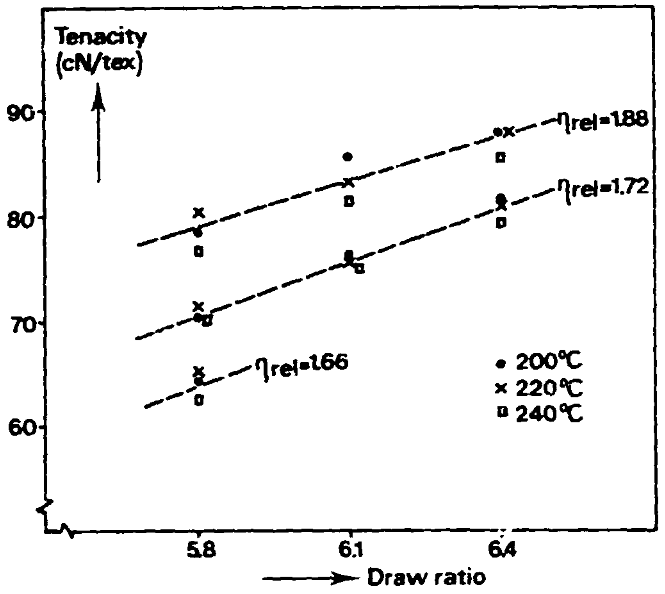


Fig. 47. Effect of draw ratio, viscosity and temperature on tenacity.

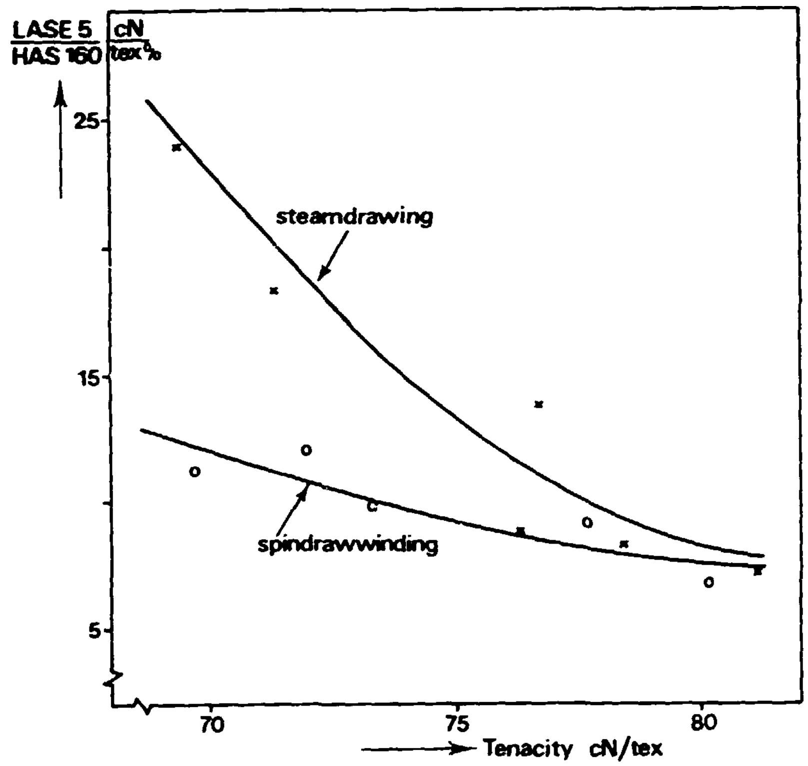


Fig. 48. Balance between tenacity and modulus-shrinkage ratio for steamdrawing and spindrawwinding process.

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International Conference on
Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

PETROCHEMICALS AND FIBRES IN INDIA — NEED FOR SPEEDING UP UTILISATION OF AVAILABLE RAW MATERIALS

P. K. DAVE

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PETROCHEMICALS AND FIBRES IN INDIA — NEED FOR SPEEDING UP UTILISATION OF AVAILABLE RAW MATERIALS

P. K. DAVE

This brief presentation aims to highlight the need for an urgent review of the programmes for the creation of new capacities for olefins and fibre intermediates in the light of (i) the delays that have already occurred in the initiation of the presently planned capacities; (ii) the markedly higher availabilities of gas and crude oil from Bombay High; (iii) the need to prevent the burning of the olefin streams in the associated gas, and the aromatics precursors derived from Bombay High crude; and to that end also, (iv) the severe resource constraints already visible in the Sixth Plan.

2. Reliable estimates of crude oil production from Bombay High indicate that approximately 30 MT would be produced by 1985-86. This raises the availability of associated gas from the 2.7 MM NM^3 per day (Million Normal Cubic Metres per day) on the basis of 9.1 MT of crude oil production assumed by the Lavraj Kumar Working Group, to about 8.9 MM NM^3 per day. The ethylene/propylene availability thus increases to the following figures assumed that LPG will retain the higher priority in any fractionation scheme:

'000 MTA

At 2.7 MM NM^3/day		**At 8.9 MM NM^3/day**
Ethylene	394	1182
Propylene	58	174

The present manufacturing scheme has the following indicative product pattern:

Ethylene	295,000 MTA
Propylene	77,000 MTA (inclusive of FCC of gases utilisation)
LDPE	160,000 MTA
PP	60,000 MTA
EG	50,000 MTA

It is by no means suggested that the additional availabilities should necessarily be taken into the single location manufacturing scheme presently preferred. Gas utilisation now indeed assumes dimensions quite different from those considered earlier, and there is need for a quick and comprehensive review of manufacturing schemes and locations.

3. The implications of the much higher level of crude oil production from Bombay High for the availability aromatics cannot be considered very accurately, for it is by no means certain that very much more than the already assumed production of 9.1 MTPA would be refined in the Indian refineries in a time span of any relevance to this discussion. Hence the availability may for the present be assumed at levels worked out by the Lavraj Kumar Working Group report and the manufacturing schemes and locations of downstream aromatic and fibre plants also assumed generally as recommended. These locations for grass roots plants are likely to be (i) Mathura (Salimpur) for 150,000 MTA of DMT/PTA, and 90,000 or 40,000 MTA of cyclohexanone/nol; (ii) Benzene/Toluene extraction plants at Cochin,Bombay(BP and HP refineries)and possibly also at Barauni. The location or locations for the conversion of cyclohexanone/nol to Caprolactam have not yet been firmed up.

4. The provisions in the Sixth Five Year Plan at 1979 costs are for the following projects:

		Rs. in Crores
1.	Gas Cracker Complex and Downstream Units	385
2.	Aromatics Recovery Unit I	50
	" " II	50
	" " III	20
3.	DMT/PTA	40
4.	Caprolactam	60
	Total	605

Against the above, the unconfirmed estimates of the Maharashtra Gas Cracker Complex at 1981 prices appear to be around Rs. 1150 crores, and for the Salimpur Aromatics Complex around Rs. 450 crores.

5. The best implementation schedules assumed by the Lavraj Kumar Working Group were of 60 months from the grant of a letter of intent. In other words, even if clearances are given in the next few months, the earliest completion of the two projects would be in 1987-88, and allowing for fairly rapid build up of production, reasonable capacity utilisation may develop by 1989-90.

6. This scenario presents the following rather disturbing aspects:

a) In the resource constraints facing the Sixth Plan even the funds shown in the Plan Document may not be available; much less of course, the larger funds needed for the economic utilisation of the additional olefins and aromatics;

b) Even though it has been assumed that the 1982-83 demands have been provided for (which is not quite correct), the demand gaps for 1987-88 will not be met to any significant extent. These gaps are LDPE 143 MTA; HDPE 73 MTA; PP 38 MTA; PVC 149 MTA; PS 23 MTA; Caprolactam 106.5 MTA; DMT/PTA 128.5 (low)/182.5 (high) MTA; ACN 12 MTA. And considering the fact that a number of downstream plants have come into existence or are in the process of being constructed, the drain of foreign exchange on raw material imports will be extremely large; (appendix I gives the CIF prices assumed for purpose of economic analysis in the Lavraj Kumar Working Group report);

c) The burning of expensive raw material feed stock, in the associated gas and in high aromatic naptha which is already current, and will keep growing rapidly in quantity over at least the next 5-6 years, is an economic loss of great magnitude. At the higher production level of associated gas, the loss would be even higher if the manufacturing schemes are not reviewed;

d) Costs of technology, equipment and construction are likely to keep on escalating at an average of 20-25% per annum, leading to a doubling of costs in 4-5 years, a prospect that must cause great concern;

7. It is clear that means must be found to remedy the great loss inherent in the picture described above. The following suggestions are offered for consideration;

a) The public sector in India has developed a considerable measure of experience in the implementation of complex petrochemicals projects; however, the assumption that all the grass roots plants must inevitably be in the public sector seems unwarranted for various reasons;

b) Fully viable alternative corporate schemes should be considered for implementation of the capacities envisaged and further capacities necessary, with reasonable levels of participation by existing public sector units where necessary, and with India and foreign participation in equity and financing (and where necessary in product marketing for export for a reasonable period) — the foreign participation could be tied to technology in the case of multi-nationals, and to financing in the case of the surplus developing countries; (cf. also suggestion of Mr. L. K. Jha in his inaugural address for developing countries participation in centrally located raw materials/intermediates plants);

c) Project implementation schedules alone should govern the question of indigenous vs. foreign goods and services;

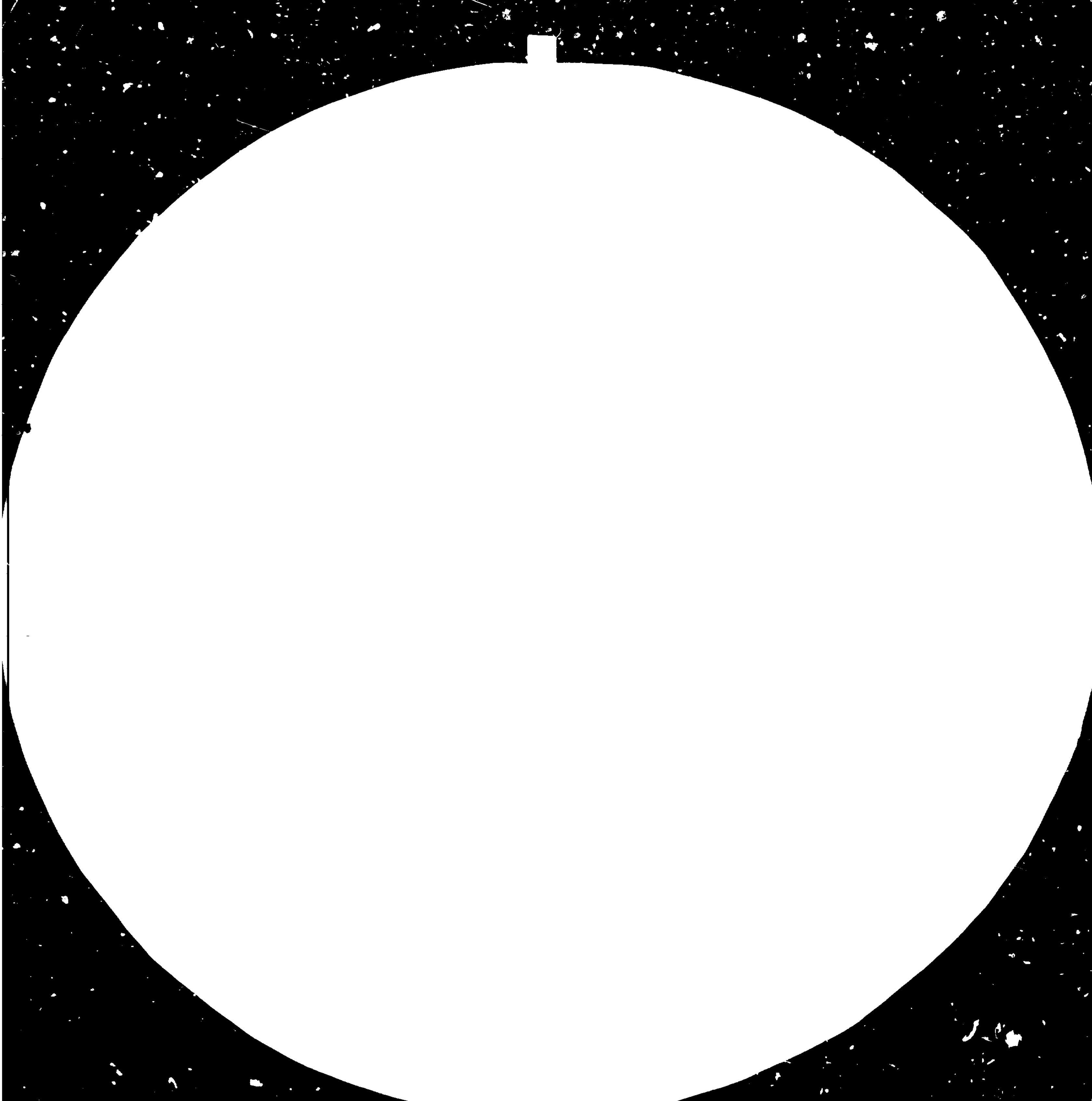
d) Special decision making and monitoring devices should be arranged to ensure that the implementation schedules are adhered to strictly;

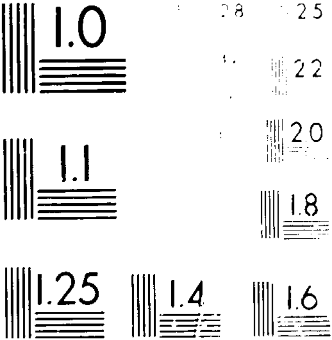
e) In all the grass roots plants, and especially those tied to export of product or of downstream manufactures, economy of scale must receive the highest importance; for the same reason, the best technology and the best product must be chosen;

f) Parallel development of manpower, both for the mother plants and for the downstream industries, should be taken in hand. Similarly for the development of equipment and technical services for the downstream industries, including for example the use of polyester in handloom, conversion to new plastics (LLDPE?), etc.;

g) Above all, the frame for developing capacities to meet growing demand should be lengthened so that the situation the country had faced in the last decade, and will continue to face in the remaining years of the century are avoided;

h) Pricing policies for raw material, and fiscal levies on intermediates and end products will ultimately determine the pace of development in the petrochemicals and fibres field. These should receive very careful consideration.

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APPENDIX I

(Ref : Para 6 (b))

Prices of Some Important Raw Material and Product Imports Assumed for the Purpose of Economic Analysis in the Report of the Re-Constituted Working Group on Petrochemicals

Item	Price CIF Rs/MT	Item	Price CIF Rs MT
Ethylene	2640	P-Xylene	3300
Propylene	2063	Caprolactam	8250
LDPE	4950	NFY	27225
HDPE	5363	PFY	29700
PVC	4620	PF	11550
Styrene	4125	Detergent Alkylate	4950
Polystyrene	5363	EG	4331
Polypropylene	5363		
ACN	4950		

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DEVELOPMENT OF NYLON FIBRES PAST, PRESENT AND FUTURE

Ir. H. JACOBS, DR. Ir. J. W. M. STEEMAN
DSM Research and Patents

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HENK JACOBS is a mechanical engineer from Delft Technological University (The Netherlands). He started his career in Akzo where he was active in both research of new polymers and the engineering of synthetic fibre plants including process design, start-up and trouble-shooting. In 1977 he joined DSM's fibre technology department, in charge of technical service and product development of fibre raw materials.

JOHN STEEMAN is a chemical engineer from Delft Technological University and a Doctor of Science.

He has had many leading positions in DSM both in research and production. He is now in charge of the department for evaluaton and research planning at DSM's Central Laboratories.

Synopsis

The historical development of nylon fibres since the commercial introduction in 1940 will be described.

Special attention will be paid to the raw material situation; an energy analysis will be presented covering both monomer—and polymer production of nylon 6 and 66, polyester and acrylics

The market position of nylon fibres will be discussed distinguishing apparel, home furnishing and industrial as main application areas. A forecast of the synthetic fibres production until 1990 will illustrate the present expectations.

In the last paragraph the position of nylon 6 versus 66 will be discussed and historical developments will be explained.

DEVELOPMENT OF NYLON FIBRES PAST, PRESENT AND FUTURE

Ir. H. JACOBS, DR. Ir. J. W. M. STEEMAN
DSM Research and Patents

1. Historical development of nylon fibres

The history of nylon started in 1928 when a basic research group was established by Du Pont de Nemours (USA), with the objective to delve deeply into the chemistry of macromolecules. The leader of this group became 32-year-old professor Wallace H. Carothers, whose name is closely connected with the development of nylon.

The group started with a fundamental research programme directed towards the polycondensation of dibasic acids with glycols and indeed obtained polymers with molecular weights between 2000 and 5000.

They made the then astonishing discovery that filaments of these 'super polymers' could be drawn to several times their original length. Disappointing, however, was their conclusion that the investigations were of theoretical interest only, as the melting points of the yarns were too low for general textile purposes.

Early efforts in the field of polyamides, at first based on ε-aminocaproic acid, were unsuccessful.

The little practical significance of the work done until then gave rise to a careful reconsideration of the project, and as a result further work was fully concentrated on polyamides, in view of their attractive melting point and low solubility.

On February 28, 1935 (a now historic date) the super polymer from hexamethylene diamine and adipic acid was synthesized for the first time. This polymer was called Polyamide 66 and its potential importance was soon recognized. The product was insoluble in common solvents and the melting point of 263 °C provided a comfortable margin of safety above commonly employed ironing temperatures. From then on, all development work was concentrated on nylon 66, and included, besides monomer- and polymer synthesis, also the development of melt spinning equipment, winding, drawing, etc.

The first commercial plant was announced in 1938, to be located at Seaford, Del. The original design capacity of 1500 mtpa was increased to 4000 mtpa already during the design stage. Early in 1940 the plant went on stream and the first nylon products were introduced on the market, mainly in hosiery, where the material resembled silk in hand and look but had superior mechanical properties, such as strength and elasticity.

At the same time, but fully independently, Paul Schlack was working at IG Farben in Germany on the basic research of polymers, with special emphasis on possible yarn applications.
On January 28, 1938 he synthesized a polyamide polymer by heating ε-caprolactam, using aminocaproic acid as a catalyst; the first nylon 6 polymer had been made!
The practical importance of requiring one monomer only was immediately recognized and after pilot production for some years, the first commercial production of nylon 6 filament yarns started in 1943 in Landsberg on the Warthe.

The introduction of nylon products on the market, type 6 as well as type 66, was very successful. Besides hosiery, many new fields of application were found and further exploited, nylon replacing silk and viscose rayon.

Figure 1 illustrates the growth of nylon fibre consumption since then, showing an actua consumption of about 3 million mtpa.
In the next paragraphs we will discuss in more

detail the present position of nylon in the various end markets and especially its future outlook here.

The discussion will be restricted to nylon 6 and nylon 66, as other nylons (e.g. 11, 12, 6 10) have never gained any significance in fibre applications.

2. Techno-economic evaluation of polyamide raw materials production

The production of nylon 6

Raw materials for nylon 6 are usually produced starting from benzene. All processes use the Beckmann rearrangement of cyclohexanone oxime to caprolactam as the most important reaction step. Differences exist only in the way the cyclohexanone oxime is produced from benzene, though all processes have to include a hydrogenation step to saturate the aromatic nucleus, an activation step for this nucleus to introduce the oxime group, and oxidation of ammonia to prepare nitrous oxides. These steps are found in all production sequences, though the order of execution may be different.

The main production schemes are:

a. The classical process and its modifications
b. The Toyo Rayon photonitrosation process
c. The Snia Viscosa process
Of these processes the classical process, with its modifications, is by far the most important. Figure 2 shows the reaction stages. The main raw materials used are benzene and ammonia.

The benzene is hydrogenated to cyclohexane, which is oxidized to produce cyclohexanone. The ammonia is oxidized to nitrous oxides, which are reduced to hydroxylamine. The cyclohexanone is reacted with hydroxylamine to yield the oxime. Caprolactam is produced from this oxime through the Beckmann rearrangement and purified.
In this scheme several variations are possible. In the first place, phenol may be chosen as an

intermediate between benzene and cyclohexanone, thus reversing the order of the hydrogenation and the oxidation steps. The reduction of the nitrous oxides to hydroxylamine used to be performed by means of sulphur dioxide, with as a consequence increased coproduction of ammonium sulphate. Modern processes use hydrogen for this reduction step.

A completely different approach to the production of cyclohexanone oxime is found in the Toyo Rayon photonitrosation process (Fig. 3). Here the oxime is prepared by a direct reaction between cyclohexane and nitrosyl chloride under the influence of actinic light. The cyclohexanone oxime is rearranged in the usual way. This process variant is very interesting from a chemical point of view, but the heavy cost incurred for the purchase and replacement of the mercury lamps needed and their electricity consumption are major disadvantages of this process.

In the Snia Viscosa process (Fig. 4), toluene is used as the basic raw material. Here we again find the usual oxidation and hydrogenation steps, but this time for the production of hexahydrobenzoic acid. This acid is reacted with nitrosylsulphuric acid to produce the oxime. From here the process is again conventional, though of course the purification has to be adapted to the impurities specific to the process route.

Generally speaking, all process routes may produce a good quality caprolactam, but due to the fact that in the first route the cyclohexanone and the hydroxylamine are both very pure, the purification costs for this process tend to be lower. There are, moreover, differences in investments relating to the more corrosive nature of the chemicals used in the latter alternatives.

The production of nylon 66

The production of nylon 66 monomers is more complex than the production of nylon 6, as here two compounds have to be produced: adipic acid and hexamethylenediamine.

Fig. 5 shows the process steps for the older adipic-acid route. It starts from benzene, which is hydrogenated to cyclohexane. This intermediate is oxidized to produce cyclohexanol and cyclohexanone in the same way as in the main nylon 6 route. To arrive at adipic acid this mixture is oxidized again, but this time with nitric acid. One half of the adipic acid is converted into adiponitrile. After hydrogenation of this nitrile, the product (hexamethylenediamine) is neutralized with the remaining adipic acid to produce nylon salt, from which nylon 66 is prepared through polycondensation.

When we compare this scheme with the production scheme for caprolactam it will be clear that the main difference is the second oxidation step, where nitric acid is used. Here an extra yield loss of around 8% is incurred, combined with a loss of two moles of nitric acid per mole of adipic acid, whereas in caprolactam manufacture the yield of caprolactam on cyclohexanone is almost quantitative (97%). This heavy loss in the adipic acid manufacture is one of the basic reasons why new routes for the production of hexamethylenediamine have been developed. These new routes produce adiponitrile, which is hydrogenated to hexamethylenediamine in the conventional way.

Figure 6 shows two of the modern alternatives: the acrylonitrile route, developed by Monsanto, and the butadiene route, developed by Dupont. In the former case acrylonitrile is dimerized in a complex electrolytic cell and hydrogenated at the same time to produce adiponitrile. In the latter case hydrocyanic acid is added to butadiene to give adiponitrile directly. Though the chemistry of these alternatives appears simple, the practical realization must be considered to be a difficult, high-level engineering achievement.

The consumption of raw materials

One of the most important aspects in the comparison of man-made fibres is the consumption of raw materials and energy in their production. Due to the sharp price increases for energy carriers, this consumption is growing more and more important as a cost price contribution. For this reason, a new tool has been developed to study this aspect: Energy analysis. In an energy analysis we calculate the total amounts of energy carriers consumed in the production process, starting from crude oil in the tanks of an oil refinery. For a consistent evaluation it turns out to be necessary to consider not only the quantity of energy carriers consumed but also their nature. From the discussion of the production processes it will be clear that in the case of polyamide production three types of energy carrier are important:

I. *Naphtha*-derived hydrocarbons: benzene, butadiene and propylene.
II. *Natural-gas*-derived chemicals: ammonia, hydrogen and hydrocyanicacid
III. *Utilities:* steam, electricity etc. The utilities can be coal or oil based.

Fig. 7 shows the result of the energy analysis for both polyamides. For nylon 66 we considered two production schemes: the adipic acid route, which is still used to a good extent, and the modern butadiene route. For nylon 6 we analyzed two situations: the more or less traditional plant as built in the early seventies and a modern plant using all new techniques developed in response to the energy price increases. From the comparison of the data it will be clear that nylon 6 has always been more energy-efficient than nylon 66. The modern butadiene route has narrowed the gap to the existing nylon 6 production plants. It will also be clear that modem production technologies can lower the energy consumption of the plants considerably, a tendency we often find in chemical and fibre industries. Figure 8 shows this effect clearly for both polyester fibres and polyacrylonitrile fibres, where reductions of 15-20% in energy consumption were possible through the use of either improved production schemes or better catalysts.

Proceeding with our analysis, we should now take a closer look at the three kinds of energy carrier consumed: naphtha, natural gas and the utilities. To convert them to a common basis, we should express them in another unit: the fuel oil equivalent, the calorific price paid for fuel oil.

The price of naphtha on a calorific basis turns out to be around 50% higher than that of fuel oil; natural gas has a premium of around 10% over fuel oil. The evaluation of the utilities is a rather complicated job. First, there will always be cogeneration of steam and electricity, which lowers the energy consumption for the electricity used. Secondly, the utilities could be either coal- or oil-based, coal having a calorific price around 50-60% of that of fuel oil. The penetration of coal in the utilities field is, however, still limited. Taking everything into account, we estimated the price of utilities to be around 70% of fuel oil. It should be noted, however, that especially the latter ratio is site-specific.
Using these conversion ratios we may now express the energy budget in a common unit: the fuel oil equivalent. For our type of industry this is the really important energy budget, as it is a good yardstick for our sensitivity to oil price increases (Fig. 9).

The differences between energy budgets are mainly due to differences in carbon efficiencies, as shown in Fig. 10. On closer inspection of the process schemes it turns out that the low carbon efficiency of the nylon 66 preparation is due to the carbon loss in the nitric acid oxidation of cyclohexanol and cyclohexanone to adipic acid, for which there is no equivalent operation in nylon 6 manufacture. This is especially important for the adipic-acid route. In the butadiene route this loss applies only to the adipic acid part of the nylon salt. In the preparation of the adiponitrile,an additional carbon loss occurs in the hydrocyanic acid preparation: For these basic reasons the carbon efficiency of the nylon 6 preparation is 5 to 10% higher than for nylon 66. In the case of nylon 6 the main loss in carbon efficiency is due to the oxidation of cyclohexane. If we use phenol as an intermediate, as shown in Fig. 2, the carbon efficiency could be further improved to 88%, but the investments needed then are higher than those for cyclohexane oxidation. With energy prices rising, however, this route could become attractive in the near future.

Investments in polyamide production

The second important parameter in the evaluation of the economics of polyamide production are the investments needed. Here a major difficulty arises, as in the case of nylon 66 two production plants are needed: the adipic acid plant and the hexamethylenediamine plant, whereas in the case of nylon 6 only one plant is needed: a caprolactam plant. For a fair comparison we should consider comparable production scales for both types of polymer. We use the so-called world scale: around 100,000 mtpa. The following capacities are considered: caprolactam = nylon 6 100,000 mtpa; adipic acid 100,000 mtpa, hexamethylenediamine 80,000 mtpa and -hence- nylon 66, 155,000 mtpa.

Figure 11 shows the capital investments needed for these polyamide plants. They cover not only the production plants proper, but also all auxiliary equipment needed, such as hydrogen plants, waste water treatment units, storage facilities, offices, etc.

It is clear that on the scale considered the investments per tonne of polymer are very similar. For nylon 6 the direct investment in the production plants is smaller than for nylon 66, as could be expected. This advantage is compensated for, however, by the heavier auxiliary investments needed, e.g. for ammonium sulphate crystallization and storage, oleum manufacture etc. Not included are the investments for ammonia production, as this chemical is assumed to be bought outside.

From these investments we calculate the fixed costs for polyamide production (labour, maintenance, depreciation and interest) to be 33% of the total investment per annum.

For the full cost price we now have to add the variable costs to the fixed costs (Fig. 12). In order to show how important the contribution of the energy carriers consumed is as a cost price factor, we made this calculation for two situations: for 1979, when the fuel oil price was around $ 3.8 per GJ, and for the present situation, with a price of 5.5 $/GJ.

From this table it will be clear that the cost price increase during this period is fully due to the increased price of fuel oil. Nowadays 40-50% of the cost price is accounted for by the energy carriers consumed in the production of the polyamides. The cost price differences between nylon 66 and nylon 6 are fully accounted for by the differences in raw material consumption and thus by the differences in carbon efficiency! Whether this difference can be compensated for by differences in physical properties between the two polymers will be the subject of the next part of this presentation.

3. Present status and future outlook of nylon markets

Three main fields of application can be distinguished in the nylon fibre markets, viz. apparel, home furnishing (including carpets) and industrial.

The subdivision of nylon fibre consumption into these markets, as shown in Fig. 13, reveals significant differences for the geographical areas concerned.

In W.Europe and the USA the home furnishing market takes the major portion of total nylon fibres consumption. Apparel is also an important outlet and industrial fibres, mainly tyre yarns, are third with 15%.

Countries outside W.Europe and the USA, for simplicity presented as 'rest of the world', show a different picture. Here, apparel is the major outlet. Industrial yarns are also important (and growing) with 25% of total nylon consumption. The share of carpet yarns is still small but its future potential should not be underestimated. The present position of nylon in these three main sectors and its future outlook will now be discussed.

Apparel

The first nylon fibres were used mainly in apparel, the traditional textile outlet. The total apparel market is still of enormous proportions, with more growth to come, to fulfil the basic needs of an increasing world population.

The role of nylon in the total apparel market is limited to its use in filament yarns, where it has found its place beside the other synthetic fibres in applications where its specific properties are optimally exploited.

In Figs. 14 and 15 the apparel market in W.Europe and the USA is broken down into the various end-uses, and the position of nylon relative to other synthetic fibres with respect to these end-uses is indicated.

Various sectors can be distinguished where nylon has developed a leading position despite strong competition, especially pricewise, from polyester and acrylics over the past years.

A typical common element in these nylon applications is the fine denier of the yarns applied. For example, the average nylon textile yarn denier in the USA in 1980 was about 45 dtex, whereas the average polyester filament yarn denier amounted to 120 dtex. Fine-denier nylon yarns combine high strength with good elasticity and are therefore particulary suited to the high speed knitting process. The fabrics so produced are sheer, light-weight and have a silk-like appearance. Some examples:

Women's hosiery, which includes stockings and panty-hoses, is fully dominated by nylon filament yarn and monofilament fibres, with a market share of more than 90%.
Nylon's strength, elasticity, abrasion resistance and silk-like hand are important in this sector. Also its excellent ability to reassume its original shape after strong deformation should be mentioned, besides outstanding texturizing properties and stretch-behaviour.

The future position of nylon in this sector seems unchallenged, as other materials cannot match nylon on these specific points.

The same applies to some extent for the group of *anklets and socks.* Nylon is often used here, in conjunction with other fibres, to increase abrasion resistance and elasticity properties, acrylics or wool enhancing softness and moisture absorbance properties. Essentially all nylon filament yarn is texturized in this sector to impart stretch and bulk.

In *underwear, nightwear* and *foundation garments*, nylon filament yarns constitute about 70% of the total of fibres used.
Principal fibres in competition with nylon are acetate yarns, polyester and cotton.

Again the excellent hand and feel of fine-denier nylon filament yarns, together with the good elasticity, explain the consumer appreciation of nylon in this end market.

Swimwear should be mentioned as a typical market where the product properties are fully utilized, together with *sportswear* in a broad field.

Besides the applications mentioned, nylon has found its place in many end-uses where abrasion resistance, strength and coloration are important features. Together with the outstanding stretch recovery performance, important in the textured yarn area, these features have given nylon a strong position in many outlets of the apparel market.

Home furnishing, household
In the home furnishing/household sector, especially the carpet market has grown to enormous proportions. Fig. 16 shows that about 2.3 billion square meters of carpet are produced yearly, which is equivalent to the use of approx 1.3 million tonnes of carpet face fibres.

What materials are preferably used in carpets and what are the criteria for their use?

Fig. 17 gives a survey of important points and compares the performance of various textile materials available in the market.

In appearance, nylon closely resembles wool and acrylics thanks its dyeability/printability properties. As to wear properties, nylon scores high due to its excellent resilience: nylon carpets easily regain their original shape after being subjected to mechanical load, for example footsteps or a piece of furniture, which is an extremely important feature for especially carpeting of hotels, office buildings and the like, the so-called contract carpeting.

The moderate behaviour of nylon regarding build-up of static electricity has been fully overcome by the development of anti-static types, based on chemical additives or, most successfully, the incorporation of one conductive filament in the fibre bundle. This conductive filament can be either metal, a metal-coated synthetic fibre or a polymer-coated carbon fibre.

Easy-care properties like cleanability and soil-hiding behaviour also have to be mentioned as aspects where new developments have brought further improvement.
The excellent abrasion resistance of nylon, already mentioned for apparel, make a nylon carpet long-lasting;a good position with respect to 'economic factors', in particular competitive pricing in comparison with wool, is the result.

This overall price/performance picture is reflected in the market position of nylon. Fig. 18 shows the historical development of the various fibre materials in W.Europe; USA figures are more or less similar and the survey may be typical for the carpet industry in developing countries in the near future.

Acrylics have lost considerable market share due to moderate durability and resilience behaviour. Wool has a stabilized position in the high-price, high- quality range of carpets, where consumers primarily seek a fine, comfortable carpet. Polyester has never gained the popularity expected at its introduction. Moderate dyeability in combination with poor resilience are

the basic drawbacks of this fibre, and its market is expected to stay low. The future of polypropylene in carpets is as yet uncertain. Major advantages esp. regarding cost price, are combined with major disadvantages, such as non-dyeability, necessitating the use of pigments.

Nylon offers the best combination of properties and its position as the dominant carpet face fibre is therefore unchallenged. Future developments with anti-static, anti-soiling and variable cross-section will further strengthen its position. Although a small market in developing countries yet, the future growth will be considerable. Therefore, its significance should not be overlooked.

Industrial fibres

Tyre yarns are by volume the most important segment of the industrial yarn market, with a large number of smaller applications, such as V-belts, hoses, fishing-nets, cables, etc., as a balance.

Global tyre yarn consumption has shown a significant growth over the last decade, initiated by the increase in the number of passenger cars as well as trucks. Increased tyre-mileage by improved tyre constructions has to some extent slowed down this growth. Still, especially in developing countries, where trucks are the most common mode of freight transportation, tyre yarns represent a significant growth market.

Commercial tyres were orginally reinforced with cotton or rayon. Soon after the invention of nylon, its potential for tyre reinforcement was recognized and the application in this area started. Today a wide variety of materials, including polyester, glass and steel are used beside nylon.

In tyres two principal designs can be distinguished, viz. the conventional cross-ply tyre and the radial tyre.
The typical properties of the two tyre types are set out in Fig. 19.

In the cross-ply tyre the woven fabric of reinforcing fibre is laid down in diagonal direction from one side of the tyre to the other. A second fabric is positioned at opposite bias to give uniform properties in all directions. In this construction, belt and carcass of the tyre are reinforced by the same fabric.

In the radial tyre concept, carcass reinforcement is realized by one fabric, laid down in radial direction, while a second fabric-which can be made of a different material-is laid down in axial direction in the belt for reinforcement of the tread. The difference in design results in different demands on the reinforcing materials, as shown in Fig. 20, where the preferred materials are listed.

In *cross-ply tyres* nylon is widely used; high strength, good elasticity and especially outstanding fatigue properties explain its position. In truck tyres, where product requirements are strong and tyres must be able to handle heavy load, nylon is used exclusively.

Optimum *radial tyre* design requires a stiff material for belt reinforcement, which explains the predominant position of steel for this purpose. For carcass reinforcement again nylon comes into play when high quality tyres are needed for operation under difficult conditions for long periods. Fig. 21 shows an estimate of tyre yarn consumption in developing countries, steel and nylon being future winners as tyre reinforcing materials.

Conclusions regarding markets for nylon

The product developments in the various end uses dealt with above have resulted in a considerable increase of synthetic fibre production.

Fig. 22 gives a survey of the history since 1970 and includes a projection by our marketing research department up to 1990.

The figures show that synthetic fibre production in W.Europe has stabilized, partly under the influence of increasing imports. The USA shows some growth,which, as far as nylon is concerned, applies mainly to carpet yarns.

Latin America and the Middle and Far East will have the highest growth rates. For nylon, this growth will mainly concern apparel and industrial uses.

Worldwide, an increase of nylon fibre production to 3.8 million mtpa in 1990 is expected, which is 0.7 million mtpa above the present level.

4. Comparison of nylon 6 and nylon 66

Since the commercial introduction of nylon 6 and nylon 66 in the forties, the production capacities for both products have been extended at roughly the same rate. This remarkable fact is a first indication of the overall similarity in properties between the two products. However, in details some differences can be noted, which will be briefly discussed.

Raw materials position

The cost price advantage of nylon 6, on account of the structurally lower energy consumption and a more favourable scale of production (one monomer instead of two for nylon 66) has already been discussed in the previous paragraph.

Whereas caprolactam can easily be stored for a long time, enabling world-wide transportation, nylon 66 salt is less stable. This explains why nylon 66 monomers have always been produced captively, close to the polymer production sites involved. This has resulted in a relatively small number of nylon 66 producers with often captive use of the materials: more than 80% of the world nylon 66 salt consumption is covered by 5 (yarn) producers.
By contrast, more than 40 producers are active in caprolactam production, sometimes directed towards local markets but also active in export. Their wide geographical distribution ensures the world-wide availability of the material.

Technology of polymer and yarn production

Nylon 6 polymer production is carried out in one-stage continuous reactors operating at atmospheric pressure. Thanks to the stable nature of the polymer, reactor design can be simple and running times (without intermediate cleaning) are as long as 2-3 years.

Nylon 66 polymerization is less simple; due to the higher degradation propensity of nylon 66, resulting in a higher evolution of degradation products and higher cross linking tendency, advanced equipment is required if reliable continuous polymerization is to be carried out. In practice, therefore, the batch process is used in most cases. Even then, more frequent cleaning will be necessary.

As an advantage of nylon 66 the 100% conversion during polymerization should be mentioned. Nylon 6 has a maximum conversion of 90% as a result of equilibrium reactions. However, the non-converted monomer can easily be separated from the polymer and recirculated to the polymerization process. In this way an overall yield close to 100% is reached.

The spinning and drawing processes for nylon 6 and nylon 66 yarns show only small differences. In general, nylon 66 processing conditions are more critical due to the high rate of crystallization (danger of spherulite formation) and the higher degradation rate in the melt, requiring special spin-pack design and higher replacement and cleaning frequencies. Furthermore, hot drawing is always preferred for all nylon 66 yarn types; nylon 6 textile yarns can satisfactorily be cold-drawn.

As a final point, waste recovery should be mentioned, especially the handling of the yarn waste inevitably produced in a synthetic fibre plant.
Both nylon 6 and nylon 66 yarn and polymer waste can be depolymerized with steam, if appropriate catalysts are applied.
Whereas caprolactam can simply be purified and recirculated to the polymerization process, nylon 66 salt recovery is more complicated, and therefore more costly.

Product properties
The physical and mechanical properties of nylon 6 and nylon 66 polymer and yarn are fully identical in many respects, e.g. tenacity, elongation at break, resistance to chemicals, fatigue, etc.

The melting point of nylon 66 is 40 °C higher than that of nylon 6; other small differences can be explained from the physical structure of the yarns. An example is the greater micro-porosity and hence better accessibility of nylon 6, which explains the faster and easier dyeing.

This similarity in properties explains why both products are used side by side in many applications.

For apparel and home furnishing, nylon 6 and nylon 66 are considered to be fully interchangeable.
Sometimes the better dyeability of nylon 6 is mentioned as an advantage; on the other hand, nylon 66 is sometimes preferred for its texturizing properties. However, the use of adapted processing conditions will overcome possible differences, so that on the whole there is no reason to prefer either of the two materials.

The same is true for the majority of industrial yarn applications. Tyres with nylon 6 yarns perform the same as nylon 66 based tyres, because relevant properties, such as fatigue and strength, are equal. The higher melting point of nylon 66, which gives a somewhat better heat stability at high temperature, does not play a role, as the operating temperatures of a tyre, even at high speeds or heavy loads, are always considerably below the level where these differences occur. The higher melting point for nylon 66 may be a small advantage for the tyre producer because the safety margin during the curing of a tyre is somewhat wider. However, when appropriate processing conditions are used no problems will be encountered for either material.

Conclusions

The overall comparison of price-performance ratios for nylon 6 and nylon 66 suggests that the two are in equilibrium. The cost disadvantage of nylon 66 as compared with nylon 6 is in actual practice to some extent compensated for by the larger scale of production of nylon 66 by a small number of producers. This explains why both materials have been used side by side during the forty years since their commercial introduction.

Fig. 23 illustrates the historical development of the market shares for nylon 6 and nylon 66.

Nylon 6 has increased its world-wide market share in the polyamide market from 55% to 62%. This increase is mainly due to the cost advantages for nylon 6 monomer, the better accessibility of the production technology, and the good availability of the raw materials needed.

The future evolution will be in line with the historical developments and thus a further increase of the market share for nylon 6 is to be expected.

Fig. 1

World fibres production 1940-1980

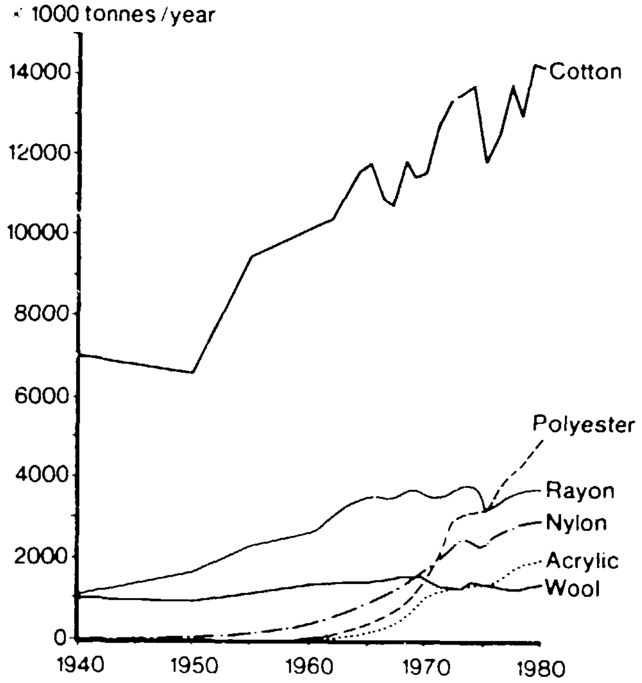

Fig. 2

Productionscheme for Nylon 6

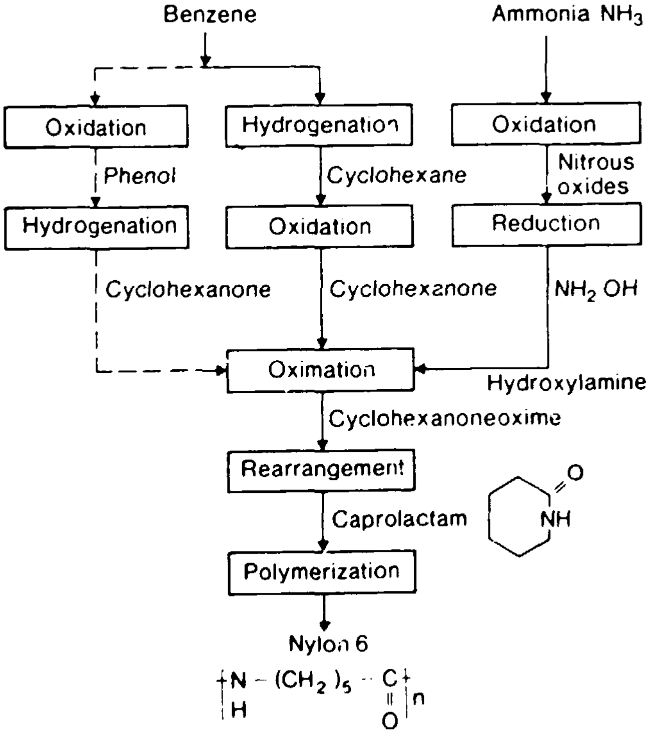

Fig. 3

Toyo Rayon photo nitrosation process

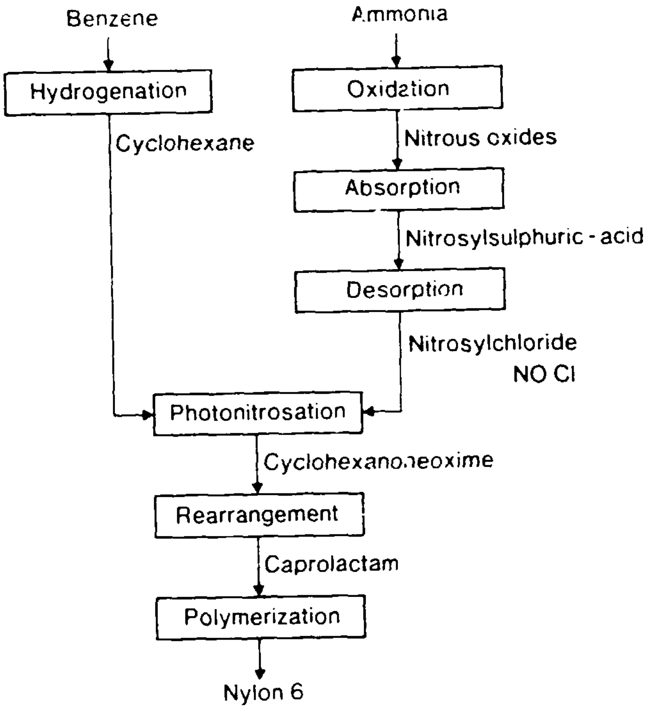

Fig. 4

Snia Viscosa process

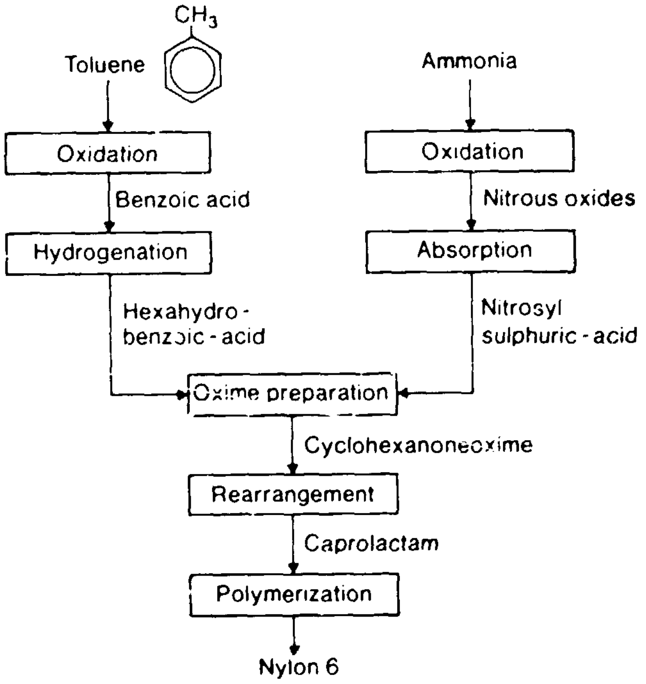

Fig. 5

Productionscheme for Nylon 66
Adipic acid route

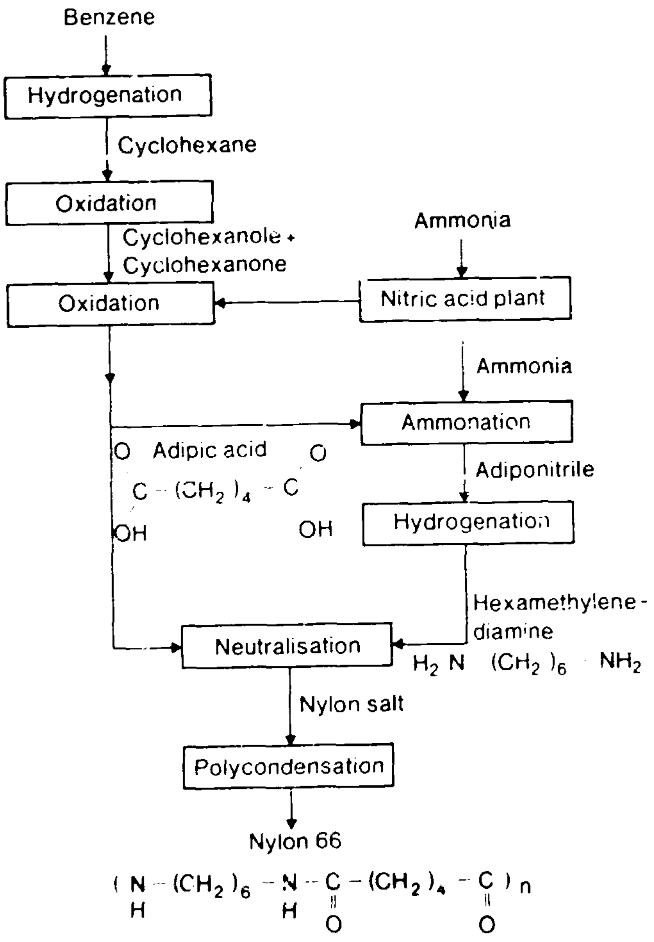

Fig. 6

Alternative routes to adiponitrile

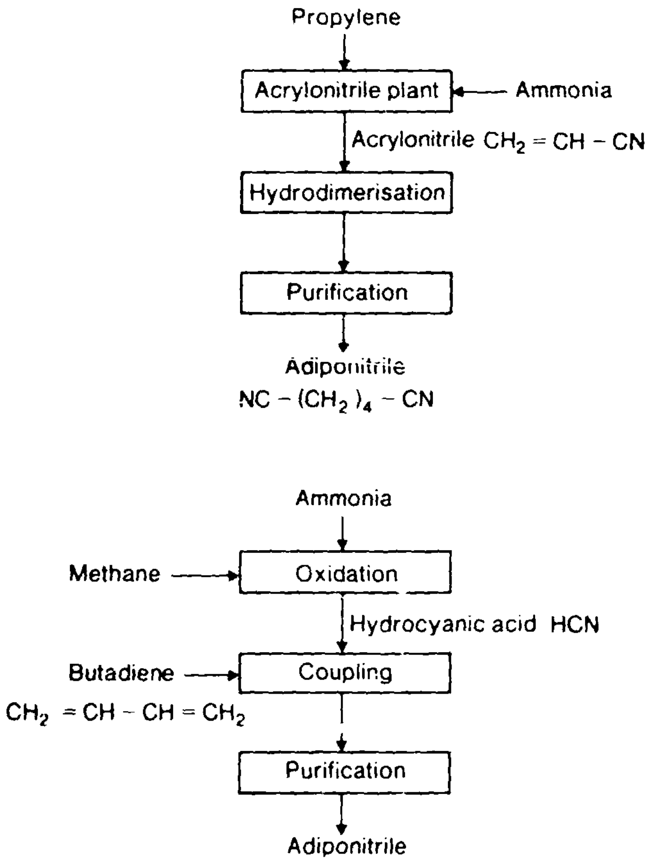

Fig. 7

Energy budgets for man-made fibres in GJ/tonne

	Nylon 66		Nylon 6	
	Adipic route	Butadiene route	Present plants	Future plants
Naphtha	67	54	63	60
Natural gas	31	39	39	25
Utilities	100	69	51	40
Monomer	198	162	153	125
Polymerization	13	13	14	14
Spinning	34	34	31	31
Fibre	245	209	198	170

Fig. 8

Energy budgets for man-made fibres in GJ/tonne

	Polyethylene Terephthalate		Polyacrylonitrile	
	DMT route	TPA route	Older catalyst	New catalyst
Naphtha	47	45	95	65
Natural gas	2	2	18	17
Utilities	89	65	13	8
Monomer	138	112	126	90
Polymerization	26	22	48	48
Spinning	40	40		
Fibre	204	174	174	138

Fig. 9

Energy budgets for polyamides

(expressed in GJ/tonne resp GJ-fuel-oil equivalents per tonne)

	GJ/tonne (Table 7)	Fuel oil equivalents GJ/tonne
Nylon 66		
Adipic route	245	236
Butadiene route	209	205
Nylon 6		
Present plants	198	205
New plants	170	177

Fig. 10

Carbon efficiencies in polyamide production

	Carbon efficiency	Energy budget
Nylon 66		
Adipic route	66 %	236 GJ
Butadiene route	71 %	205 GJ
Nylon 6		
Cyclohexane route	75 %	177 GJ
Phenol route	88 %	155 GJ

Fig. 11

Capital investments for polyamide production in $\$ \times 10^6$

	Nylon 6	Nylon 66	
		Adipic route	Butadiene route
Capacity	100,000 tonnes/year	155,000 tonnes/year	155,000 tonnes/year
Investments			
within battery limits	154	270	250
auxiliary investment	171	235	260
Total	325	505	510
Investment per tonne of polymer	$ 3250	$ 3260	$ 3290
Fixed costs per tonne of polymer	$ 1073	$ 1076	$ 1085

Fig. 12

Cost-price structure of polyamides

	Nylon 6	Nylon 66	
		Adipic acid route	Butadiene route
Energy budget (F.O. equivalents)	177 GJ	236 GJ	205 GJ
Fuel oil: $ 3.80/GJ (1979)			
Energy costs	$ 673 = 34 %	$ 897 = 41 %	$ 779 = 37 %
Variable costs	$ 927 = 46 %	$ 1127 = 52 %	$ 1029 = 49 %
Integral costs	$ 2000 = 100 %	$ 2203 = 100 %	$ 2115 = 100 %
Fuel oil: $ 5.50/GJ (1981)			
Energy costs	$ 974 = 41 %	$ 1298 = 49 %	$ 1128 = 45 %
Variable costs	$ 1305 = 55 %	$ 1579 = 59 %	$ 1420 = 57 %
Integral costs	$ 2378 = 100 %	$ 2655 = 100 %	$ 2506 = 100 %

Fig. 13

Subdivision of nylon fibres markets

	W. Europe	USA	Rest of world
Apparel	35 %	25 %	70 %
Home furnishing + household	50 %	60 %	5 %
Industrial applications	15 %	15 %	25 %
	100 %	100 %	100 %

Fig. 14

Synthetic fibres in apparel

W. Europe 1972 - 1978

	share of synthetic fibres in apparel	break-down of total synthetics consumption		
	percentage of total synthetics	poly-ester	acrylic	nylon
1. Sweaters	36 %	8 %	85 %	7 %
2. Skirts, dresses, suits, trousers	23 %	80 %	15 %	5 %
3. Footwear	16 %	-	15 %	85 %
4. Underwear Nightwear	8 %	25 %	5 %	70 %
5. Blouses shirts	7 %	75 %	20 %	5 %
6. Wind-cheaters Rainwear Sportswear	5 %	60 %	10 %	30 %
7. Linings	3 %	15 %	-	85 %
8. Swimwear	2 %	10 %	-	90 %
	100 %			

Fig. 15

Nylon shipments [illegible], apparel, 1980

	x 1000 tonnes/yr
hosiery	28
anklets and socks	20
sweaters and accessories	5
underwear	18
nightwear	21
foundation garments	6
robes and loungewear	11
swimwear	5
other top weights	17
other bottom weights	40
other apparel	7
total	178

Fig. 16

World carpet production, 1980

		mill. m^2
W. Europe		711
E. Europe		238
USA/Canada		1050
Latin America		42
Japan		136
Oceania		48
Rest of world	abt.	40
		2265

Fig. 17

Survey of properties of carpet face fibres

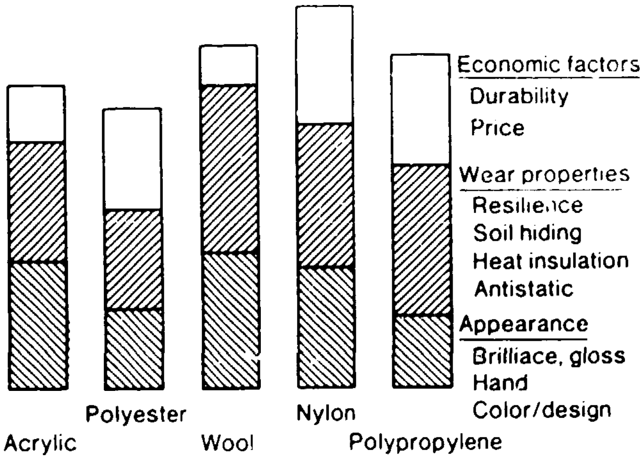

Fig. 18

Market position of fibres in tufted carpets W-Europe

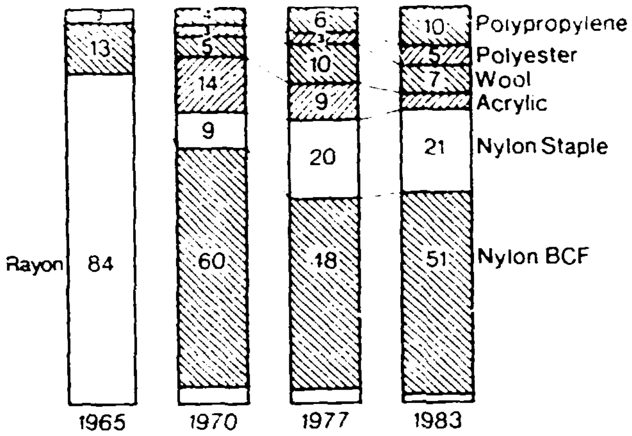

Fig. 19

Comparison of cross ply and radial tyre

Cross Ply	***Radial***
- less sensitive to carcass damage	– high life-time
– comfortable driving at low speeds and under bad road conditions	– under good road conditions and at high speeds better driving properties lower friction, less fuel consumption
– low manufacturing costs	

Fig. 20

Major tyre reinforcement materials

	passenger car tyres	truck tyres
cross-ply tyre	nylon rayon polyester	nylon
radial tyre		
· belt	steel	steel
· carcass	nylon rayon polyester	nylon steel

Fig. 21

Tyre yarns in rest of world

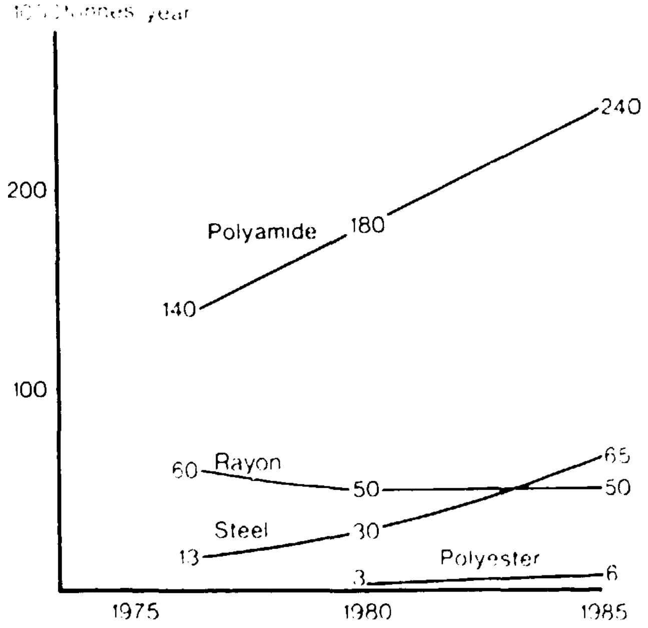

Fig. 22

World synthetic fibres production 1970 - 1990

	(x 1000 tonnes/year)				
	1970	75	80	85	90
W.Europe					
Nylon	599	630	647	650	650
Polyester	459	682	762	820	860
Acrylic	399	540	732	770	800
USA					
Nylon	614	843	1070	1250	1400
Polyester	666	1358	1809	2200	2550
Acrylic	223	238	354	390	420
Japan					
Nylon	303	279	318	325	325
Polyester	309	445	625	670	700
Acrylic	263	243	353	365	375
East Europe					
Nylon	181	355	494	575	635
Polyester	91	280	456	725	900
Acrylic	74	163	227	320	400
Latin America					
Nylon	117	175	230	280	325
Polyester	75	250	383	520	660
Acrylic	19	66	114	150	180
Middle and Far East					
Nylon	89	207	366	450	520
Polyester	45	351	1097	1540	1950
Acrylic	25	141	303	385	465
Total world					
Nylon	1903	2489	3125	3530	3855
Polyester	1645	3366	5132	6475	7620
Acrylic	1003	1391	2083	2380	2640
Other (olefins etc.)	550	825	1250	1450	1700

Source: DSM Marketing Research Organic Products.

Fig. 23

Production of nylon 6 and 66 fibres

	1970			1975			1980		
	66	6	6+ 66 (T/yr)	66	6	6 + 66 (T/yr)	66	6	6+ 66 (T/yr)
W.Europe	52 %	48 %	599	52 %	48 %	630	47 %	53 %	647
USA	71 %	29 %	614	67 %	33 %	843	67 %	33 %	1070
Japan	2 %	98 %	303	9 %	91 %	279	9 %	91 %	318
E.Europe	5 %	95 %	181	3 %	97 %	355	2 %	98 %	494
Latin America	52 %	48 %	117	44 %	56 %	175	42 %	58 %	230
M. and Far East	28 %	72 %	89	15 %	85 %	207	10 %	90 %	366
World	45 %	55 %	1903	42 %	58 %	2489	38 %	62 %	3125

Source: DSM Marketing Research Organic Products.

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POLYAMIDE FIBRES—PRODUCTION, PHYSICAL PROPERTIES AND USE

B. v. FALKAI, BAYER AG, *WEST GERMANY*

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DR. BELA VON FALKAI, born in Budapest, studied Chemistry at the Technical University of Budapest. During the World War II, he worked in a research institute for plastic materials in Hungary. He took the degree in 'Doctor rer. nat' in Mainz under the guidance of Prof. S. A. Stuart. Since 1956, he is working in the fibre division of Bayer AG in Dormagen. In 1961, he got the management of technical research spinning department and eight years later became the Head of the research laboratories and in 1970, got the degree of a confidential clerk. In 1973, he has the mastership for man-made fibres at the University of Stuttgart. In 1981, his book 'Synthesefasern' was edited by Verlag Chemie. His main fields of scientific work include physical and textile technological characterisation of man-made fibres and the technology of fibre production.

Synopsis

The paper discusses the production of Polyamide fibres starting from the Monomer and polymer manufacture, spinning of the polymer, drawing and after treatment. The Conventional methods of High-speed spinning and spin-drawing have been dealt with. The important physical properties have been highlighted with their possible applications.

Because of the very interesting properties and possibilities of modification, polyamide fibres and filament yarns are very important class of fibres which help to meet man's effective demand for textiles.

POLYAMIDE FIBRES — PRODUCTION, PHYSICAL PROPERTIES AND USE

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Introduction

The linear polyamide of ϵ-aminohexanoic acid was described back at the turn of the century in work on ring-closure reactions of ω-aminocarboxylid acids. It is natural that, as the level of technology stood at that time, the enormous significance of this polymer for the production of high-quality synthetic fibres was not recognized. It was only the comprehensive, systematic work by W. H. CAROTHERS and his colleagues about linear polyesters and polyamides, which was begun in 1929 at the firm DuPont in the U.S.A., that led to the discovery of filament formation from melts of high-molecular weight polycondensates and to the realization that the solid filaments could be hardened by a cold-drawing process. In 1938, plans were drawn up in the U.S.A. for manufacturing the synthetic polyamide fibre, nylon 6.6, the polycondensate from adipic acid and hexamethylene diamine. Within the space of 3 years, an excellent team succeeded in making the machines required for producing the fibre and developing a suitable technology. Production was started by the melt-spinning process, with use also being made of the know-how from glass-fibre production. A special phenomenon was that, for the first time, it was noticed that the polyamide fibres could be cold-stretched. Production was increased during the war to 15,000 tonnes per year. Nylon only became available to the general public, however, after the war.

The polyamide fibre based on ϵ-caprolactam, which was developed at about the same time in Germany by P. Schlack, did not come into industrial production until the beginning of the fifties because of the effects of the war.

The annual world production of polyamide fibres grew exponentially during the first three decades, although the 3 - 4 years which it took in the fifties for production to double took 5 - 6 years in the sixties. As can be seen from Table 1, the annual increase in production slowed down even further after 1970. It is the polyamide 6 and 6.6 which account for the vast majority of polyamide fibre production. Whereas, in 1953, the proportion of polyamide 6 fibre was only 9 % (polyamide 6.6 = 91 %), the production figures during recent years have moved very much in favour of the polyamide 6 fibres (production in 1978, approx. 55%). Alongside these polyamide types, which are the most important economically, a few other polyamides have become established for special application (1).

1. The production of polyamide fibres

1.1 Monomer and polymer manufacture

The raw materials of synthetic fibres in general and, accordingly those of the polyamides as well are essentially intermediates from petrochemistry. It is from these intermediates that the monomers are produced which, because of their reactivity, are suitable for the production of fibre-forming linear macromolecules.

The following types of reaction have achieved technical significance for the formation of polyamides:

(a) polycondensates from dicarboxylic acids and diamines,
(b) polycondensates from ω-aminocarboxylic acid with more than four CH_2 groups,
(c) polycondensates from lactams with more than six ring-links.

Despite the extreme variability of these reaction types, it can be seen from the few properties of various polyamides summarized in the next table (Table 2) why the two polyamides with the border round them have been able to establish themselves best of all in the textile and technical sector:

> the raw material basis is available for production of the monomers adipic acid and hexamethylene diamine or caprolactam. Fibre production is relatively simple. The melt points of the two polymers are suitable for fibre production, further processing and for the actual use of the textiles. The specific gravity is interestingly low, without being so low that it might also cause problems.

We shall now discuss the various industrial methods of synthesis used in the production of monomers for nylon and polyamide 6:

Fig. 1 shows the most important way of producing the AH-salt (adipic acid + hexamethylene diamine) for nylon.

The starting material can be *benzene, butadiene or acrylonitrile.* The monomer is produced by the following reaction stages:

(a) **The benzene route:**

benzene → hydration to cyclohexane,
→ oxidation to cyclohexanol/cyclohexanone,
→ atmospheric oxidation to adipic acid

(b) **The butadiene route:**

C_4 fraction of the LDF pyrolysis, extraction dehydration butane to *butadiene*

butadiene → hydroxyanic acid addition in the presence of a zerovalent Ni-complex catalyst according to a process from DuPont

→ hydration of the adiponitrile to HMDA

(c) **The acrylonitrile route:**

acrylonitrile— **hydrodymerization** on Pb electrodes to **adipoinitrile**

→ hydration of the adiponitrile to HMDA

It is these three basic products, benzene, butadiene and acrylonitrile, which are of the greatest market interest for producing the adiponitrile. (The future outlook for benzene is poor, since aromatics have to be added to petrol.)

Polycondensation of the AH-salt is carried out in a 60% aqueous solution in the autoclave under N_2 under 275° - 280° C. The first step is pre-condensation under pressure, the second step polycondensation for 10 - 16 h under vacuum.

The next diagram (Fig. 2) shows different methods of *producing caprolactam:*

Starting materials are

toluene → oxidation to benzoic acid, hydration (200 atm, 160 - 170° C, Ni) to give hexahydrobenzoic acid, reaction with nitrosyl sulphuric acid to give caprolactam)

benzene → via cyclohexanone, nitrosyl chloride to the oxime, the process provides less ammonium sulphate because of the omission of hydrazone sulphate

phenol → as from benzene via cyclohexanone oxime. For the production of 1 t caprolactam, 4.5 t ammonium sulphate occurs as accidental by-product.

cyclohexanone→oxidation with peracetic acid or hydrogen peroxide to give caprolactone, reaction with ammonia.

Ammonium sulphate is almost impossible to dispose of in the industrial countries as a fertilizer. Therefore the trend towards processes which avoid the oxime stage (2).

Polymerization of the caprolactam: 80 - 90% aqueous solution, autoclave 250 - 260° C, N_2 or by a continuous process which will be discussed later.

For synthesizing the spinning raw materials from the monomers, work was done at an early stage on continuous methods. The next illustration (Fig. 3) compares the various types of processes based on the example of nylon.

In the first phase of development, the discontinuous process (1) fully complied with the requirements. Since, unlike AH-salt, ϵ-caprolactam can be continuously polycondensed relatively easily, a process of this kind was developed and introduced on an industrial scale as long ago as the early fifties (processes 2 - 4). The development of continuous extraction and drying (process 3) made it possible to reduce the costs of polymer production even further. Finally, methods that could be used on an industrial scale were found for vacuum extraction in the metl, as a result of which direct spinning of the polymer (process 4) was achieved.

With this latter process, it is possible to achieve the lowest production costs, particularly with large through-puts. The problem is however, that the process is not as variable as the other methods (1 - 3). For this reason, direct spinning is used above all for producing staple fibres. It must not be forgotten that a breakdown in a fully automatic process interrupts the entire production line.

During continuous vacuum extraction, a large part of the monomer is removed from the polymer melt, which consists of several components and remains in equilibrium. This intervention in the kinetics of polycondensation is a deep one and is not so easy to handle as far as control and instrumentation are concerned as in the discontinuous method. In the case of process 2 and, to a certain extent, also process 3, the individual steps in the process can be run at the most favourable kinetic conditions, which makes control and instrumentation of the process very much simpler (3).

1.2 Spinning the polymer

Apart from the polyamides from β-lactams, which have to be spun from solutions, the economically important polyamides are spun in the melt flow at temperatures up to approx. 300° C.

Particularly in the case of polyamide 6, the extruder has succeeded over recent years in gaining further ground over the melting grid as a melting device. Besides the shorter dwell time of the melt, the homogenization and the reduced post-condensation, the main advantage of the extrusion process lies in the large melting capacity, which amounts to about 6 - 8 t per day for a screw diameter of D = 150 mm. For melting polyamide granules, screws with a length of 20 - 30 D are preferred. An additional mixing zone following on from the compression zone improves the homogeneity of the melt and enables the throughput to be increased. After this, the polyamide melt is fed at constant temperature and regulated pressure to the spinning positions. Differences in dwell time, which come about as a result of the parabolic velocity distribution as the melt flows in the pipelines, are best compensated by static mixers. Irregularities in the polyamide melts cause differences in dye affinity, especially with filament yarns. It has been possible during recent years to improve not only the economy and reliability of the equipment, but also the quality of the spun products (4).

1.3 Drawing

1.3.1 Conventional method

The filaments spun at normal spinning velocities have, in the undrawn state, a high degree of deformability due to the low orientation of the chain molecules (e.g. with polyamides 400 - 500 % elongation). One of the most important stages in aftertreatment is therefore the drawing, by which the filament is given the necessary strength while, at the same time, the elongation at break and single fibre titre decrease. The chain molecules are oriented by stretching in the longitudinal fibre direction — a process which was initiated during conventional spinning through the draft. Figure 4 shows the drawing process in schematic form.

From the spinning bobbin, the filaments are wound several times over the top godet and finally below the lower drawing godet. Through the tension on stretching, the filaments begin to constrict at one point — the neck point (Fig. 5). In this actual stretching zone, the entangled chain molecules come apart and the unordered molecules lay themselves in the direction of the filament. This now enables the transverse forces (e.g. hydrogen bridges in the case of polyamides) to fully form between the chains, which were previously only effective at particular points. Where the chains are connected by bridges of this kind, they adhere more strongly to one another. The filament gains high strength, one of the most important properties of synthetic fibres.

The next illustration (Fig. 6) shows a finished spinning bobbin on removal from the spooling device.

Staple fibres are spun from the same spinning melts and on the same machines as filament yarns. However, whereas with the spinning of filament yarns each bundle of filaments runs individually onto one bobbin, the filaments for the production of staple fibres come together from a number of spinnerets, which usually have a large number of holes, to form a "tow". When drawing, several thin spinning tows are combined into a thick sliver, taken to the drawing section and then, in one operation, heated up, drawn, crimped and, depending on the type of fibre, suitably heat-set. After this, they are either cut into staple fibres and pressed into bales or coiled uncut in cardboard boxes as stretch-broken tow.

1.3.2 Spin-drawing

As with polymer production, economic reasons led at an early stage to attempts to carry out the spinning and stretching process in one operation without interruption.

The so-called *spin-stretch process* has been used for decades now for the production of regenerated cellulose fibres. It has also been state of the art for some time now for the spinning of polyamide and polyester monofilaments and bristles. As far as the production of textile filament yarns is concerned, it was not until the beginning of the seventies that the designers succeeded in achieving on an industrial scale the high final, winding speeds and, on the other hand, it was believed that, for example a definite period of time between spinning and drawing would result in advantages as regards the quality of the polyamide 6 end-product.

With the usual spinning velocities for the textile titres up to 220 dtex of around 1000 - 1400 m/min, the winding speed with stretching directly afterwards must be 4000 m/min. in line with the draw ratio of about 1 : 3 to 1 : 4.

The spin-stretching or spin-drawing process, in which the filament after take-off from the godet is stretched without interrupting the course of the thread (Fig. 7), is now used on an industrial scale for multifilament spinning, particularly for the production of textile titres 78 dtex and for the production of high-titre technical silk at winding speeds of between

2200 and 3600 m/min. The condition for this was a command of the high winding speeds, which has existed since the beginning of the seventies (5).

1.3.3 **High-speed spinning**

Since the production capacity of a spinning mill can be increased by raising the take-off speed, there has been no lack of attempts to establish, on the one hand, the limits of this possibility and, on the other, to examine the influence of this increase in speed on certain fibre properties.

It was observed very early that, in the case of polyamide 6 fibres for example, the drawability expressed in the degree of drawing drops by 0.13 - 0.15 as a result of increasing the take-off speed by 100 m/min. From a straight-line extrapolation, this would mean that the filament would be fully stretched as from about 2500 m/min. However, since there is no linear relationship between take-off velocity and residual draw at higher take-off speeds, it is only possible to obtain completely drawn fibres at very much higher take-off speeds.

In the first half of the sixties, there was no spooling element available, which could be used on an industrial scale for this "high-speed spinning process". When, at the beginning of the seventies, winding machines with speeds of up to 4000 m/min. and above were developed for spin-drawing, they also became increasingly used for high-speed spinning.

The possibilities and the limits of this process were re-examined and it was found that, with high-speed spinning, the throughput capacity per spinneret is increased by approx. 30 % compared with normal spinning, while the residual draw is reduced. The next diagram (Fig. 8) shows the change in throughput and residual draw for nylon and polyamide 6 filament yarn (6).

The increase in throughput is appreciable up to a spinning velocity of 2000 - 2500 m/min, but at higher speeds the gain is relatively small in view of the higher repair and energy costs, even though it does differ from one fibre to another.

For this reason, it is normal in practice to work at winding speeds of 2000 - 2800 m/min. The filament yarn produced in this way — also called POY yarn (partially oriented yarns) — has a residual elongation of 80 - 120 % and can therefore not be processed without subsequent drawing. This pre-oriented filament yarn is very suitable for subsequent draw-texturing.

High-speed spinning also has a beneficial effect on the uniformity of the yarn, because the increased velocity gradient in the draft zone of the thread increases not only the molecular orientation, but also the drafting force, which is a necessary condition for uniformity of the physical properties along the length of the thread.

Finally, it should be mentioned that it is also possible to spin without godets (Fig. 9). This means that not only the godets but also drive motors and the frequency generator belonging to it can be dispensed with. High-speed spinning without godets is made possible by increasing the tension of the thread with the spinning velocity. During the high-speed spinning, thread tensions are reached, which lie in the range of the necessary winding tensions and thus benefit pre-orientation of the filament.

1.4 Aftertreatment

The stretched filaments have good strength and elasticity properties, but are still of only limited use to the textile industry. The fibres have none of the crimp which a natural fibre has. For this reason, they have to be crimped. Where manmade spun yarns are produced by the classic methods of natural fibre processing, then the tows have to be cut. Suitable apparatus is available for crimping and cutting, though I shall not be dealing with the details here. The most important process of aftertreatment is heat-setting, which we will look at more closely.

Thermodynamically, the stretched and crimped fibres are not yet in a state of equilibrium. This means that they are still unusable for most textile and technical applications because, due to their thermoplasticity, they do not have any dimensional stability when subjected to heat. Instead, they will shrink to a varying extent, depending on the production technique. In addition, fabrics produced from these filament yarns or spun yarns have an undesirable tendency to crease during use. This means that a heatsetting process is required. This is achieved by subjecting the yarns to heat in the presence or absence of swelling agents and with or with tension. A distinction has to be made between prolonged exposure to heat at low temperatures in the presence of swelling agents (e.g. steam of 100 - 135° C) and the use of temperatures close to the softening point of the fibres. In the latter case, the treatment times have to be short (5 - 30 s). The heat-setting operation has a particularly favourable effect on the elastic properties and the dimensional stability (shrinkage resistance, crease resistance) and it also benefits the handle of the fabrics.

In the heat-setting process, the bonds between the molecule chains, which are frozen under tension, are given greater mobility through a supply of heat, resulting in the chain segments changing place. The consequence is that the chains assume a lower-energy and thus more relaxed state. Heat setting begins during fibre manufacture and ends during making up of the fabric, in other words, to achieve certain objectives, various types of heat treatment are carried out on synthetic yarns at all stages in processing and even by the consumer, e.g. ironing, hot washing. For the mechanism of the heat-setting process and the heat-setting effect, the selected conditions are of fundamental importance. Between the two border cases: heat setting without tension, in which the greatest amount of freedom is given to the molecule segments to change places, and heat setting with tension, in which the structure is only moderately loosened up, there are a number of overlaps which are utilized in practice. Other important process parameters are the temperature, heating-up rate, type of heat setting medium, dwell time and cooling rate.

The heat treatment results in an improvement in the crystal structure, leading to a complete rearrangement of the crystalline-amorphous matrix, in which there was previously a virtually statistical distribution of the crystalline and amorphous regions. The crystalline part increases with a simultaneous strong disproportioning of the mixed phases. Accordingly, a genuine heat setting is only possible with partially crystallizing fibre materials unless fixed points are created by chemical reactions. In general, however, this can be ignored for synthetic fibres. The increase in the degree of order as a function of the heat-setting conditions can be followed from the examples of polyamide 6, nylon and polyamide 12 fibres through the change in density (Fig. 10).

The dyeing tests carried out on the same three polyamide filaments indicate the considerable loosening up of the amorphous phase which has, on the other hand, taken place (7). Fig. 11 illustrates the influence of saturated steam treatment on the increase in the dyeing rate. There are several physical, mechanical and chemical methods available for determining the degree of setting and for carrying out a systematic control of the production process. With these thest methods, such as x-ray analysis, thermomechanical analysis, differential thermoanalysis etc., the increase in mechanization and automation of the apparatus, sometimes coupled with data processing units, is gaining increasing importance all the time.

2. Physical properties

I shall now deal with the physical properties of polyamides with regard to their possible applications. It is naturally impossible to talk about the applications of any textile fibre and only take into account the physical properties. When a consumer decides in favour of a particular fibre for a certain purpose, he will always look not at his demands individually, but as a whole. These include the chemical properties, and economic considerations will naturally also play a role.

The physical properties of importance to the consumer are :

(a) high breaking strength combined with high elongation at break, which results in a high energy absorption before breaking (toughness). For all normally stretched yarns, the modulus of elasticity through the entire usable elongation can be regarded as average for textile yarns.

(b) high chafing resistance.

(c) good elastic properties, namely degree of elasticity and speed of recovery after deformation, particularly after low deformation, are outstanding.

(d) the ability to be set or moulded in a given for heat and/or moisture, i.e. the ability to take on a permanent, unchangeable shape.

(e) sufficiently high melt points for all practical purposes.

(f) controllable shrinkage without any major change in other chemical properties.

(g) outstanding fatigue resistance.

With their high tensile strength and elasticity combined with excellent abrasion resistance and insensitivity to rotting and moth infestation, polyamide fibres are superior to all natural and regenerated fibres. Through heat treatment, textile fabrics made of polyamide fibres can, by forming further hydrogen bridge bonds between the carbonamide groups of the chain molecules be set to improve dimensional stability. The polar carbonamide groups also bring about a swelling of the polyamide fibres in water and other polar solvents, which means that polyamide fibres — unlike polyester or polyolefin fibres — can be dyed in simple dyeing processes with disperse, acid or metal complex dyestuffs.

Table 3 summarizes the most important technological data.

This short description of the fibre properties is enough to show that polyamide staple fibres and filaments can be recommended wherever the wear behaviour of the final article has to be improved. It must, however, be mentioned that the initial enthusiasm of using polyamides in every possible area of the textile sector, as existed 25 to 30 years ago, has not passed.

There are certain textile and technical applications which have become an established domain for polyamide fibres during recent years. These include bulk yarns, ladies' hose, knitted fabrics, carpets, tyrecord etc, and I would like to deal with these now.

3. Fields of application

Bulk yarns

After spinning and drawing, the synthetic filament yarn is almost as smooth and straight as metal wire. For many purposes and fashion effects, however, a voluminous, bulky and, for certain applications such as stockings and tights, a highly elastic yarn is needed. These properties are obtained by texturizing the filament yarns.

The texturizing process can be carried out separately after stretching. In some cases, however, the stretching is performed in one operation together with the texturizing on the texturing machine (draw-texturizing).

There are a number of different texturizing processes. Probably the most common one proceeds as follows. A smooth, thermoplastic filament yarn is twisted to about 2000 twists per metre or more. This creates twist spirals in the filaments, which can be fixed permanently into the yarn by heat, since the structure inside the filaments is loosened up by the heat and takes on a new spiral order. If — and this is the second important stage in this process — the yarn is now twisted back again, then the fixed twist spirals can no longer assume their previous smooth form but form loops. This can be seen if the yarn is relaxed: the twist spirals have become crimp loops. Fig. 12 shows a smooth filament yarn (top), a spun yarn (centre) and a texturized yarn (bottom).

The process has been improved on enormously over the last two decades. Originally, there were three separate steps: twisting up, setting, twisting back, each on a different machine. Since then, the more economical continuous false-twist process has been introduced (Fig. 13).

Here, the filament yarn passes over a twisting element. This first gives the yarn a twist in one direction, e.g. a Z-twist, and then twists it in the opposite direction (S-twist). If there were no heating zone, the yarn which has been twisted back to zero again would have only been given a temporary, false twist. However, the brief heating as the yarn passes through is enough to fix the twist, and it is this which brings about the crimp as the yarn is twisted back again. The faster the twister works, the faster the yarn can run in order to obtain the same number of crimps per centimetre. By ensuring that the twist spindle is suspended without friction, e.g. in a magnetic field, very high speeds can be achieved — sometimes more than a million per minute. This process produces a yarn of very high extensibility, the type known as "stretch yarn". If we now heat-set again the yarn we have just texturized on the false-twist machine under low tension before it is wound, we can reduce the very high elastic elongation is undesirable for many garments. This results in a so-called "set yarn", which develops a high bulk and gives the finished articles warmth, fluffiness, a soft handle and a compact surface appearance.

There are of course a number of other texturizing processes which cannot deal with here.

The majority of bulk yarns are manufactured from nylon. The reason for this is very simple: nylon, with its higher melt point and greater softening temperature range can be treated with heating methods that work at higher temperatures than those possible with polyamide 6. This results in a more effective heat transfer and an improved setting effect. The somewhat higher modulus of elasticity with nylon is responsible for a greater crimp rigidity of the yarns compared with polyamide 6 yarns. Because of this, nylon yarns have a considerable advantage in practical use. They are used, among other things, for men's hose, swim-wear and stretch fabrics.

Ladies' stockings and tights make up an interesting group of products, because there is virtually no other yarn that can be used for this purpose. The physical properties, such as strength and stretchability, rapid recovery after deformation, abrasion resistance and the possibility of heat-setting combine to give polyamides their dominant-position. In this situation, every manufacturer tries to supply something special so that the customers buy his products. Over the course of the years, many strange assertions have been made but, apart from the appearance of bulk yarns, there have been few fundamental changes. One of the recent developments was a new knitting process which gave rise to the ladderproof stocking. This re-emphasized two physical properties, namely the setting shrinkage and the flexibility. The shrinkage has to be greater than it is with other stockings in order to ensure a good fit, particularly on the ankles. The yarn must be easily pliable in order to give the stocking its softness; otherwise, the handle would be hard as a result of the tack loops in every row of stitches.

Warp-knit fabrics

The economic advantages of the warp-knitting process are so obvious that there is no need to emphasize them. It is only possible through the physical properties of the polyamides to produce lightweight, hard-wearing, dense fabrics. The enormous breaking strength, high elongation at break, rapid-recovery after heavy deformation and the uniformity of continuous filament yarns are all absolutely essential for warp-knitting. Due to the uniformity of the yarn, we can warp very long lengths, which means that long, uninterrupted knitting is possible. Due to its elastic properties, the yarn can pass through the many complicated operations of the machine mechanism without suffering any damage. Its good breaking strength means that fine yarn can be used. Because of its structure, the warp-knitted fabric, as it comes from the warp look, has neither the dimensional stability of a woven fabric nor the shape retention required by the consumer. It is the thermoplasticity of the polyamides which makes it possible to overcome these problems. Through the appropriate application of heat and/or moisture, fabrics can be manufactured which retain their shape.

Since the middle of the seventies, one of the major growth sectors has been the production of polyamide/elastane knits for foundation fabrics (8).

Carpets

One of the main products for nylon and polyamide 6 is carpeting. The fundamental and absolutely essential physical properties of carpets are: abrasion resistance, resilience and retention of their original appearance. It is these properties which determine almost completely the wear resistance and appearance of the carpet. In the case of polyamides, these properties are so outstanding that it is not surprising that the demand for this yarn should be increasing all the time.

It is important that a distinction be made between the contribution made by polyamides as regards the wear resistance and appearance of woven carpets and the enormous boom in carpeting resulting from the tufting method.

Tufting is a very much cheaper method of making carpets than weaving. Its success is dependent on the uninterrupted supply of a uniform yarn of high titre. In order to produce a crimp which is aesthetically pleasing, the yarn must have a considerable amount of bulk.

In order to increase the performance properties of polyamide carpets and to satisfy the wishes of fashion, polyamide staple fibres were produced with a triangular profile. At equal titre, a fibre with a clover profile is more difficult to bend than a fibre with a circular profile. This means that the deformation of the carpet through pressure is lower if the yarn has a clover-shaped cross section. The clover profile is also an important factor as regards the appearance of the carpet. The light reflection properties bring about an attractive glittering effect. We cannot maintain that this is a specific property of polyamide, but it is possible with this material to create any desired profile more easily by melt spinning than with any other spinning process.

We should, however, make special mention in this connection of one physical property. The high refractive index of nylon and polyamide (approx. 1.52) and the clover form combine to produce an optical system in which light, which falls on the fibres from certain directions, is completely reflected in the inside of the fibre and leaves again in the direction of incidence. Light coming from other directions is scattered. It is these processes which cause the pronounced glittering.

The next diagram (Fig. 14) shows the various possibilities of this light reflection.

Technical applications

Whereas the main points for clothing textiles are elegance, fashionable patterns, crease resistance and easy-care properties, the emphasis with technical applications is on high strength combined with low weight, good working properties and resistance to ageing, chemicals and rotting.

Thanks to intensive development work, polyamides have become well established in technical applications. The main products here are tyrecord, conveyor belts, ropes and coated fabrics. Smaller, but still important sectors are fishing nets, industrial sewing yarn and industrial fabrics such as filters, fire extinguishing hose etc.

There are a number of reasons for using nylon in car tyres. Its very high breaking resistance and excellent resistance to impact and fatigue make it possible for a tyre containing nylon cord to react satisfactorily even under extreme conditions.

As far as the fatigue properties are concerned, the next illustration (Fig. 15) shows a comparison which demonstrates to what extent the strength of impregnated polyamide, polyester and viscose cord declines after a fatigue test of 12 hours on the Firestone Flex Tester, in each case at the same cord angle. It can be seen that a nylon cord of 940 dtex still has a residual strength of 80 % after 12 hours. The strength of comparable polyester constructions declines over the same period to 20 %, while viscose filament yarn has broken a long time ago under these conditions at this low cord angle. Nylon is used for

- aircraft tyres,
  primarily because of their outstanding impact resistance. At present there is no other reinforcing material that could replace nylon for this application.
- tyres for overland vehicles, building vehicles, earth-moving machines and for use under extremely difficult conditions.

  They are usually the crossply types because of their better sidewall stability.
- high-speed tyres for cars, crossply and radial types, also for certain lorry and truck tyres.

The disadvantages of polyamides are :

- flat-spot behaviour
  By this we mean that the tyre becomes flat or oval after the vehicle has been standing for some time.
- heat shrinkage
  and for polyamide 6, lower resistance to hydrolysis. After the car and lorry tyres have been vulcanized they have to undergo a special aftertreatment — post-cure inflation — to counter the heat shrinkage. Here, the tyres are placed on a special form and cooled under internal pressure so that the cord is prevented from shrinking.

In practice, only nylon is used for car tyres, while both nylon and polyamide 6 are used for lorry tyres. The reason for this lies in the different vulcanizing conditions for car and lorry tyres.

The physical properties of polyamides, which make them so suitable for tyrecord, are the same as those which also make polyamides so popular in other industrial applications. Conveyor belts, tarpaulins and ropes require very high tensile strength and usually the highest possible modulus of elasticity in order to keep the deformation on stretching as low as possible.

Finally, there is another interesting technical application for polyamide filament yarns. As you know, the undrawn material is useless for general textile requirements. On aircraft carriers, however, this material is used in the form of catch-nets. In a false landing, the aircraft is caught in a net and can be safety brought to a standstill through the very high energy adsorption, which is combined with a 400 - 500 % elongation. This net can, of course, only be used once, since this elongation is not elastic but plastic. This principle can always be used where large amounts of energy have to be absorbed and an object slowed down over a long distance.

Summary

Let me summarize: After discussing polyamide production from its basic raw materials, I talked about the most important physical properties of polyamide fibres with regard to their possible applications.

If, after the conditions I have described, we look at the question of which properties of the classic polyamide fibres should be modified any further, we find that there are hardly any consumer wishes which have not yet been fulfilled. This applies all the more now that number of manmade fibre manufacturers are already producing differential-dyeing types specifically for use in floor coverings and permanently antistatic fibres, also for floorcoverings but equally as fine-filament yarns for underwear and foundation garments.

One problem, which has been repeatedly discussed and which primarily affects floorcoverings but also sometimes occurs in ladies' underwear and foundation garments, is that of the completely harmless, yet unpleasant electrostatic charges. This has now been permanently overcome through the addition of suitable auxiliaries to the polyamide.

Thus, because of their very interesting properties and possibilities of modification, polyamide fibres and filament yarns are indeed a very important class of fibres, which help to meet man's effective demand for textiles.

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year	production / t	percentage / %
1940	5400	> 95
1950	62 000	90
1960	410 000	58
1970	1 908 000	38
1975	2 490 000	33
1979	3 284 000	31
1980	3 125 000	28

Table 1: World production of polyamide fibres

	production	processing	melt point °C	density g/cm^3
	of fibre raw material			
Polyamide 4	possible	problematical		1.25
Polyamide 6	good	easy	217	1.14
Polyamide 6.6	good	easy	255	1.14
Polyamide 6.10	satisfactory	easy	195	1.10
Polyamide 7	possible	easy	225	1.10
Polyamide 11	possible	easy	190	1.08
Polyamide 12	good	easy	182	1.08

Table 2: Some important conditions for the production of aliphatic polyamides

Specific gravity / g/cm^3	1.14
Tenacity / cN/dtex	4 - 6
Breaking elongation / %	35 - 50
Loop breaking force relation / %	65 - 85
Loop breaking elongation / %	60 - 80
Initial modulus / cN/dtex	40 - 50
Moisture absorption / % (20 °C and 65 % rel. humidity)	3,5 - 4,5
Meltpoint / °C	255/217

Table 3: Textile physical fibre data for Nylon and polyamide 6 fibres

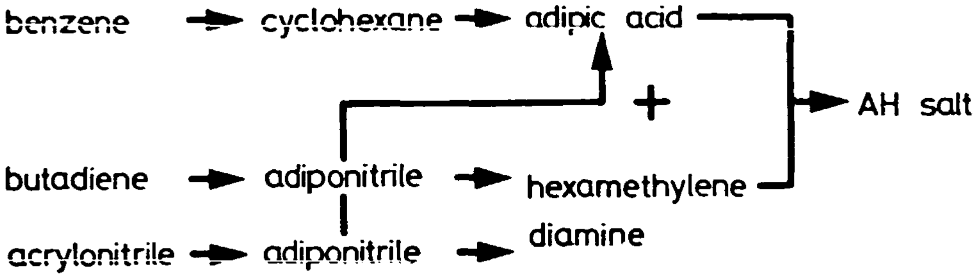

Fig.1: Industrial monomer production for polyamide 66

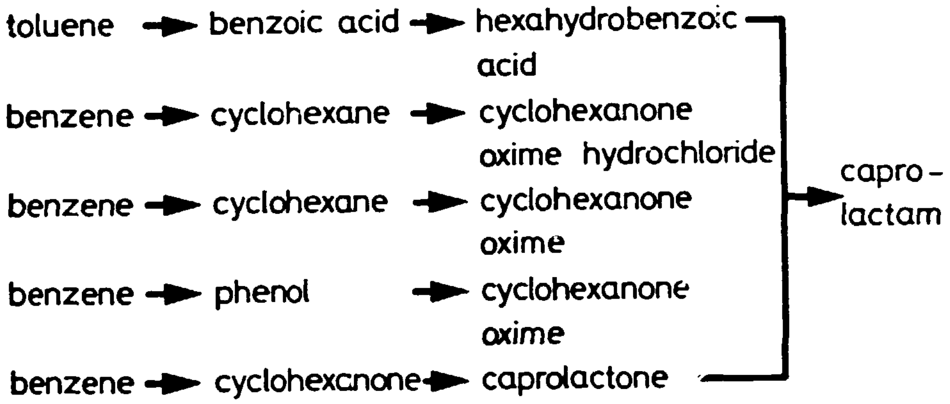

Fig.2: Industrial monomer productions for polyamide 6

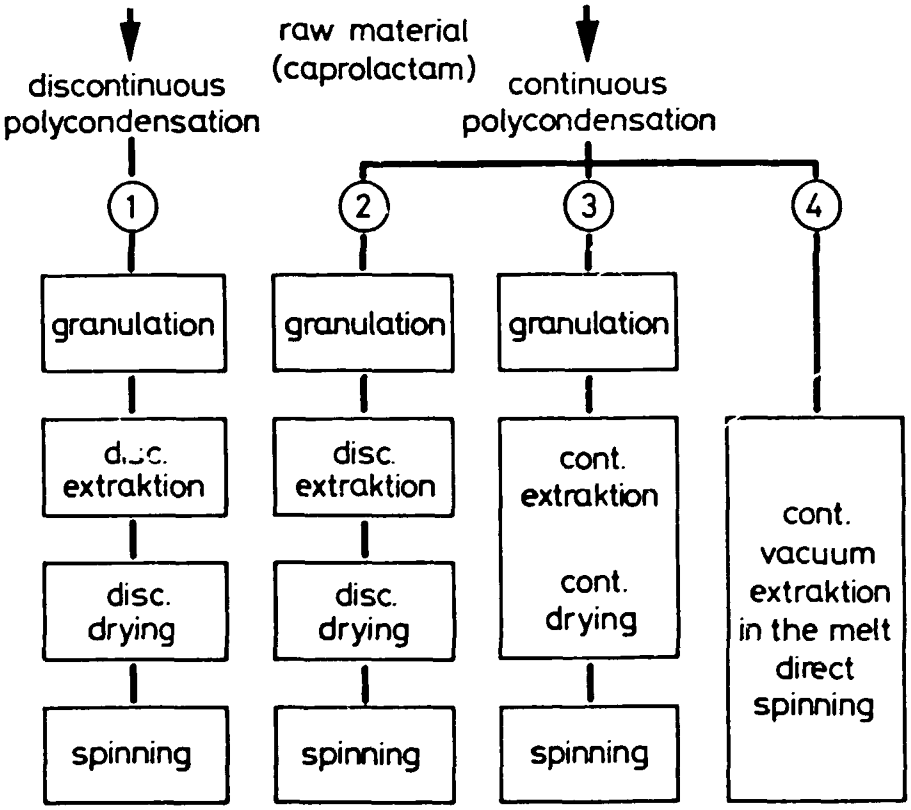

Fig. 3: Flowchart for the production of polyamide 6 fibres

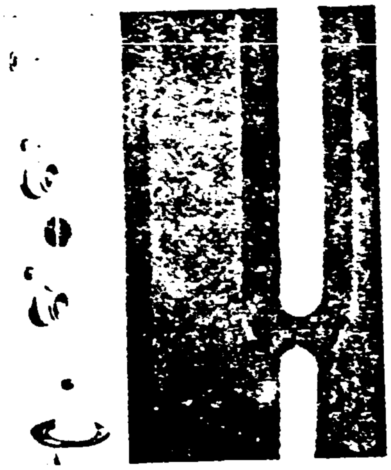

Fig. 4

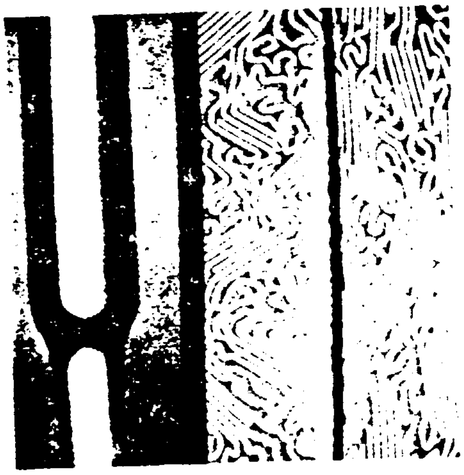

Fig. 5

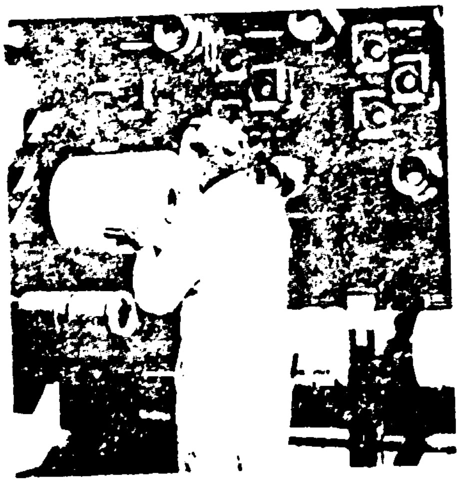

Fig.6

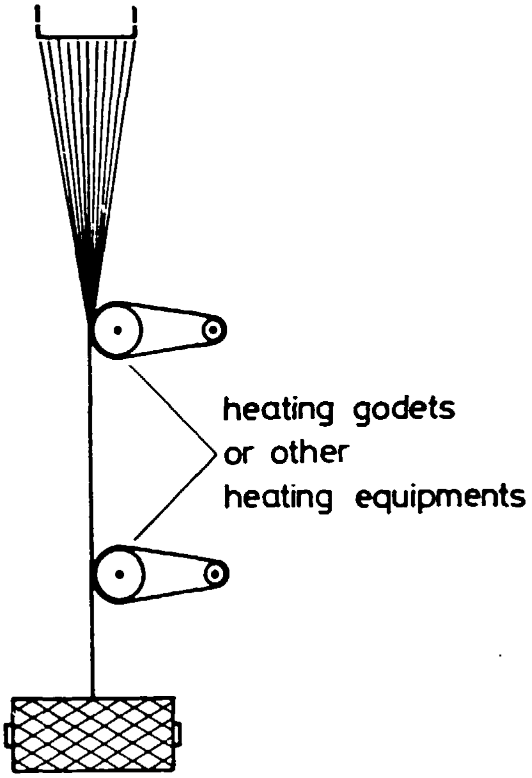

Fig.7: Spin - drawing

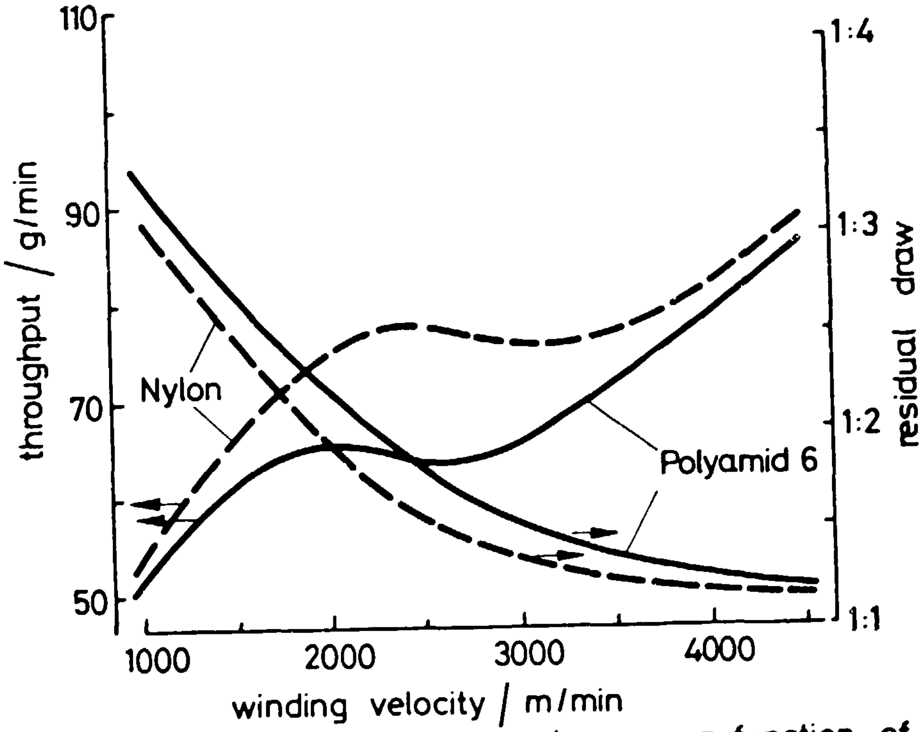

Fig.8: Throughput and residual draw as a function of the winding velocity (167 dtex)

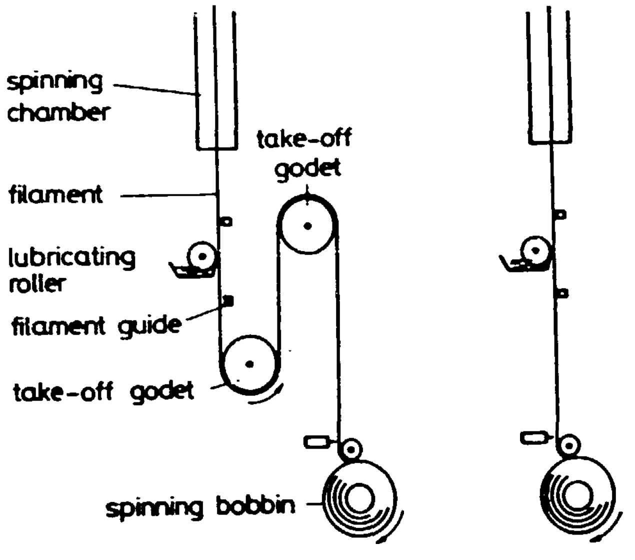

Fig.9 : Filament take-off , left with godet, right without

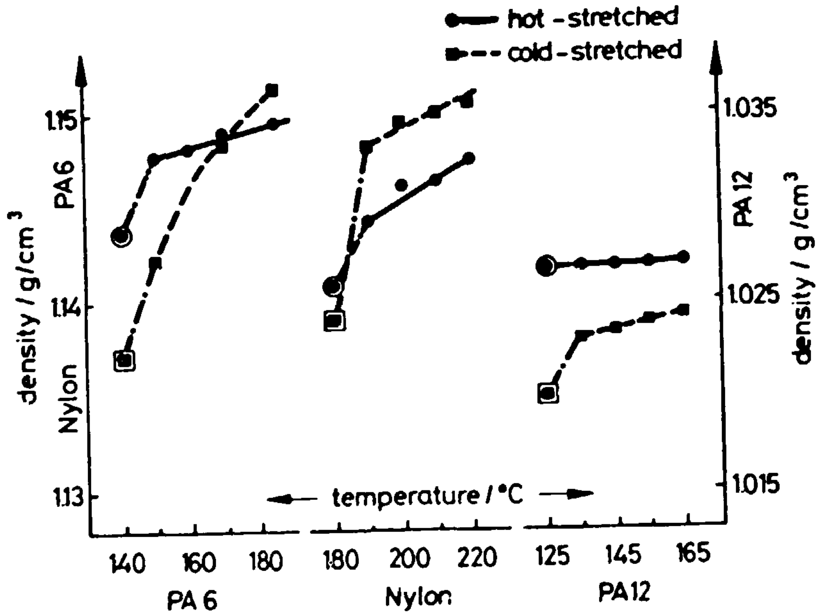

Fig.10: Influence of heat-setting temperature on density

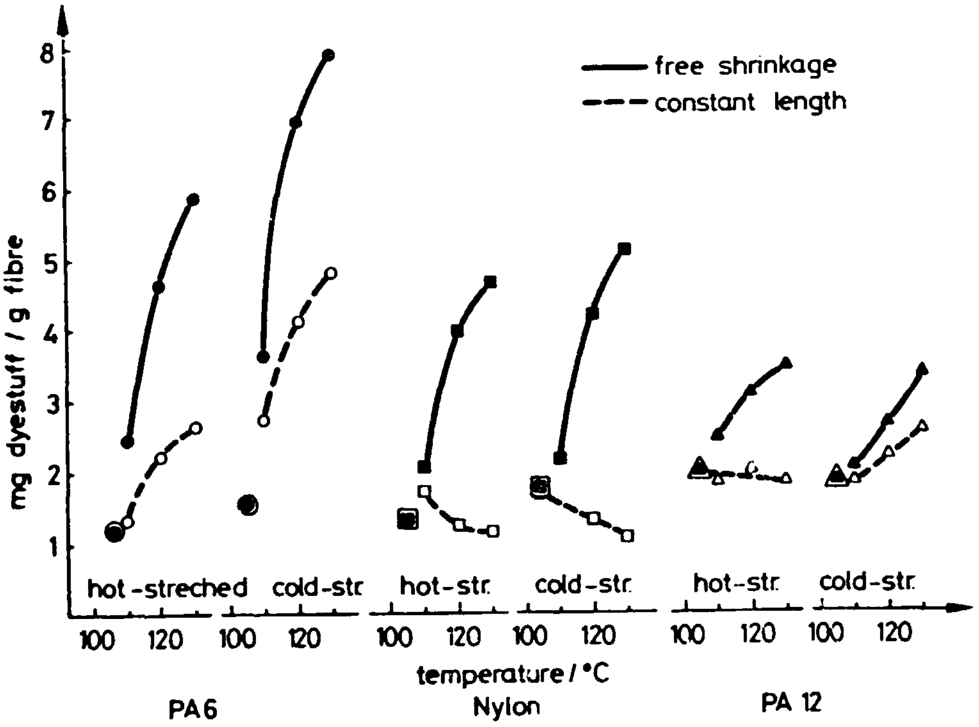

Fig. 11: Influence of steam treatment on dyeing rate

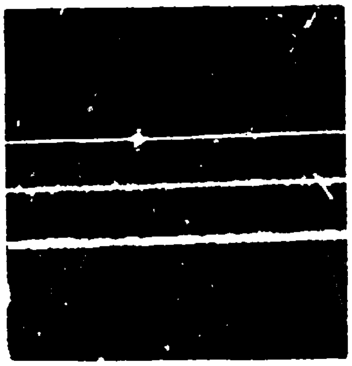

Fig. 12

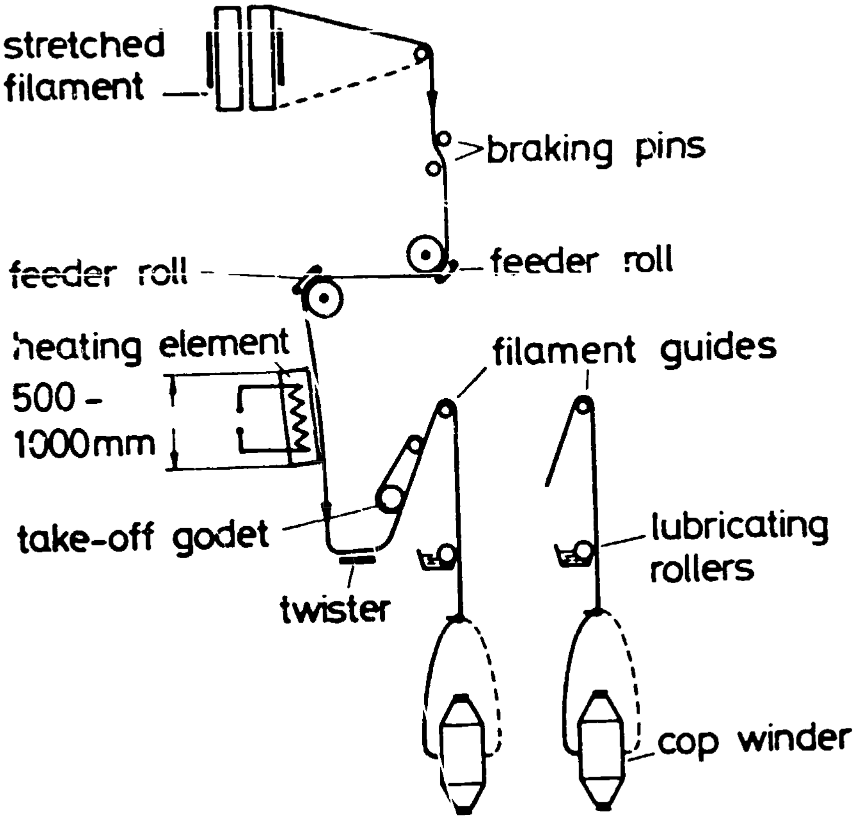

Fig.13: Texturising process

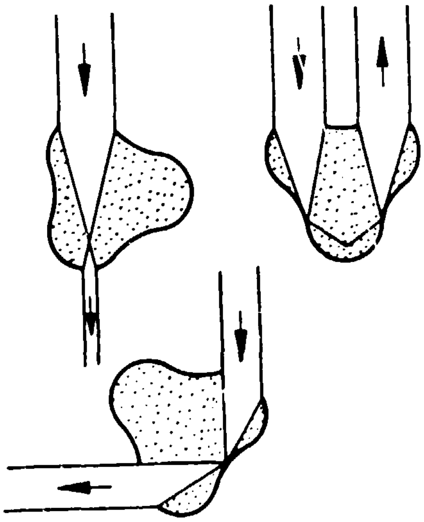

Fig 14: Light reflection on trilobal fibre cross-section

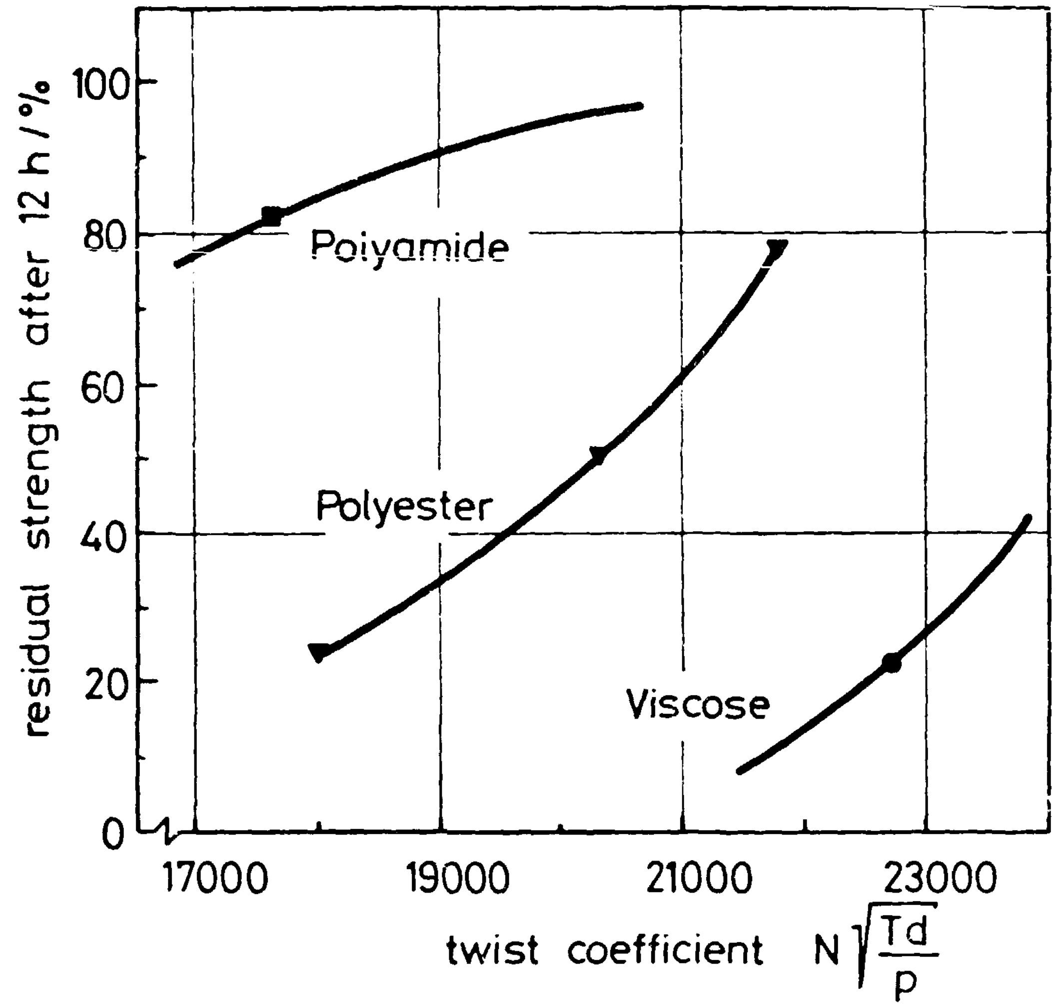

Fig.15: Residual strength after fatigue test on impregnated tyrecord with a Firestone Flex Tester

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MODERN PROCESSES FOR PRODUCTION OF STAPLE FIBRES

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Federal Republic of Germany.

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The Paper discusses the trend of production of filament yarns and staple fibres in different countries and analysis the expansion of staple fibre production in the individual world regions. Next the paper points out the advantages of man-made fibres and then discusses in details the processes as well as the modern machineries used for the production of fully synthetic staple fibres viz. Acrylonitrile, Polyamide, Polyester and Polypropylene which are of importance in the textile industry.

Synopsis

MODERN PROCESSES FOR PRODUCTION OF STAPLE FIBRES

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Introduction

Staple fibres are cut fibres which — in comparison to endless threads — are procesed to yarn either purely or blended with other fibres in classical secondary spinning mills.

Whilst upto the mid seventies the production of endless yarn had undergone a rapid advance due to the development in texturising the trend has turned back to staple fibres since then.

Figure 1 will show you this development. From 1974 to 1980 the production of endless threads has increased by 28%, the one of staple fibres by 55%.

The expansion of staple fibre production during this period has taken a very different course in the individual world regions.

Fig. 2 represents the development in the USA, Western Europe, Japan, Eastern Europe, Latin America and the "Others Countries". Whilst the Western European and Japanese development in production practically stagnated, Eastern Europe and Latin America faced a steady but low increase, the USA and especially the "Other Countries" have scored an important increase in production.

Many experts foresee a trebled production for the period from 1980 - 2000, i.e. from 11 Million tons to 35 Million tons per year.

In my view, the latter seems only to be realistic when the production in the "Other Countries", in Eastern Europe and in Latin America will continue to rise substantially.

The further development of man-made fibre production will be advanced by following facts:

— The raw material supply of the textile industry is guaranteed by synthetic fibres. They can be produced in whatever quantities; therefore, they can be adopted to the growing world population and the increasing demand of quality of life.

— Easily preservable clothing and home textiles can be made from synthetic fibres.

This enables strongly required conveniences in textiles facilitating housework and meeting modern demands.

- Synthetic fibres allow textile production for certain purposes, especially technical clothes.
- Fibre blends enable many fashionable variations and optimium properties of use.

Speaking about man-made fibres we have the 4 important groups in mind which are of importance in the textile industry:

- Acrylonitrile fibres
- Polyamide fibres
- Polyester fibres
- Polypropylene fibres

In the following we will in detail discuss their production process resp. the required machines.

A. Acrylonitrile Fibres

For processing acrylonitrile fibres two different processes are in use, i.e.

- dry spinning process
  and
- wet spinning process.

Opposite to the other mentioned fibres the melting point of acrylonitrile is higher than its decomposition point. Therefore, acrylic fibres are spun out of solvents.

Figure 3 shows as scheme of a *dry spinning process*. After start of spinning the tows are prepared on a draw-off wall, pass a tow stacking unit and are plaited into cans by means of a can plaiting device.

Within a separate process many tows undergo a subsequent treatment identical to the wet process which will be explained in the following.

Figure 4 shows a scheme of a *wet spinning process*. Here, the acrylonitrile is extruded in a spinning bowl at essentially lower speed; subsequently, it is drawn and washed. Washing is followed by finishing, drying, finishing, crimping, and heatsetting. Depending on the application tows are now plaited or cut. In order to ensure economical transport, tows as well as cut fibres are compressed in the baler, wrapped with foil and strapped with strings.

Special priorities in developping the described processes had been given to the increase in capacity per line upto 10 Million den per production range, to introducing the continuous dyeing process, to improving the washing process, to continuous heatsetting as well as to fully-automatic packing of bales.

Current lines for acrylic fibre production show a daily performance of 20 - 80 t. The dry spinning process rather suits for great chemical industries whilst the wet spinning process is easier to be introduced. Therefore, it meets a greater expansion.

B. Polyamide, Polyester and Polypropylene Fibres:

Materials of this fibre group can be spun out of the melting agent and solidify in the air directly after leaving the spinneret.

Fig. 5 shows a scheme of a polyester spinning line. Within the spinning manifold the spinning liquor is uniformly transported through the filters and spinnerets by means of gear spinning pumps. After leaving the spinnerets air is blown towards the threads to have them growing rigid.

So-called draw-off walls take care for a preparation of the threads which are stacked to tows via deflector godets. Finally, they are plaited into cans by means of toothed godets.

In a second processing step the tows are drawn off from many cans and fed to the drawing line.

Figure 6 shows a scheme of a drawing line for Polyester — Cotton Type — high tenacity (high modulus). From the draw-off creel the individual tows are converged via a foreguide and taken over by an intake unit. Subsequently, they are finished in a bowl and drawn between so-called drawings units, heatset under tension, crimped, dried, plaited in tow-shape or cut by a cutter. Finally, they are prepared for despatch in a baler.

In principle, polyamide resp. polypropylene fibres are similarily processed.

Today, those lines are manufactured for daily capacities of 20 - 250 t.

For smaller capacities — mainly for polypropylene — compact lines have prevailed in practice which are especially suited for production of spun-dyed fibres.

Figure 7 shows such a compact line. With this line processing takes continuously place from the extruder to the baler.

Capacities of those lines are between 5 and 20 tons per day. Due to their compact dimensions, i.e.

Length	35,0 m
Width	6,0 m
Height	5,5 m

they are especially suited for smaller companies.

The further development of these lines had been characterized by automizing as far as possible, increase of performance per m^2, amelioration of the fibre quality, and reducing of the energy consumption.

It will be the best to discuss the improvements at the occasion of the description of the individual machines.

C. Machinery for Acrylic Fibre Production

Fig. 8 shows a scheme of a wet spinning frame for acrylic fibres.

The spinning solution is transported by means of spinning pumps via filters and spinning pipes through the spinnerets, it emerges in a coagulation bowl where individual capillar threads solidify.

The construction engineer has to stress special attention on the fact that all capillar threads have to be subject of the dwelling time in the same bowl concentration. Today, spinnerets for acrylic fibre production have more than 40.000 holes, sometimes even upto 150.000 holes per spinneret. Machines of this design are assembled one after the other in order to enable spinning of tow thicknesses of upto 8 Million.

Another frequently used spinning frame is shown on Figure 9.

With this machine spinning is effected every other time from front to rear and resp. from rear to front (as seen by the operating personnel).

Subsequently, the spun tows are converged via deflector godets in direction of the longitudinal machine axle and guided to the following washing and drawing line.

The requirement — same dwelling time in bowls of same concentration for each capillar fibre — is to be realized easier with this design. A common circuit system provides the same concentration in all spinning bowls.

For coagulation liquor a solving agent thinned with water is used. Temperature varies from -5 to 50° C depending on the solving agent. As uniform as possible these spun fibres are now lead to the subsequent pre-drawing unit.

Fig. 10 shows a scheme of a draw frame. Drawing is effected in several stages, with the wet spinning process the drawing ratio amount upto 1 : 15. Pre-drawing has to be subject to very careful treatment, normally the resp. ratio amounts to 1 : 2. Both drawing processes take place in a water bath at temperatures between 20° C and 100° C. With the pre-drawing process the water bath already provides a part of washing-off of the solving agent. However, proper washing-off takes place in the washer.

Fig. 11 shows the scheme of a washer.

The tows are fed in via an intake roller, they pass several spraying systems, reach the actual washing liquor. Here they are deflected via a perforated drum and leave the first washing position via a squeezer unit.

At standstill the water level of the perforated drum corresponds to the one in the washing bowl. As soon as the circulation pump is started, the water level inside the drum sinks and the washing liquor is transported through the tow from the washing bowl into the drum's interior.

Supply of washing liquor into the entire machine is effected acc. to the counter flow system, i.e. from the last unit up to first one.

The washer's main job mainly consists in a fast take-off of the solving agent as well as in providing fresh liquor to the fibre in order to have the solving agent diffused out of the fibre due to the difference in concentration. Dwelling time depends on the resp. process. With certain processes upto 25 washing bowls are combined in series.

The washing process is followed by wet drawing on a draw frame corresponding the one described for pre-drawing. Subsequently, the tows are provided with finish in a bowl and dried in a dryer.

Fig. 12 shows a perforated drum dryer which has proved its worth for fibre drying for years.

The tows are fed to the dryer via an infeed conveyor, automatically taken over by the first perforated drum and lead on. Depending on the resp. process upto 24 drums are arranged in a dryer.

Fig. 13 shows the system of the perforated drum dryer. The air is lead over radiators; heated-up, it is uniformly guided across the working width through the goods to be dried, sucked off by a fan and returned over radiators to the goods to be dried. Fresh air suction — the counter current system is applied — is effected through the hot dried goods at the discharge end of the dryer, resulting in a constructional heat recovery. This drying process working acc. to the flow-through system reaches the very best heat passage parameters.

Fig. 14 shows the airing systems used with different dryers:

- — parallel airing
- — jet-type airing
- — trans-airing

Fig. 15 shows the advantages of the trans-airing system. It represents the drying speed drawn on the surface in kg/m^2 h on the moisture content in % covering the three aforementioned airing systems.

Generally, drying is followed by another finishing, crimping, heatsetting, cutting resp, plaiting and baling — processes which should be discussed in details with the production of polyester fibres.

Moreover, fig. 16 shows an arrangement of crimpers which is typical for a acrylic fibre processing line. For instance, with a line of 8 tows 8 + 1 crimpers are arranged one after the other.

D. Machinery for Polyester Fibre Production

The fibres leaving the spinning frame are wetted on the preparation wall, converged and plaited into cans via draw-off unit and sunflower reel plaiter.

Such an arrangement is shown on fig. 17.

The development of the recent years has been characterized by an essential increase of throughput per spinning position thanks to using spinnerets with more holes.

Whilst formerly tows of 100.000 den had been plaited into cans, today tows of 300.000 den and more are plaited. This means that the size of the cans has been growing respectively. Modern can plaiters are designed for cans of volumes of upto 5 m^3. Round as well as rectangular cans are used.

When the provided filling amount is reached, the filled can is automatically replaced by a ready empty can.

In order to plait high tow thicknesses impeccably into the cans even at speeds of upto 2000 m/min a sunflower reel plaiter operating without any tolerances is necessary. Unprecisely working reel plaiters require high overfeeding in comparison to the tow speed which could lead to disorder in the tow bundle. Plaiting failures would cause frequent standstills when the tows are processed further on on the drawing line.

The cans filled this way are transported to the draw frame by means of different systems — in general by means of a fork truck — and put up in the can creel.

Fig. 18 shows a can creel with intake unit as it is often arranged for feed of the fibre processing line.

Normally, the cans are set up in 4 rows. The tows are drawn off from two rows and the two other rows remain in waiting resp. exchange position.

Above each can thread guiding devices are mounted which could be lowered to facilitate threading up.

By means of a infeed unit with intake rake the tows are drawn out of the cans. The intake rake prepares the tows for an uniform infeed into the draw frames. The better this preparation of the tows prior to bed into the fibre processing line, the less standstills due to lap formation are to be expected.

In front of the intake unit the tows are first drawn through a finish bowl before entering the first drawing unit.

Fig. 19 shows the scheme of a finish bowl.

The finish bowl consists of a top and a bottom tank. The bottom tank is equipped with heating coils in order to heat the liquor.

The bowl temperature is kept constant by means of temperature regulators.

The liquor level in the bottom tank is controlled via a floater switching. Supply is effected from a storage tank. By means of a circulation pump the finishing liquor is pumped from the bottom tank into the top tank. Via an overflow device it is returned into the bottom tank. Circulation is intensive in order to keep temperature and concentration of the finishing liquor constant.

The incoming tows are lead over an intake roller and immersed into the finishing liquor by means of two rollers which can be lowered by compressed air cylinders, and leave the bowl via a discharge roller. Subsequently, the tows are squeezed off by a squeezer unit causing a reduction and uniformity of the finish application.

The finishing bowl serves to heat the tows and to provide an even finish application. Subsequently, the actual drawing process starts. Its job consists in aligning the chain molecules to the fibre axle and to reach the required textile-physical properties.

Drawing is effected between the drawing units.

Fig. 20 shows such drawing units. Depending on the tow thickness to be drawn they can be differently dimensioned. Working widths can amount upto 1600 mm.

In order to avoid slipping the tows are lead around several rollers. In general, all rollers of a drawing unit have the same circumference speed. Drawing is a result of the different speed of the drawing units in comparison to each other.

The total drawing ratio amounts to about 1 : 3 upto 1 : 5. In order to achieve an uniform drawing setting of the drawing point is of special importance. With the most processes the draw point is set at the discharge end of the first drawing unit. To enable adjusting of all required processing parameters depending on the resp. process the rollers of the drawing units can be heated or cooled.

In order to heat the rollers uniformly across the working width either double coating godets or hollow godets are used.

Fig. 21 shows a scheme of a double coating godet. With this kind of godet the heating medium, e.g. water, steam or thermal oil is supplied or lead off via rotation couplings.

The medium has to follow a forced flow through the annular gap of the double coating which ensures a good temperature distribution.

With the hollow godet steam is used as heat carrier.

Fig. 22 shows the scheme of a hollow godet.

The steam is supplied via rotation couplings, disperses across the interior of the godet and condenses at the walls. The condensate is sucked off by means of a funnel via the rotation couplings.

Often, a heating duct is provided between the drawing units.

Fig. 23 shows the arrangement of the duct. Heating is effected by means of steam or thermal oil and the heat passage from the surface of the upper and lower box to the fibre material via radiation and convection.

For amelioration of the heat passage over-heated steam can additionally be blown in.

As the drawn material is subject to shrinkage during the following crimping and drying process, it is impossible to produce fibres of so-called high modulus type.

In order to maintain the small elongation of break heatsetting under tension is required. This process is realized on calenders following the drawing unit.

Fig. 24 shows a scheme of such a calender. The rollers are executed as double coating godets as described under fig. 21. Due to the required high temperature thay are normally heated by means of thermal oil.

After thermal heatsetting or after drawing when normal types are processed, another finishing of the fibres follows in order to prepare them for the subsequent treatment.

Fig. 25 shows a sketch of such a spraying finishing unit. From top and bottom finishing liquor is sprayed on the tows and subsequently partly squeezed off by means of a pair of squeeze rollers.

This is followed by the preparation for the crimping process. First, all tows have to be converged to have the tow width being correspondent to the chamber width of the crimper.

Fig. 26 shows the system of such a tow stacking unit.

The individual tows are deflected through horizontally adjustable rollers in such a way that optionally one or two tows of the required width are shaped.

This tow is guided over a tensioning control unit in order to adjust the required tow tension for optimum crimping.

Fig. 27 shows the system of a dancer roller to control the tow tension.

At the intake and discharge end there are stationary rollers, in the middle a vertically moveable roller is arranged. When the tow tension is changed, this roller moves up- or downwards. By means of a potentiometer adjustment the intake speed of the crimper roller and thus the tow tension is controlled. Frequently, a steaming duct is arranged between dancer roller and crimper to prepare the fibre for the crimping process by means of a steam treatment in optimum kind.

The crimper operates acc. to the stuffer box process.

Fig. 28 shows the system of such a process. The tow is pressed in the stuffer box by means of the crimper rollers causing a crimp in the fibre. This kind of crimping can be altered by changing different parameters such as chamber pressure, chamber height, chamber length, steam injection etc. As the crimper rollers are heated — especially at higher speeds — cooling must be provided.

Modern crimper design allows fast opening of the chambers and rollers for cleaning purposes and automatic return to starting position by means of a push button.

By means of a sketch fig. 9 shows how the crimper can be opened for cleaning purposes. Depending on the kind of fibre, crimping is followed by drying and cooling or shrinking of the fibre, e.g. to achieve a residual shrinkage of less than 1%. For these processes for instance perforated drum dryers, heatsetting ducts, or conveyor plate heatsetters are used. The perforated drum dryer has already been explained by means of fig. 14.

Fig. 30 shows a heatsetting duct stuffing the tow in direction of production in order to achieve higher dwelling times.

Fig. 31 shows a conveyor plate heatsetter for so-called cross plaiting for longer dwelling times.

With the heatsetting duct the dwelling times amount to about 1 minute, with the conveyor plate heatsetter with cross plaiting resp. higher.

In both cases heating is effected via air circulation over resp. radiators.

At the discharge end the material passes a cooling path. Off this path it is optionally guided to the cutter or the tow plaiter via an optical draw-off control.

The material is plaited when it should be processed on in tow-shape. Acrylic fibres for instance are frequently not cut but processed on by converter lines. Or polyester and nylon tows are spread out on tow bulking lines shaping webs and are directly made to clothes.

All these examples require despatch in shape of tows.

Fig. 32 shows the system of a tow plaiter. The tow is transported via a conveyor belt to the point of infeed and taken over by a plaiting funnel. The funnel is oscillating and allows uniform plaiting on simultaneous cross movement of the carton. Resp. in the right-hand and left-hand final position of the carton movement the plaited material is compressed by means of a stamp. As soon as the required length is plaited, automatic exchange of the filled carton by an empty one is effected.

For costs saving purposes tows are more and more compressed in balers, wrapped with foil and despatched as bales. Main savings are met with:

- — packing material
- — transport costs
- — labour costs
- — storage

Fig. 33 shows the system of a fully-automatic packing line for tows.

The tow plaiter plaits the tow into a metal sheet can which had been lined with a foil bag before. The filled can is automatically transported to the baler station after the foil bag has been closed with cover foil by means of a special device.

In front of the baler the can which is equipped with a false bottom is drawn off from the filled bag and the bag is guided into the baler. When pressing room is closed compression by means of a pressing stamp as well as automatic strapping take place. The ready bale is ejected and the empty can transported back to the plaiter.

Depending on the amount to be packed a resp. number of cans and plaiters is required.

A fully automatic packing line has a capacity of more than 150 t per day.

For smaller capacities a semi-automatic line is used. Plaiting corresponds to the automatic line. However, execution of the metal sheet can is sturdier because it is used as press box in the press as well. With this line provision of the foil as well as wrapping with strings is effected by operating personnel. The capacity of such a line is resp. lower and amounts to approx. 100 t per day.

The main part of man-made fibres is despatched as cut, so-called staple fibre and not as tows. In this case the tow is not plaited but lead over to the cutter.

For several years a cutting system acc. to patents of Eastman Kodak has prevailed world-wide.

Fig. 34 shows the system of such a cutter. The tow is wind up around a reel which is equipped with a number of knives mounted in radial direction to the circumference. Outside the rotating cutting reel a pressure reel is mounted which has a fixed adjustable distance to the cutting reel. With increasing winding thickness the distance between knive edges and pressure reel is filled up by the tow, a pressure is built up and inside fibres are cut by the knives due to the exerted force.

The distance of the knives determines the length of the cut fibres.

Fig. 35 shows a small and a greater type of cutter. For an impeccable cut the tow infeed tension has to be kept constant. This is assured by means of a dancer roller or by means of a tensioning unit.

From the cutter the cut fibres are pneumatically for instance transported on to the flock press. Frequently, the cutter is arranged above the flock press to have the cut fibres fall directly into the press without pneumatical assistance.

Fig. 36 shows a scheme of a so-called pre-press which could for instance be directly combined with a cutter.

The cut material is transported by means of a feeding device to the mobile press box of the pre-press and pre-compressed by a pressing stamp. Such a pre-press is mounted following to each fibre processing line.

The filled press boxes are guided to the fully automatic central press by means of a transport system.

Fig. 37 shows such a scheme.

You will recognize the position of the 5 pre-presses as well as the transport way of the full and the empty press boxes to resp. from the central press.

Fig 38 shows the functioning of a central tandem press in 8 positions.

Position 1. The press box filled in the pre-press is in the compressing station.

Position 2: The fibre material is compressed.

Position 3: The press box without bottom is drawn upwards.

Position 4: The compressed material is transported to the right-hand side packing position together with compressing plate and bottom plate to be lined with foil; simultaneously the compressing plate and the bottom plate are transported from the left-hand packing station into the press and lining of the foil around the compressing plate and the bottom plate is effected.

Position 5: The empty press box is set onto the bottom plate which is equipped with foil, the foil-wrapped fibre material is transported into the strapping station where automatic strapping takes place.

Position 6: The empty press box is returned to the pre-press and the ready bale is ejected.

Position 7: A new filled press box is introduced and in

Position 8: a further compressing takes place.

In practical use the described operations run simultaneously, i.e. phase-shifted for the right- and the left-hand side of the packing station allowing daily capacities of upto 300 tons.

A special advantage of this pressing system is represented by the fact that the fibres do not directly contact the press. Therefore, different fibre qualities can be compressed one after the other without taking the risk of mixing.

As shown in figure 39 it is possible to compress cut fibres as well as tow on the same line one after the other. In one case filling of the press cans is effected by means of the pre-press, in the other by means of tow plaiters.

The ready bales are weighted, registrated and transported into storage halls.

Furthermore, it should be mentioned that most of the described machines are driven by individual DC-motors and connected to each other by means of tachogenerators.

A process control covering speeds as well as temperatures is more and more applied enabling relatively fast and easy exchange from one fibre quality to another. Even great lines of capacities of 200 t per day and more can be flexibly run.

World synthetic fiber production except olefin (textile organon)

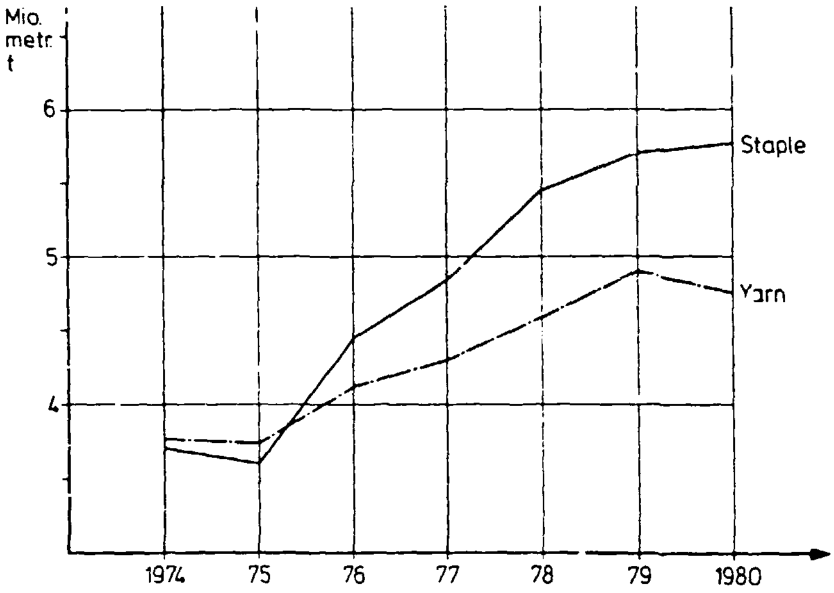


Fig. 1

World synthetic fiber production except olefin (textile organon)

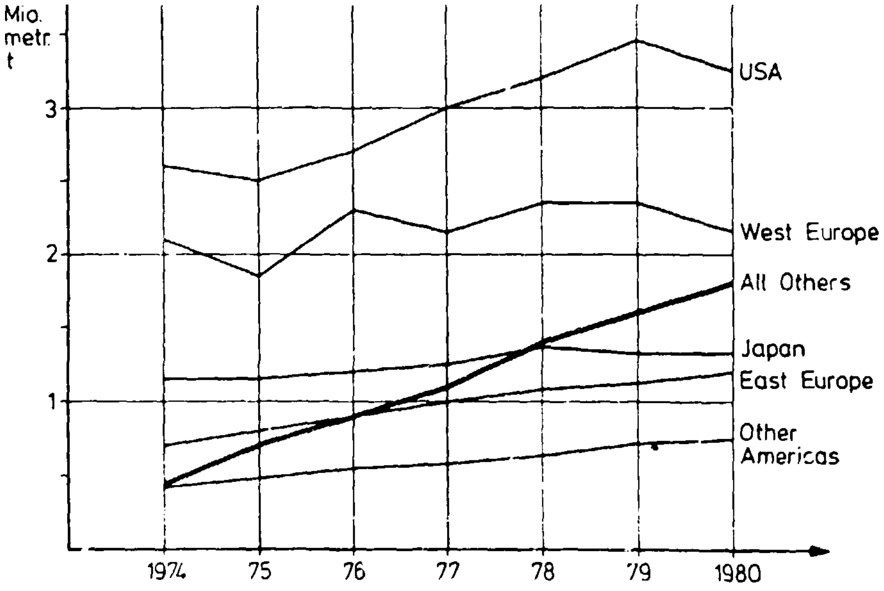


Fig. 2

PACN - Dry spinning line with tow feeding unit

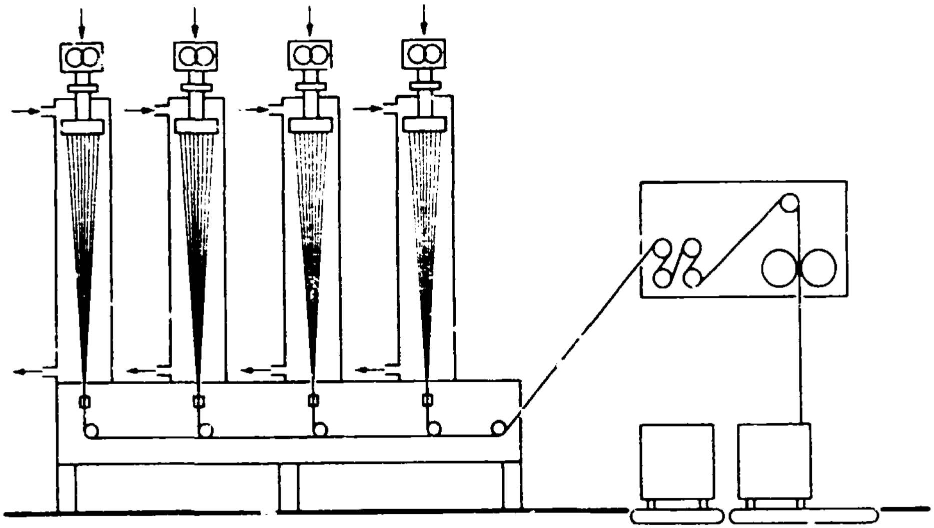


Fig.3

PACN - fibre tow processing line wet spinning process

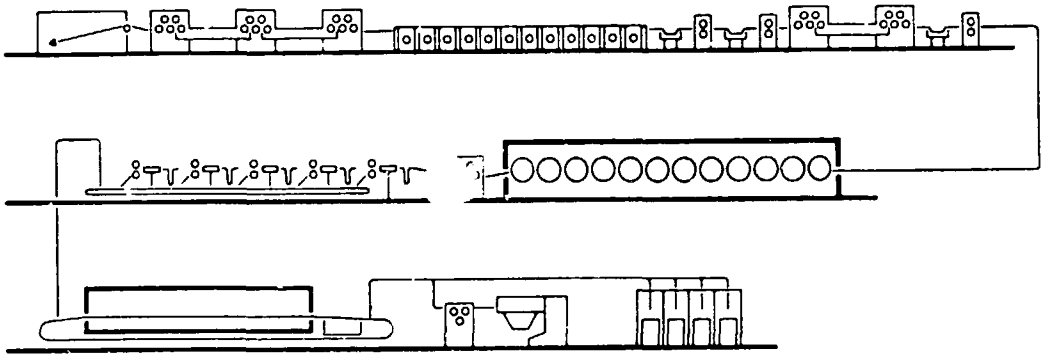


Fig.4

Spinning system with can plaiting

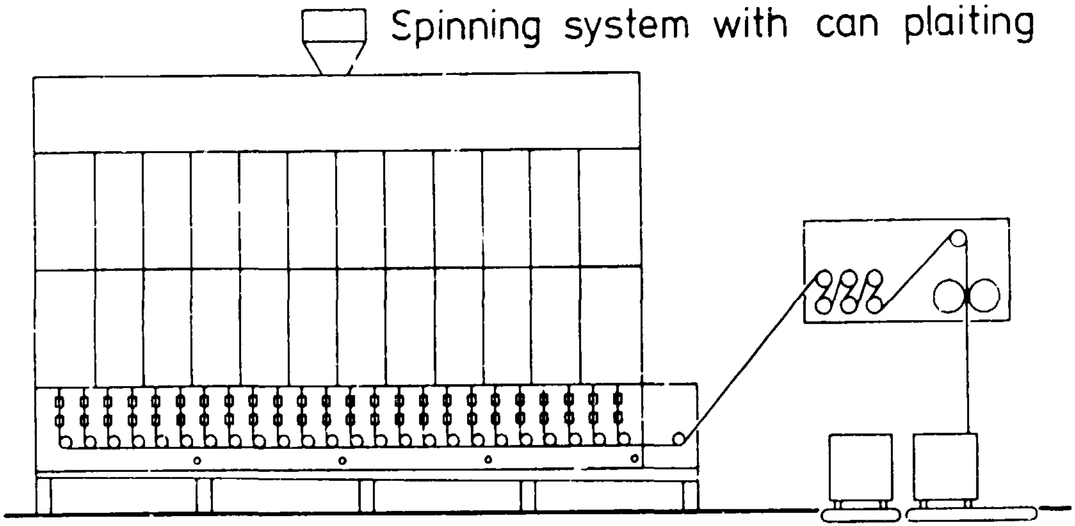


Fig. 5

PES - Fiber line

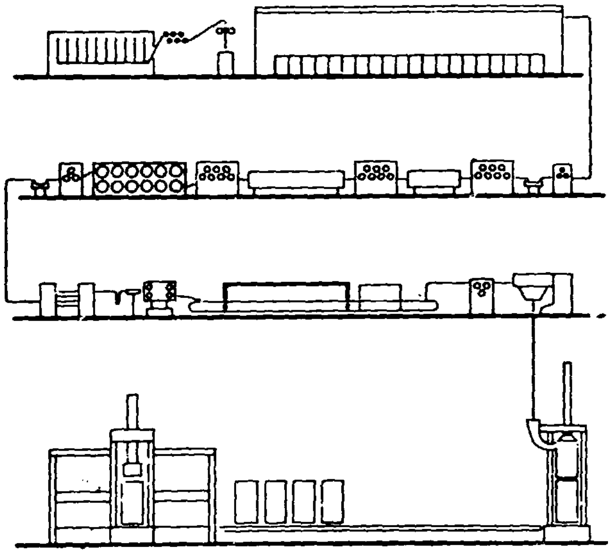


Fig. 6

PP - compact line

Fig. 7

PACN - Wetspinningframe

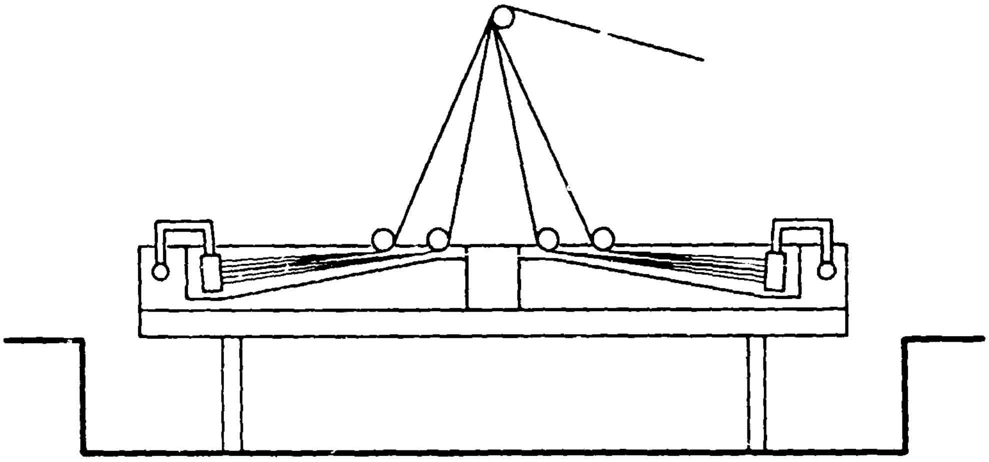


Fig. 8

PAC spinning frame

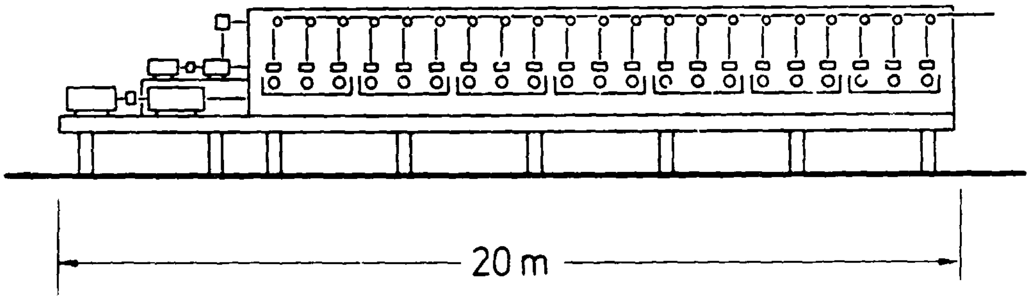


Fig. 9

Wet - drawing

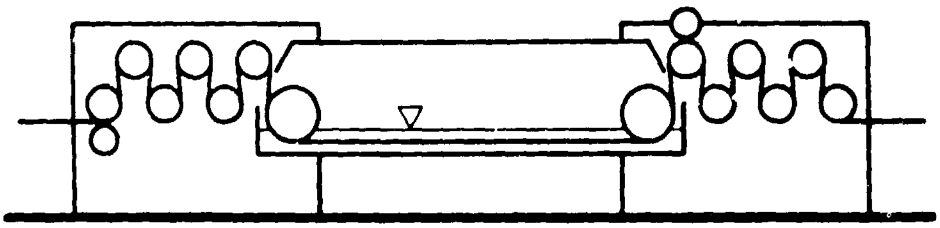


Fig. 10

Tow-washer

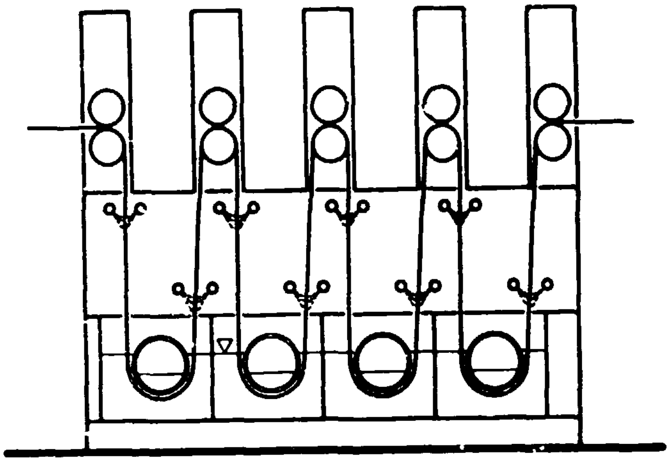


Fig. 11

Perforated drum dryer

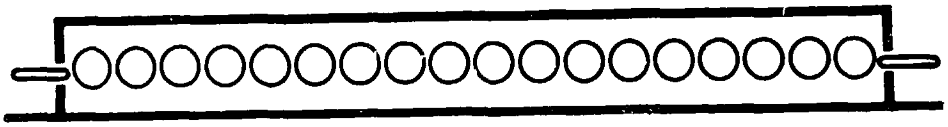


Fig. 12

Drum heatsetter

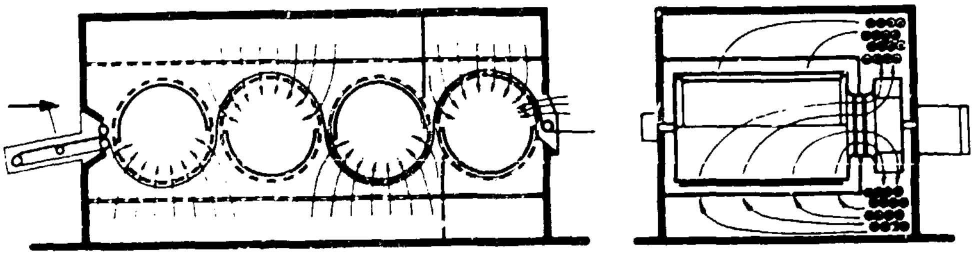


Fig. 13

Ventilation systems

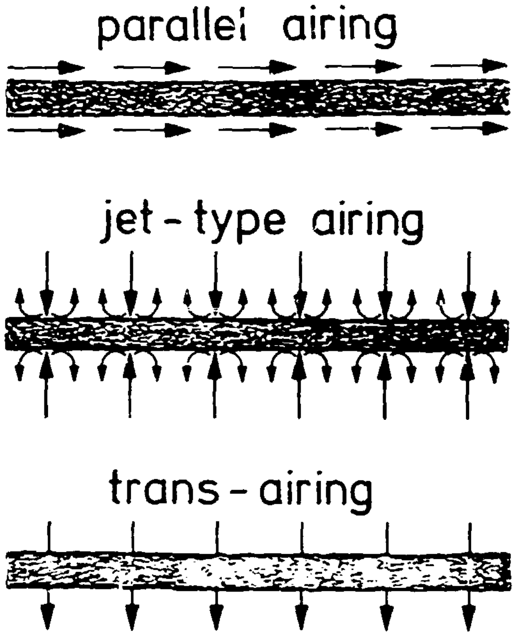


Fig. 14

Drying curves

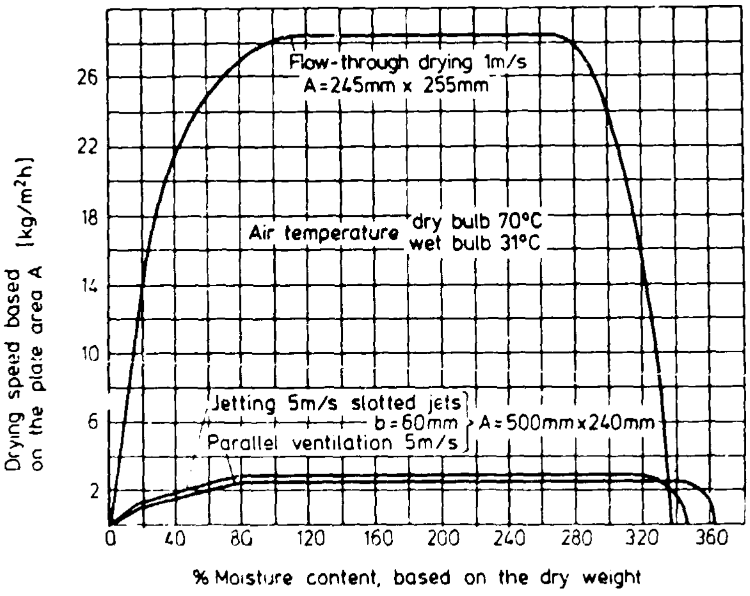


Fig. 15

Crimper line

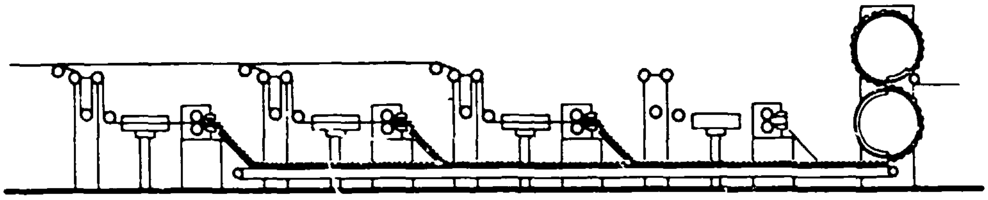


Fig. 16

Draw-off wall with can plaiting

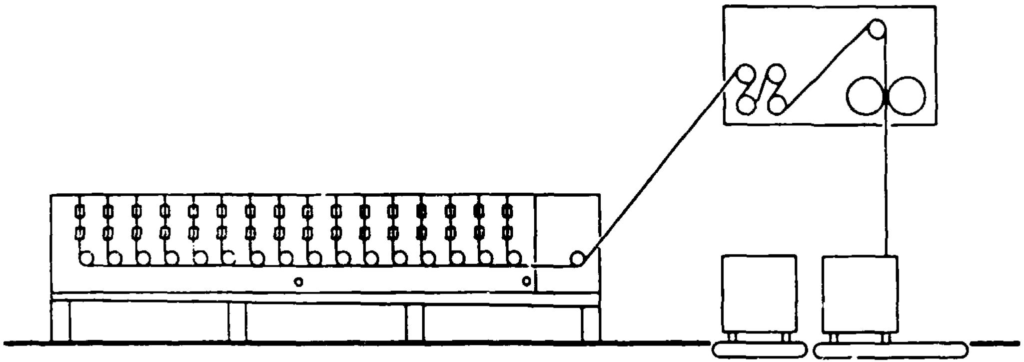


Fig. 17

Can creal with intake unit

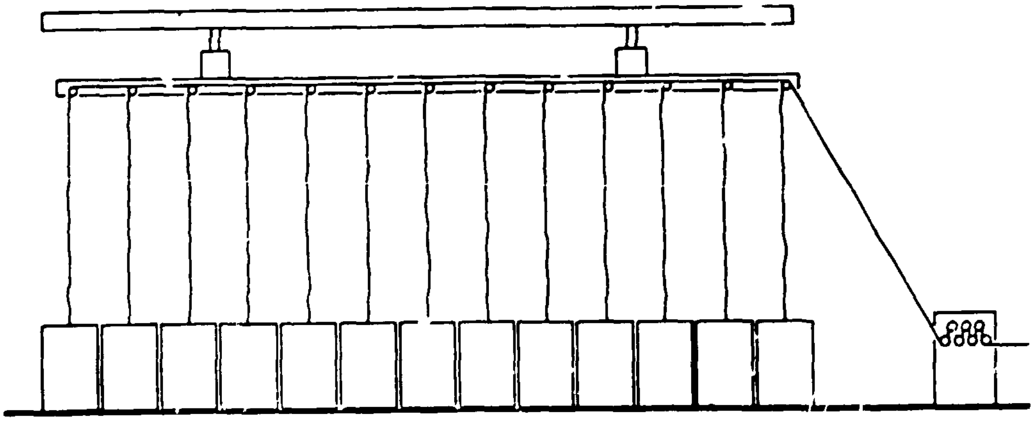


Fig. 18

Finish immersion bowl

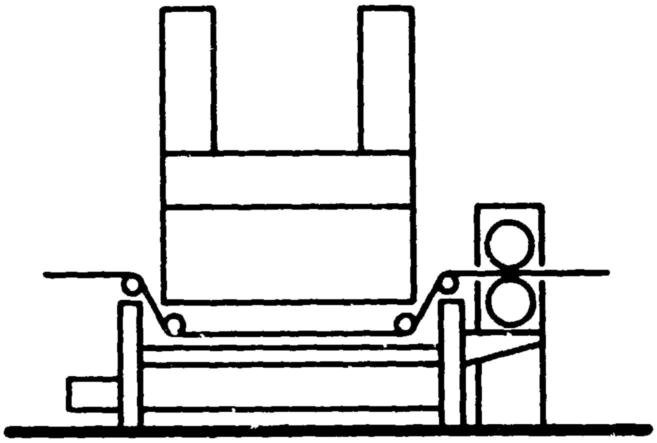


Fig. 19

Drawing units

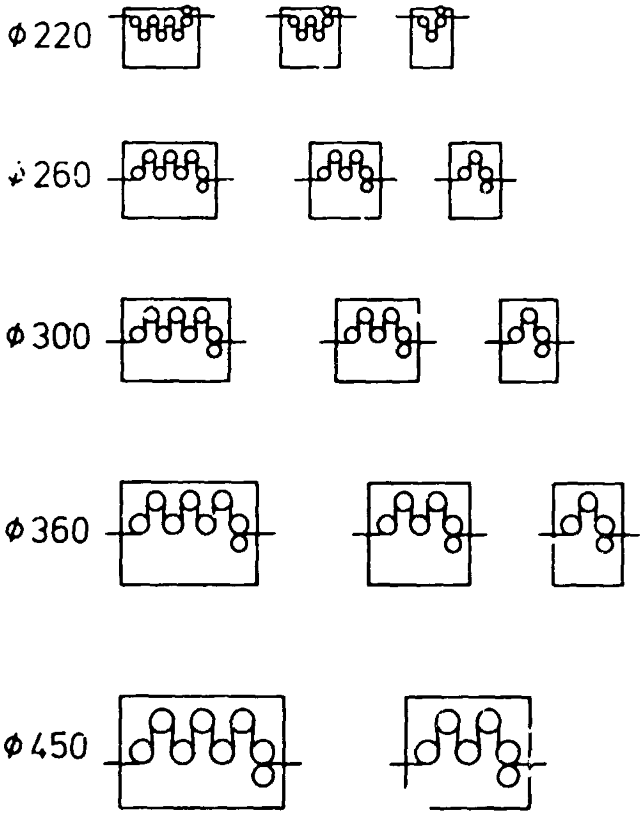


Fig. 20

Double coating godet

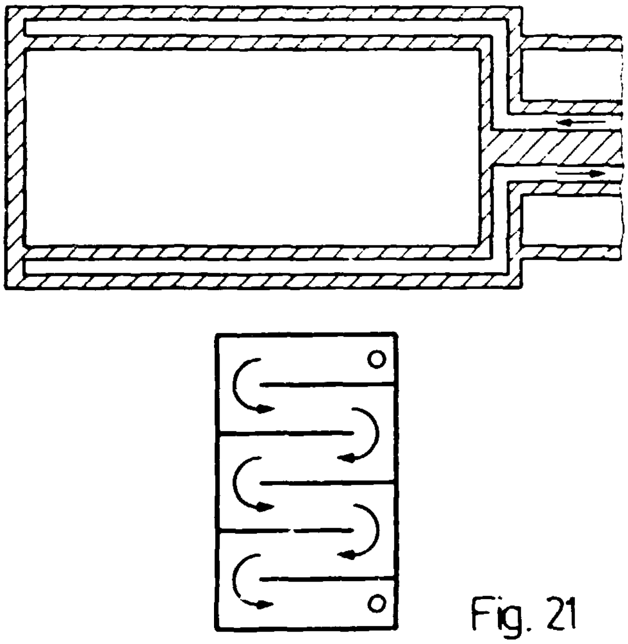


Fig. 21

Hollow space godet

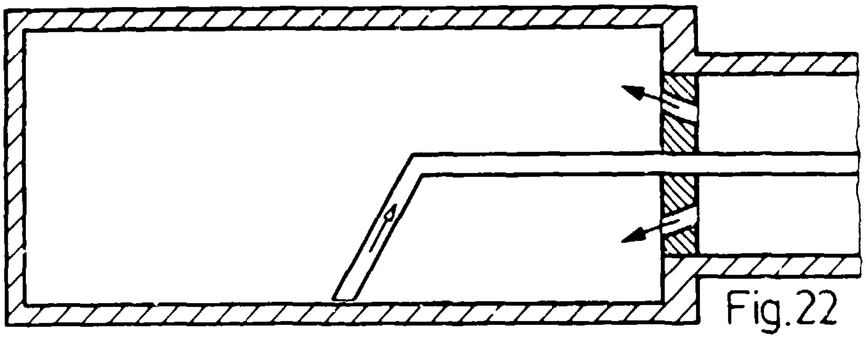


Fig. 22

Hot drawing

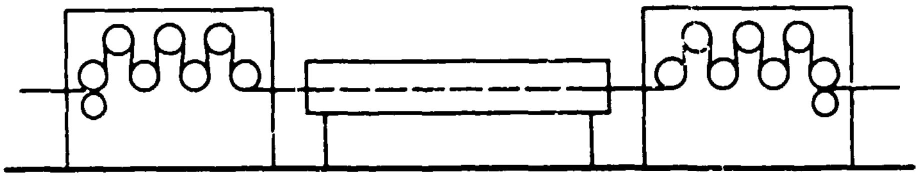


Fig. 23

Calender

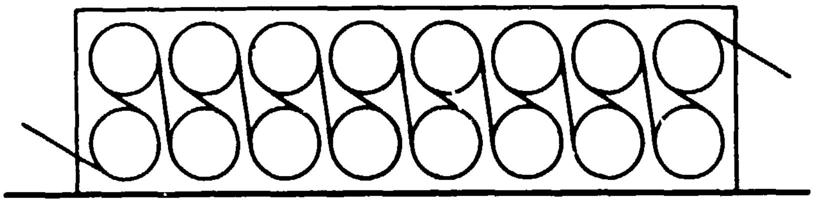


Fig. 24

Spray finishing

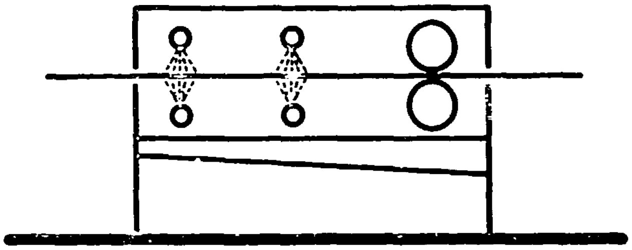


Fig. 25

Tow stacking unit

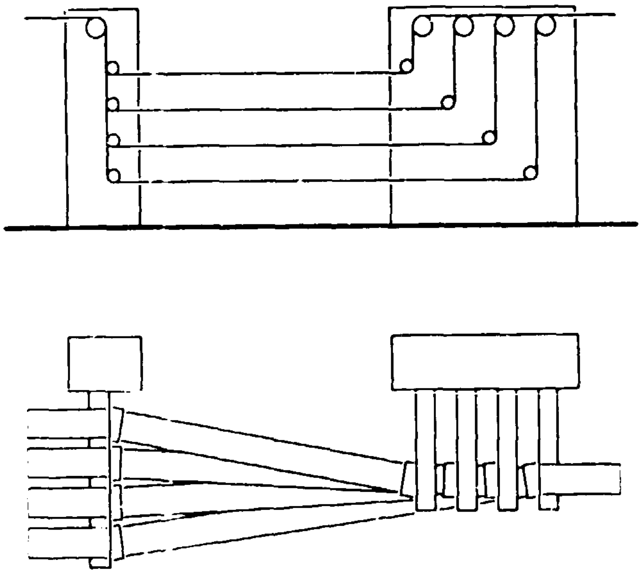


Fig. 26

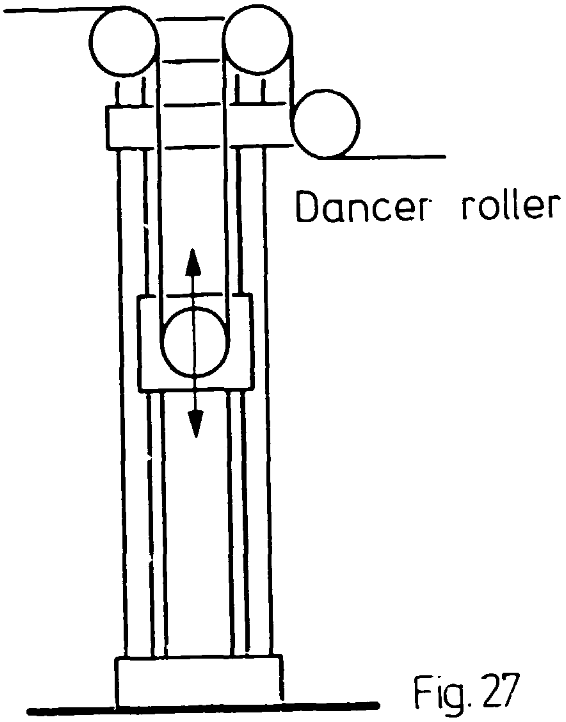


Fig. 27

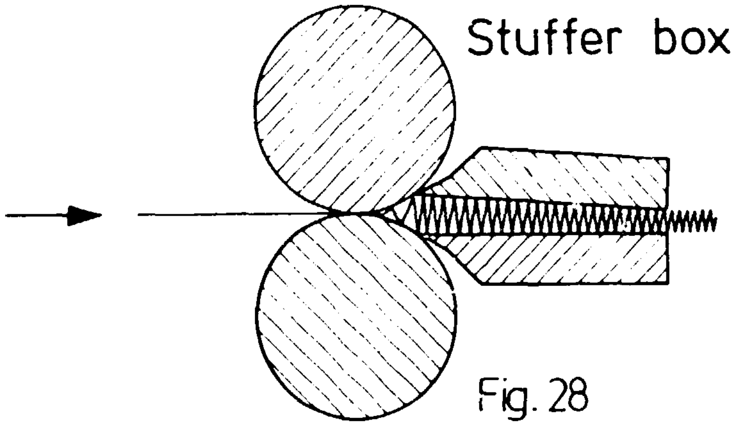


Fig. 28

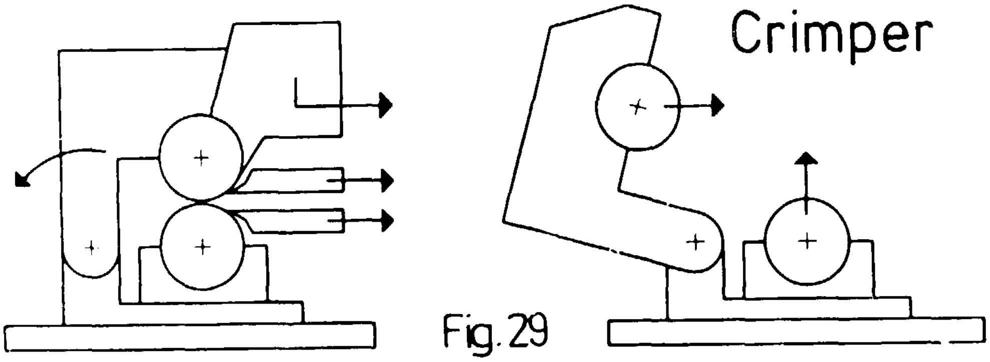


Fig. 29

Heatsetting - duct

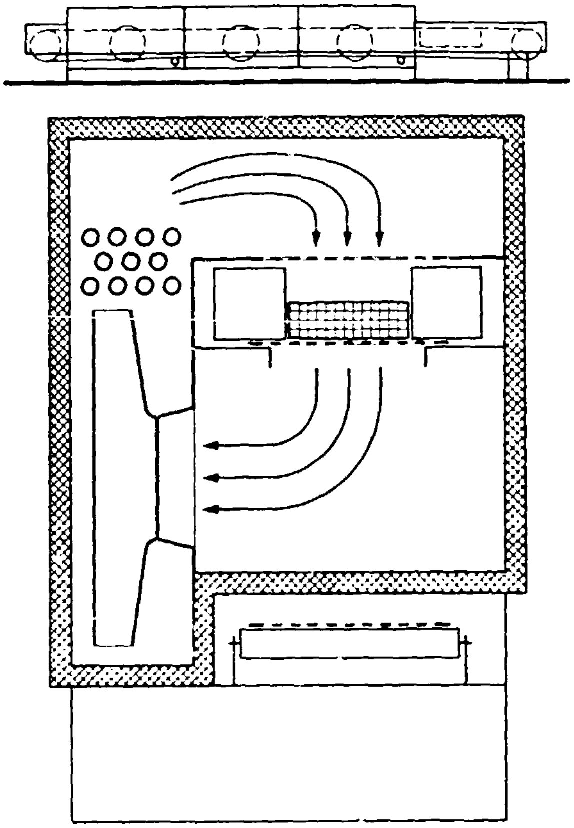


Fig. 30

Plate conveyor heatsetter

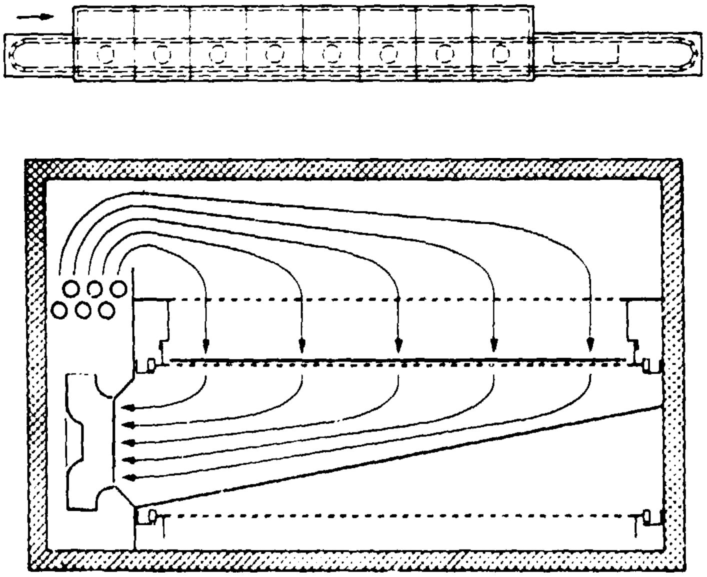


Fig. 31

Tow plaiter

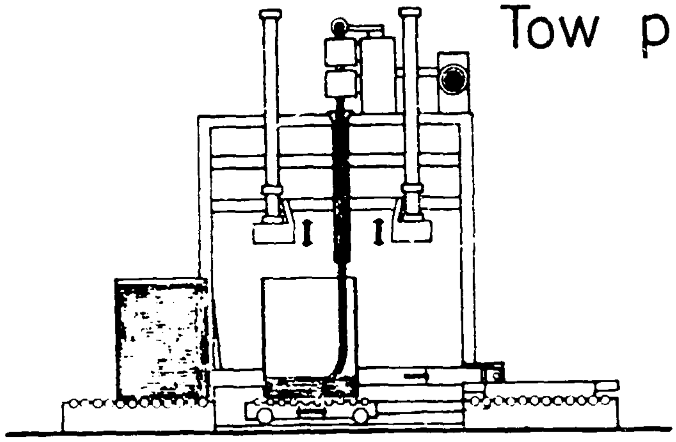


Fig. 32

Tow baler

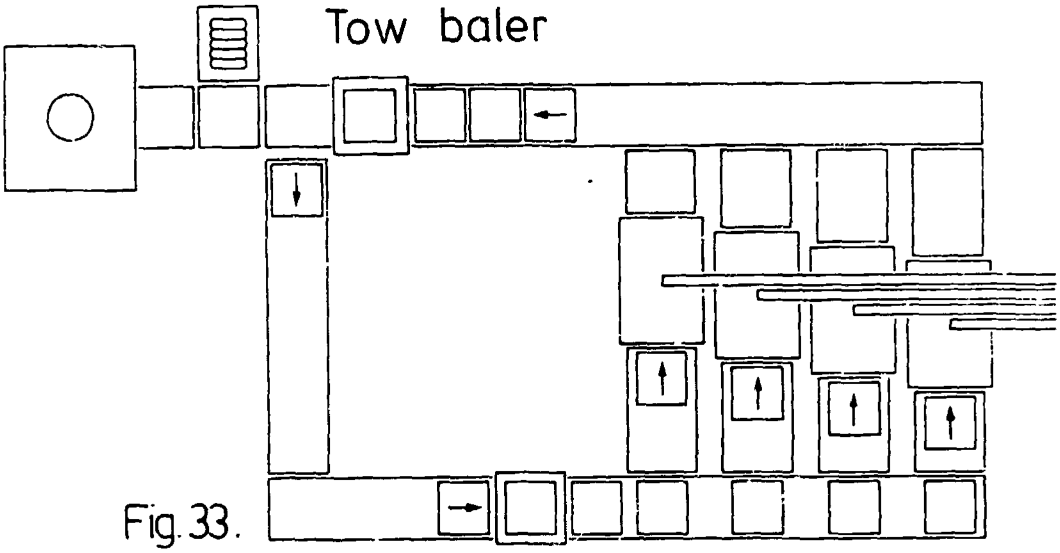


Fig. 33.

Cutting principle

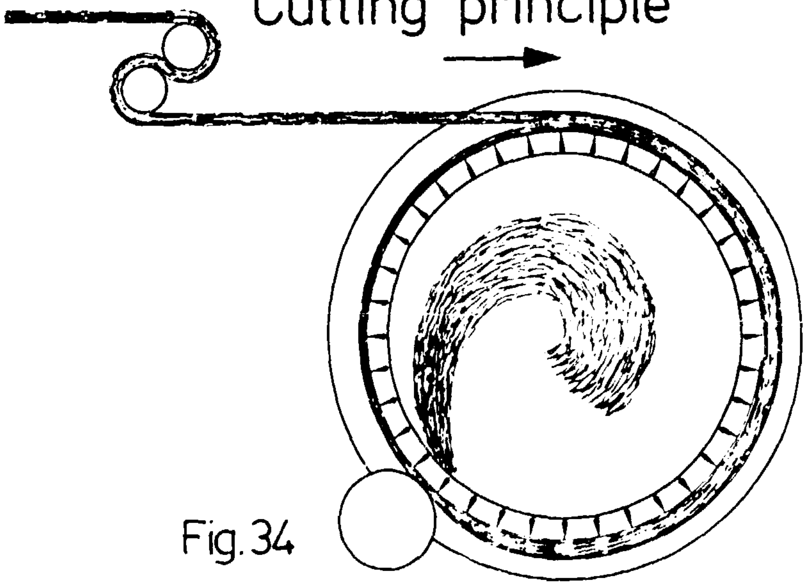
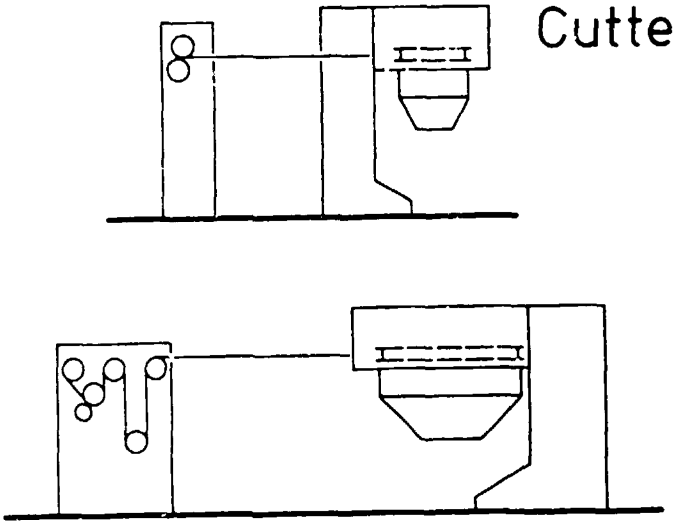
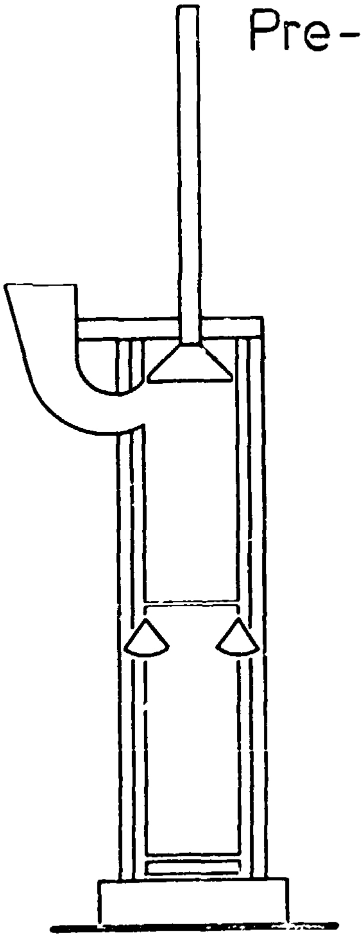


Fig. 34



Cutters

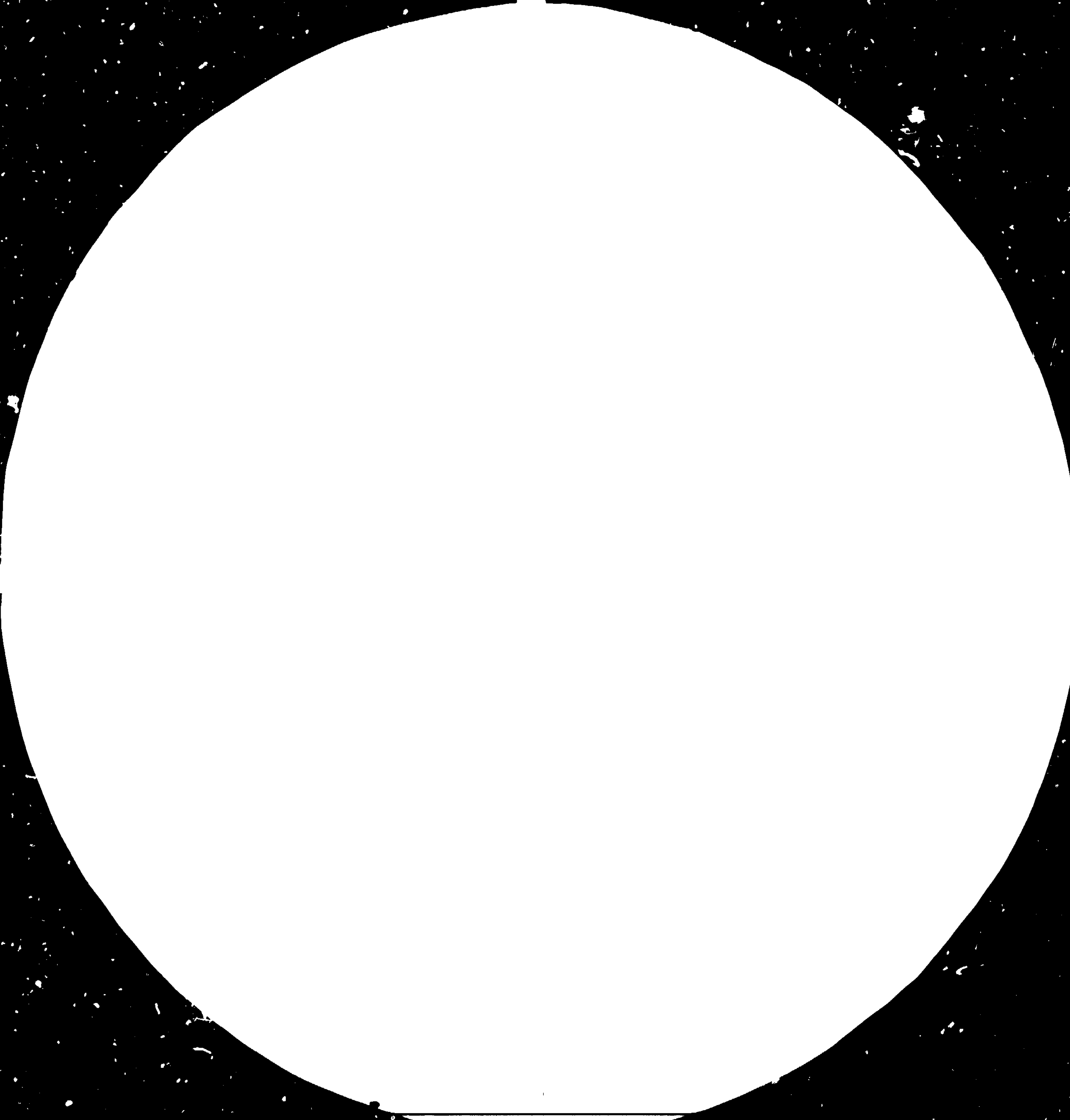
Fig. 35

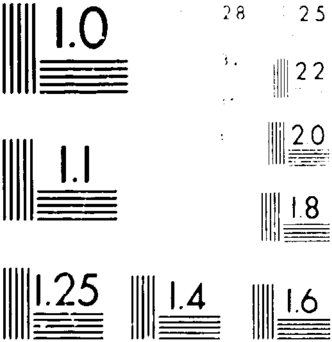


Pre-Press

Fig. 36

85.12.06




1.0
28
25
22
20
1.1
1.8
1.25
1.4
1.6

Fibre baler

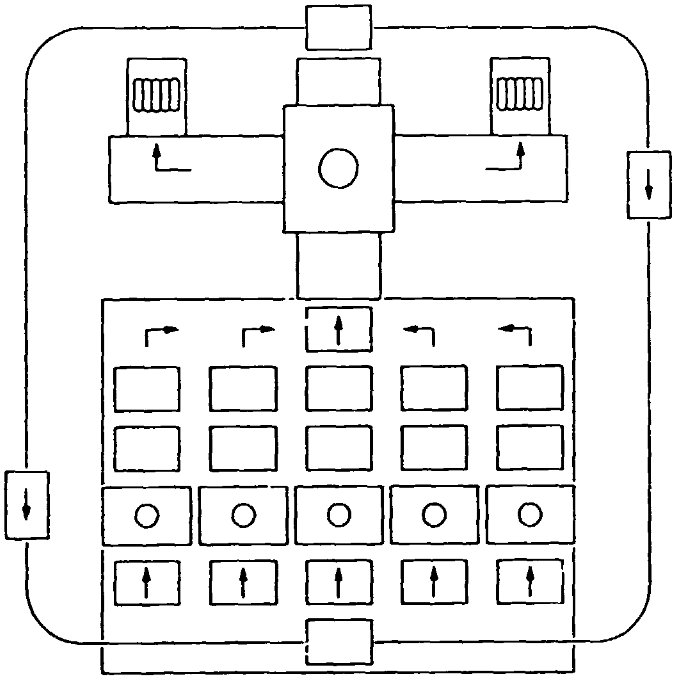


Fig. 37

Baler combined for tows and flocks

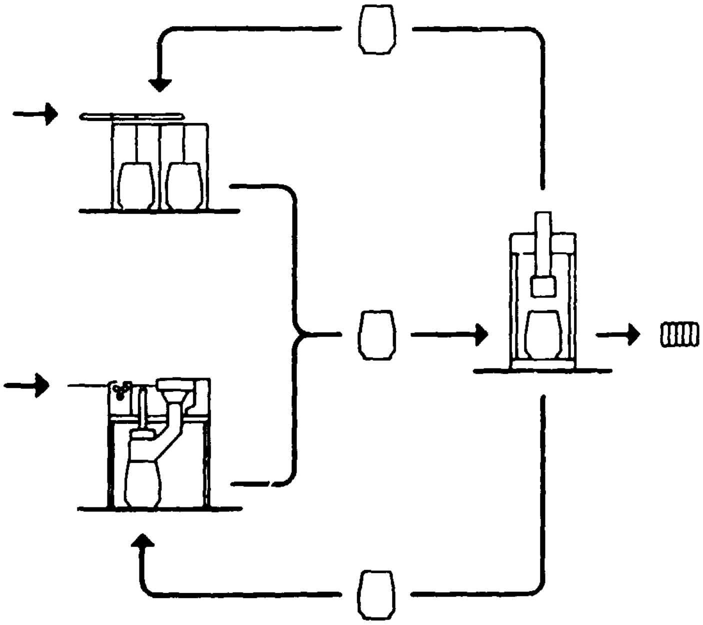


Fig. 39

Working method of the central tandem press

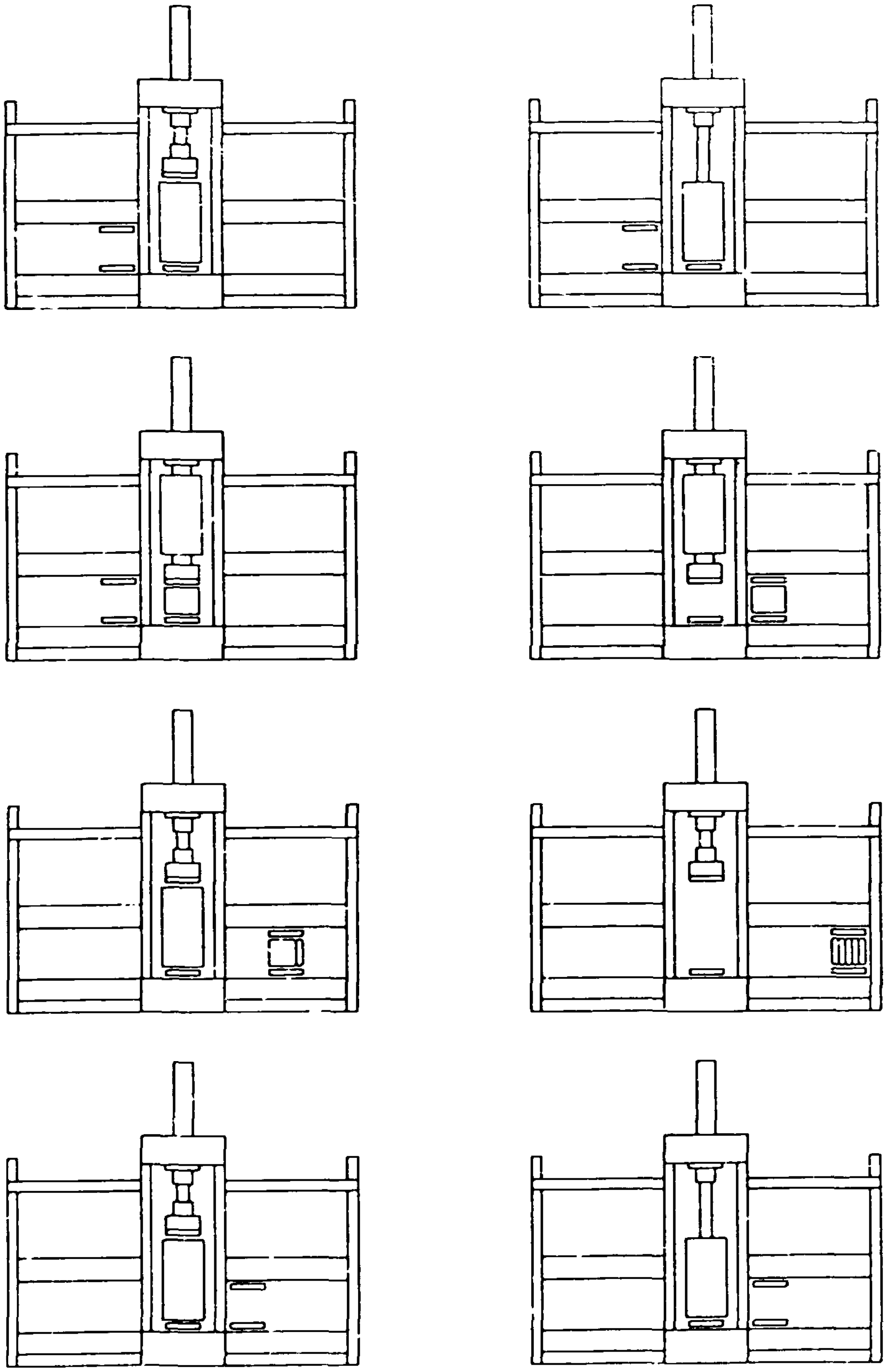


Fig. 38

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International Conference on
Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

SPUNBONDED WEBS
PRODUCTION AND APPLICATION AS GEO-TEXTILES

DR. ROMAN H. HOFFMEISTER
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Frankfurt/Main, Germany

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DR. ROMAN HOFFMEISTER was born in 1927 in Berlin/Germany. He received a Doctorate in Organic Chemistry from the University of Greifswald/Germany in 1955.

The following years he was an employee of a Synthetic Fibre producing company and then a Plant Manager of an Acrylic Fibre Plant. In 1970 he joined to Lurgi's Polymer and Fibre Division.

After being responsible for the Fibres R & D Facilities he at present is Deputy Head of Lurgi's Fibre Division.

Synopsis

The paper initially discusses the various methods of producing the non-woven material and then explains the difference and advantages of spunbonded web along with its manufacturing process. The suitability of polymers particularly polyester versus polypropylene have also been discussed. Application of spunbonded webs for various end-uses have been indicated. Special attention is paid to its use as "Geo-Textiles", a new civil engineering material, for roads, railroads, tunnel-construction, foundation engineering etc.

SPUNBONDED WEBS
PRODUCTION AND APPLICATION AS GEO-TEXTILES

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1. Introduction

In my today's topic there are two terms we have to look at a bit closer:

"Spunbondeds" and "Geo-textiles"

"Spunbondeds" are about 12 to 15 years old now, the term "Geotextiles" is half this age, nevertheless, there were materials used as Geotextiles much longer but there was no comprehensive word to describe this category of construction materials.

But let us start with the non-wovens first. Here, in general, we have to distinguish between two categories:

1. The first step is always the production of a virgin web which obtains its cohesion only on the entanglement of the fibres themselves.
2. Out of these virgin webs the true non-wovens fabric — the bonded product — is made by various consolidating processes which we shall discuss in a moment.

But let us first consider the various methods used for making the textile webs which form the first stage in the production of non-wovens. Here, four main methods are used, although they vary in importance:

1. The dry method, used for mechanically formed webs (using cards, possibly also cross-laying devices).
2. The dry method, for aerodynamically formed webs (using a variety of blowing methods).
3. The wet process, for hydrodynamically formed webs (using more or less modified papermaking machines).
4. Single-stage processes in which melt-spun filaments are immediately drawn and then deposited to form a random web for making spunbonded fabrics.

None of the textile webs produced by these four methods possess the desired properties to make them usable in a textile sense — they must somehow be consolidated because the cohesion between the individual fibres in the web is still much too low to withstand the stresses to which the end product will be subjected. These consolidation processes convert textile webs into non-woven bonded-fabrics. Consolidation may be achieved by the following techniques:

1. Chemical bonding by a dry method using a powder or fibres with a low melting point. The other chemical possibilities consist of spraying, impregnating, coating, partial solution or the use of threads consisting of two different materials.
2. Mechanical bonding, shrinking, needling, calendaring, sewing/knitting etc.

The enormous versatility of non-wovens is explained by the variations of the three components, namely

Slide-No.

(1) 1. the fibre (natural, regenerated or synthetic)

(2) 2. the process used to form the fibre web

(3) 3. the type of bonding used.

2. Spunbonded webs

The starting material for the dry and wet processes are staple fibres, whereas in Spunbonded webs the feed-stock are polymer granules, that means the step to produce staple-fibres can be omitted.

The term "spunbonded" expresses the characteristic feature of this process: spinning and bonding, including all intermediate steps in an integrated operation.

The first step of the process is conventional melt spinning comprising extruder, spin pumps and one or, usually, several spinnerets. Using thermoplastic materials such as polyamides, polyester or polyolefines (polyethylene, polypropylene, etc.) continuous filament is spun in the normal fashion, drawn off and stretched either mechanically or aero-dynamically.

(4) The next slide illustrates the Lurgi DOCAN-Process, which has a unique aerodynamical draw-off system. The air-jets are operated with high compressed air drawing the filaments up

to a speed of 3.500 to 4.000 m/min. This gives them exactly the properties of POY (Preoriented Yarn) as it is well known in synthetic fibres production. Only this drawing at very high speeds give a sufficient degree of drawing and, thus, optimal textile properties such as strength and elongation.

Using various techniques such as electrostatic charging, fanning the draw-off air stream—as in the DOCAN-Process —or the application of secondary air streams, the bundles are separated into individual filaments and carried to the web forming zone. Here they are deposited as random web on a moving screen belt, through which the surplus operating air is sucked off.

The excellent degree of separation and the absolute random arrangement of the filaments are most important for the lowest possible uneveness in the web as well as for the high elasticity expected from spunbonded webs.

By suitably setting the extrusion and spinning conditions as well as the speed of the screen belt, webs from 18 to 1000 g/m^2 can be manufactured. These virgin webs must be subjected to one of the consolidation processes. They can be needled, heatsealed, thermo-fused or chemically bonded.

Combinations of these are also possible. The choice of different polymers, deniers, fabric weights and consolidation methods permits the manufacture of an enormous number of webs differing in characteristics and applications.

Despite their many external appearances all spunbonded webs have two characteristics in common:

Spunbonded webs consist of continuous filaments and due to the random arrangement of these filaments are isotropic, i.e. they have equal properties in every direction.

As spunbonded webs consist of continuous filaments they possess a very high tear strength. Due to the random arrangement of the continuous filaments they exhibit this high tear strength in every direction. A further advantage—essentially needed in geo-textiles—is the high elasticity of the spunbonded webs in comparison with the wet and dry laid webs.

The post-treatment of the web is—as already mentioned—

the most important step as far as the end-use is concerned. Spunbondeds are mainly either needle-punched or calendered. The next slide shows the basic weight ranges for (5) these two post-treatment processes.

3. The applications

The webs with lower basic weights—the calendered ones—are used as diaper coverstock, in medical and surgical applications, as carrier-webs for PVC- and Polyurethane-coating in the matress-, upholstery and automotive industry. A considerable market have these webs also as primary carpet-backing for tufted carpets. These qualities are widely spread, hundreds of million of square meters are produced. Most of these products are produced with polypropylene as feed-stock, due to its outstanding heat-bonding properties and, of course, due to its comparatively low price against Polyester or Polyamides.

The higher-weighted webs which are needle-punched are used in the carpet-industry—as needle-punched carpets-, filtration media and with tremendous growth-rates as GEO-TEXTILES.

This brings us to the second term in our today's topic, the GEO-TEXTILES.

4. GEO-TEXTILES (G. T.)

They are relatively young construction materials, nevertheless, they have reached remarkable versatility and wide spreading. To be precise: Not all G. T. are spunbondeds or even webs. Also woven materials are used as G. T. and there are some composites in the market which comprise a combination of web and woven structures. But it is allowed to state that the majority of G. T. are spunbonded webs.

The GEO-TEXTILE-spunbonded web has a basic weight between 150 and 300 to 400 g/m². The width is preferably 5.0 meters.

Lurgi's DOCAN-licensee in Austria "Chemie Linz AG" which is producing DOCAN webs with a width of 2.5 meters have developed a special cross-drawing-process to enlarge the width of these 2.5 m webs to 4.5 to 5.0 meters. The combination of Lurgi's DOCAN-Process and this drawing step is of course a very economic inline operation from the Polymer chip to an end-use GEO-TEXTILE good.

These spunbonded/drawn G. T.'s have in different G. T. applications different tasks. These can be:

separation, filtration, drainage, load distribution or reinforcing.

Separation	means mechanical prevention of mixing of individual soil strata and penetration of fines into soils with high voidage.
Filtration	means free passage to the water holding back the soil.
Drainage	is the conductive ability of a material to lead-off water.
Load distribution	is needed where soil of poor bearing capacity has to be stabilized to safe-carry the structure on it.
Reinforcing	is needed where strength of a constructing material has to be improved.

All this sounds a bit theoretical. Let's, therefore, take a closer look on the different applications where spunbonded G. T. are used and how this is done:

Road Construction:

(6 - 9) PP-Spunbounded G. T. form an ideal separation and filter layer which prevents penetration of granular material into the subsoil, so that the load distribution effect of the applied filling will keep its full effect. The pore water is allowed to drain through the G. T. Any mixing of filling material and subsoil is prevented.

(10 - 12) **Civil Engineering Hydraulics**

Here, the filter effect of the G. T. prevents the washingout and subsurface erosion of the embankment, but ensures the unhindered water exchange between channel and ground water. Due to its flexibility, the G. T. splendidly adapts itself to the irregularities of the subsoil and the placed covering. It also resists the high mechanical strains which occur when the covering stones are placed

(13) Railroad Construction

The G. T. here is an effective plane filter and prevents extraction of soil out of the subsoil and its penetration into the upper ballast bed.

Settlements of the substructure, which are dangerous for the railroad construction and its operation, are prevented and what may be the most important thing, the necessity for expensive repair works does not arise.

(14) Tunnel Construction

This is a special application where the G. T. has a triple function. Applied between the shotcrete, i.e. the genuine rocks, and the concrete tunnel shell the G. T. acts as a mechanical high-stress course for protection of the water-insulating foil-layer, and drains the water leaking through the rocks and regulates and compensates the movements between the shotcrete and the tunnel shell.

(15) Foundation Engineering

Very often when the erection of a building is planned, unfavourable ground conditions are a problem. G. T. offer a number of solutions in foundation engineering:

filter effects, load distribution and separation between different soil layer may improve the local ground situation. During the last years Lurgi in cooperation with its licensee, Chemie Linz in Austria, has gathered a whole bundle of different know-hows to serve and solve all these problems.

The DOCAN based Polyfelt TS a 100 % Polypropylene Spunbounded Web is a very versatile material for the various applications which were mentioned here.

(16) Polypropylene as the starting material for this special G. T. has beside its attractive price very advantageous properties: UV-stabilized: the material can be stored for months at the construction-site even under extreme sunlight exposure without loosing strength.

(17) The resistence to hydrocarbons is good. In contact with concrete the Polypropylene-web keeps its strength for months, whereas a comparable Polyester-web, mainly in the presence of water will loose strength remarkably.

(18) Civil Engineering and Building construction G.T. are here not only used for foundations, they are also applied as roof insultation material called "Safecoats".

If one looks at the development of the G. T. the progress of the last 10 years is really surprising. Just to give you an idea of the magnitude of the market:

In Europe in 1977 the consumption was 45 Million m^2/a
in 1981 already more than 70 ,,

In the USA a forecast says that until 1985 the annual growth rate will be 25 %, the following years until 1990 still 12 to 14 % per year.

The total consumption in the US in 1980 was 85 million m^2
The cited report predicts for 1990 was 600 ,,

The dominating raw material will be Polypropylene is said.

To summarize: GEO-Textiles will have a tremendous growing market, the main-product amongst the G. T.'s are and will be the spunbonded webs, because of the very economic one-step processes to produce these non-wovens.

The main and by far dominating raw-material will be the Polypropylene.

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International Conference on
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POLYACRYLIC FIBRES — VARIOUS FORMS, THEIR PRODUCTION AND APPLICATION

B. v. FALKAI, Bayer AG
Dormagen, West Germany

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DR BELA VON FALKAI, born in Budapest, studied Chemistry at the Technical University of Budapest. During the World War II, he worked in a research institute for plastic materials in Hungary. He took the degree in 'Doctor rer. nat' in Mainz under the guidance of Prof. S. A. Stuart. Since 1956, he is working in the fibre division of Bayer AG in Dormagen. In 1961, he got the management of technical research spinning department and eight years later became the Head of the research laboratories and in 1970, got the degree of a confidential clerk. In 1973, he has the mastership for man-made fibres at the University of Stuttgart. In 1981, his book 'Synthesefasern' was edited by Verlag Chemie. His main fields of scientific work include physical and textile technological characterisation of man-made fibres and the technology of fibre production.

Synopsis

The paper discusses the growth in production of acrylic fibres during the period from 1960 to 1980, the reasons for this phenomenal growth and covers all aspects from production to application. The production process is dealt in detail which includes the minimum size of plant required, production of the spinning solution, different spinning processes and the after treatment such as scouring, stretching, crimping etc. given to the fibres. The acrylic fibres are then classified, based on chemical composition which governs the dyeability and the modifications carried out for giving it specific properties. The textile characteristics, chemical properties, physical structure and future problems of these fibres and the suitability for its utility for different types of fabrics have been elaborated.

POLYACRYLIC FIBRES — VARIOUS FORMS, THEIR PRODUCTION AND APPLICATION

B. v. FALKAI, Bayer AG
Dormagen, West Germany

Introduction

Acrylic fibres have made a decisive contribution to the rapid development of manmade fibres over the past 20 years. From Table 1 it can be seen that, up to the end of 1980, their production had increased by about twenty times since 1960 and thus accounted for 18 % of the total production of synthetic manmade fibres. Despite the high growth rates of synthetic manmade fibres generally and polyester fibres in particular, the proportion of acrylic fibres has remained virtually constant during this period.

Since the production of polyacrylonitrile filament yarns is very small, the proportion of acrylic staple fibres is equal to about 35 % of the total synthetic staple fibre production throughout the world.

If we look at these figures, we might ask ourselves why this considerable growth took place. In our opinion, it can be characterized as follows:

The technical perfection and both qualitative and economic optimization of the technology behind the production of the raw materia led to a considerable reduction in the price of acrylonitrile compared wit other fibre raw materials. Table 2 shows the world market prices (as at first quarter 1982) of the major manmade fibre raw materials. The price of the acrylonitrile monomer is still very favourable compared with caprolactam and AH salt. The various possibilities for polymerizing acrylonitrile allow, compared with other monomers, more economical processes to be used and, at the same time, permit virtually universal control of the chemical composition and molecular weight distribution through the addition polymerization.

The polymer offers many possibilities of modification for obtaining specific property data for a wide variety of applications. The range (unbleached fibre, dope-dyed, shrinkage fibres, converter tow, tops etc.) offered by the manmade fibre manufacturers as well as the excellent performance properties enable the use of economical processing methods, considerable versatility in the textile and technical fields of application and the ability to keep up with the latest fashion trends.

1. The production of acrylic fibres

It would probably be useful at this stage to briefly describe the entire production of staple fibres with the aid of a diagram. The process itself can be seen in the Fig. 1. The most important steps in the production of the fibres — which is carried out in solution by the dry or wet spinning method because of the fact that the polyacrylonitrile will not melt — are thus the polymer production, dissolving the polymer, spinning and aftertreatment.

To obtain an acrylic fibre of good quality with a sufficient profit margin, a high level of specific know-how is required. Since the economy of fibre production is also linked to a certain minimum capacity, it has been found — as an analysis shows — that only plants in the order of 6,000 — 140,000 t/year are in operation. The smallest production unit for polyacrylonitrile fibres is around 5,000 — 7,000 t/year. These are wet-spinning capacities. The smallest capacity for a dry-spinning unit is given as 10,000 t/year.

Of the total capacity of 2,128 million t/year covered by the analysis, 718,000 t/year (34 %) is accounted for by plants producing 5,000 — 50,000 t/year, 895,000 t/year (42 %) by plants with 51,000—100,000 t/year (24 %) by plants producing 120,000 — 140,000 t/year [1].

Figure 2 shows the capacities of certain sizes of plant. The capacities of single plants have been rounded off into figures divisible by 6,000 t.

1.1 Production of the polymer

The principle monomer for the production of all the polymers used for manufacturing acrylic fibres is acrylonitrile. At least 85 % must be contained in every acrylic fibre, since the valuable properties of the fibre (light stability, dimensional stability, high elasticity) are only guaranteed down to an acrylonitrile content of approx. 85 %. Acrylic fibres with an acrylonitrile content of less than 85 % are known as modacrylics.

With decreasing content of acrylinitrile, the regularity of the molecular structure declines, in other words, heat resistance, light and dimensional stability, chemical resistance and modulus of elasticity all deteriorate. In addition, the solubility of the fibre in various organic solvents increases.

In his paper, Professor Herlinger has already referred in detail to these relationships but, for the sake of completeness, they should be briefly mentioned again here.

The lack of any functional groups apart from nitrile groups makes dyeing more difficult, whereas the high regularity of the molecular structure gives rise to the difficulty in dissolving the polymer. The introduction of 5 - 10 % comonomers, such as vinylacetete, methylacrylate or methylmethacrylate increases the flexibility of the macromolecules, facilitaties dissolving of the polymer, improves accessibility of the fibre for diffusion of the dyestuffs and also makes it possible to obtain fibres with a given level of shrinkage. The additional introduction of 2 — 3 % vinyl monomers with carboxyl, sulpho or pyridine groups means that the polyacrylinitrile fibres can be dyed with basic (cationic) or acid dyestuffs without impairing the other fibre properties.

For this reason, the acrylic fibres produced at present for textile applications are generally obtained from a ternary copolymer.

The homopolymer of polyacrylonitrile is only used where technical fibre types are being produced. These fields of application will be discussed later.

Acrylinitrile can be polymerized in mass, in emulsion and in solvents or can be obtained by suspension polymerization in water.

With suspension polymerization, the polymers for the production of acrylic fibres are, in the vast majority of cases, produced by continuous suspension polymerization in water.

The *suspension polymerization* is generally initiated by redox systems soluble in water, e.g. by sodium chlorate/sodium sulphite, hydrogen peroxide/thioglycerin etc. Particularly important is the redox system sodium bisulphite/ potassium persulphate, whereby more sodium bisulphite is added than potassium persulphate. By means of acids, e.g. sulphuric acid, the pH is adjusted to between 1 and 4. The polymer becomes insoluble in water even at molecule masses of only a few hundred, with the result that the polymerization continues with insoluble macroradicals, using up adsorbed monomer particles, until it is broken off by bimolecular reactions.

The initiator concentration is between 0.1 and 5 %, calculated on the quantity of monomer. Polymerization is best carried out at 40 - 55 °C, with the heat of polymerization being eliminated by cooling.

The polyacrylonitrile produced by the technical redox polymerization in water is a white powder. The normal molecule masses Mw lye between 80,000 and 180,000 [2].

For the final product, the fibre, it is above all the consistency of the properties which is important. This means consistency of the technological properties, the natural shade (whiteness) and the dyeing properties. For the polymer, it means consistency of the chemical composition, molecule mass, molecule mass distribution and whiteness. These values are therefore constantly controlled during the course of polymerization.

A large amount of development work has also been carried out in the field of *solution polymerization* [3]. Only a few manufacturers have, however, decided to set up production facilities for working with this process. The reason is that, with suspension polymerization and the production of the spinning dope by dissolving the polymer, it is easier to produce the various copolymers in the same unit, in other words a wide range of different polymer types can be manufactured in one and the same plant.

Since, in practice, the question of the spinning properties (spinnability) of a solution is one of the basic problems in fibre production, and since spinnability is, with certain restrictions, particularly dependent on the quality of the spinning dope, it is intended, after discussing the production of the polymer, to deal with the preparation and characteristics of the spinning dope.

1.2 Production of the spinning solution

Polyacrylonitrile is very difficultly soluble or not at all soluble in most of the familiar solvents. This is due to the high regularity of the molecule structure and the presence of strong intermolecular nitrile/nitrile bonds. In the meantime, however, more than 20 solvents have been found and 7 of these are actually used in practice.

The part played by the individual solvents in the present world production of acrylic fibres is probably in line with the estimates given in Table 3.

Due to both historical and technological factors, dimethyl formamide holds the leading position as a universal solvent for acrylic fibre production and is, in our opinion, likely to continue to do so in the future.

The polymerization and solvent variations used today on an industrial scale are summarized schematically in Table 4 together with the spinning principles used.

Economic calculations have shown that the use of dimethyl formamide, concentrated NaSCN solutions, ethylene carbonate and concentrated HNO_3 solutions as solvents are all the same from an economic point of view, since the recovery of the cheaper solvents (concentrated NaSCN and HNO_3 solutions) is more complicated and expensive than recovery of the more expensive organic solvents.

The technological properties of the spinning solutions of polyacrylonitrile in various solvents differ considerably. The polymer is chemically stable in all solvents except concentrated HNO_3. In an HNO_3 solution, the polymer undergoes slow hydrolysis at 0 °C, but at higher temperatures a rapid hydrolysis with a gradual conversion of the nitrile groups into amide and carboxyl groups. This can lead to differences in shade when dyeing the filaments. As far as the viscosity is concerned, the spinning solutions differ considerably from one another. It is possible, for example, to obtain spinning solutions of equal viscosity (500 s by a falling ball method) from one and the same starting polymer when its concentration corresponds to the data given in Table 5.

A fibre manufacturer who uses, for example, concentrated NaSCN solution will therefore require 50 % more solvent than he would if he used DMF and will consequently also need more room for containers and filter presses.

The stability of the spinning solutions in various solvents during storage and heating depends on the particular solvent. Concentrated polyacrylonitrile solutions in Na SCN solutions have sufficient stability during storage and heating. Spinning solutions in dimethyl formamide must not be kept at much below 70 °C or for a prolonged period above 100 °C. At low temperatures, gelling occurs via secondary valence forces, and at high temperatures, gelling results from crosslinking reactions. The higher the viscosity of the solution and the molecular mass of the polymer, the greater is the tendency to gelling, and the more uniform the molecular weight of the polymer, the lower is this tendency to gelling [4].

Aqueous zinc chloride solutions and solutions in dimethyl sulphoxide and ethylene carbonate also have a tendency to gelling.

Now let us deal with the spinning processes.

1.3 Spinning of the polyacrylonitrile fibres

Since, as has already been mentioned, polyacrylinitrile cannot be melted, acrylic fibres can only be produced in solution either by the dry or the wet-spinning method.

The difference between wet and dry spinning lies, in theory, only in the actual spinning process and the coiling of the tow, which is a necessary intermediate stage in dry spinning. The other machines and equipment can be used both in the dry and the wet-spinning processes.

It would probably be a good idea now to have another look at Figure 1, which shows the production of staple fibres in its entirety. Thus the most important steps in fibre production are polymer production, dissolving, spinning and aftertreatment.

1.3.1 Dry spinning process

The dry spinning process is very old. It is now about 70 years ago that the very first filament yarn, Chardonnet artificial silk, was manufactured from nitrocellulose by this method. Nowadays, the acetate spinning process is the oldest existing dry-spinning method and can, to a certain extent, be regarded as the prototype of dry spinning. The production of acrylic fibres by this process was begun nearly 30 years ago using the solvent dimethyl formamide.

Particularly with the dry-spinning process, it is very important when selecting the solvent to take into account not only the good dissolving power, but also other aspects such as boiling point, heat of evaporation, thermal stability, possibilities of recovery, inertness towards the dissolved material, non-toxicity and a low tendency to electrostatic charges and explosions. According to these criteria, dimethyl formamide would seem to be a very suitable solvent for polyacrylonitrile [5].

The technical process of dry spinning is extremely simple in that the spinning solution emerging from the spinnerets is freed of the solvent by means of hot air. The coagulation takes place in vertical spinning chambers, in which heated air or a heated inert gas is fed in co-current or countercurrent to the spinning solution, which is emerging through a number of very fine holes. With the dry-spinning process, the filaments are generally spun from top to bottom, in other words the spinning solution is fed into the spinning chamber from the top and the finished filament drawn off at the bottom. Use is thus made of the forces of gravity. The air generally flows in the same direction as the filament.

The spinning chamber consists of a spinning head and a fall tube, in which the solvent is evaporated from the fibres as they are formed. The fall tube is therefore provided with a heated jacket, which can be brought to the desired temperature by means of a heating liquid. Below the spinning chamber is a take-off device, which takes the bundle of fibres as it is formed. Fig. 3 shows a spinning head.

It is understandable that, over the course of time, fibre manufacturers have considerably improved the dry-spinning process and the spinning machines for reasons of economy and to improve the quality. It has, for example, been possible to increase the efficiency of the spinning positions by adopting technical measures, such as afterheating the spinning air before entry into every spinning chamber and through the central opening of the ring-shaped spinneret. According to various publications, spinnerets are nowadays being manufactured for dry spinning with, depending on the spinning titre, between 200 and 2,000 orifices [1].

The throughput velocities nowadays being used range from 250 - 350 m/min, depending on the fibre titre.

As has been discussed earlier, the coagulation of the filament takes place through diffusion of the solvent through the already solidified fibre surface, resulting in the fibre form shown in the next picture (Fig. 4). The unstretched filaments have areas with a spongy structure in their dumb-bell-shaped cross section — a sign that these filaments are permeated with cavities. The surface is relatively smooth and structureless. Through a suitable aftertreatment, this sponge-like structure inside the capillaries disappears completely. Fine longitudinal cracks can be seen on the surface, although the outlines on the whole appear rather more washy. With the aid of suitable subsequent processes, it is thus possible to produce a virtually compact structure.

The overall properties of dry-spun fibres will be discussed in comparison with those of the wet-spun fibre after dealing with the process of wet spinning.

1.3.2. Wet-spinning process

The second spinning process used for the production of acrylic fibres is the wet-spinning method. Without making a qualitative assessment, it can be said that, in the last twenty years, mainly as a result of the patent protection set up by DuPont and Bayer for the dry-spinning process, there has been a development towards wet spinning, irrespective of the differences in the quality and properties of the fibres resulting from the two processes. These will be discussed later.

Worldwide, approx. 70 % of polyacrylonitrile fibres are at present manufactured by the wet-spinning method and approx. 30 % by dry-spinning.

With the wet-spinning process, the direct spinning operation is not interrupted as it is with dry spinning; aftertreatment follows on continuously.

The principle of the wet-spinning process is the transfer of the polymer in fibre form into the precipitating bath in which the filament is solidified. A characteristic of wet-spinning is the diffusion, accompanied by osmotic processes. There are two directions in which the diffusion can take place. Firstly, there is with all precipitations a diffusion of solvent into the precipitating medium. This process then leads to an increase in the concentration of the polymer in the spinning solution and finally to coagulation. The other possibility, diffusion of precipitating medium into the spinning solution, is a necessary condition for coagulation and solidification. In addition to the loss of solvent through diffusion, there is also a displacement of the solvent through the precipitating medium; the polymer finally congeals into a dilute, highly swollen gel. It is logical that, depending on the solvent-precipitating bath combinations, filaments can be manufactured with varying cross-sectional forms. In the next illustration (Fig. 5), cross sections and surfaces of wet-spun filaments are shown after spinning and after drawing. As with dry-spun material, the aftertreatment is intended to produce a more compact structure.

Besides the coagulation variables we have already dealt with, other process parameters, which affect the structure of the freshly spun filaments and the properties of the final fibre, have to be taken into account. Among the possible variables which have a direct influence on the filament forming process are, in particular, the solution concentration, the temperature and composition of the precipitation bath and the throughput velocity.

As the concentration of the spinning solution increases, for example, so the homogeneity of the fibre structure improves under otherwise constant conditions. As is shown in Figure 6, this is expressed as a distinct reduction in the cavities.

Since the throughput velocity is a criterion both for the spinning properties and for the economy of the process, maximum throughput velocities are aimed at. Fig. 7 shows the relationship between the maximum throughput velocity and important spinning parameters of a polyacrylonitrile dimethyl formamide solution polymer spinning solution. It is evident from the illustration that some of the process parameters run contrary to one another, which makes careful optimization essential [6].

1.3.3 Melt-spinning process

Since, with polyacrylonitrile, the decomposition temperature is, under normal conditions, lower than the melt temperature, people started considering some time ago how to lower the melt range and make melt spinning of the polymer possible. The advantage of this process could be that no solvents are required and, as a result, production costs are therefore lower.

It was realized as early as 1952 that, at room temperature, mixtures of 40 — 70 % polyacrylonitrile and 30 — 60 % solvent, e.g. tetramethylene sulphone, could be processed in a kind of melt-spinning process.

In fact, it was even earlier, in 1948, that the production of melt-spun fibres using water as the softener was described. Since this process proved to be practicable, several fibre manufacturers have recently been following this direction of development. It was found that the presence of water caused the formation of hydrate with the nitrile groups of the polymer, resulting in a lowering of the melt point of the system. The melts are, for example, produced at temperatures of around 180 — 200 °C, spun at 160 — 190 °C with pressures of 30 — 50 bar and drawn off at speeds of between 40 and 150 m/min. Special care has to be taken to avoid bubbles in the spinning material. To do this, degassing of the frozen melt, spinning into a pressure chamber containing water vapour and an accelerated cooling of the filaments are recommended. It is possible to produce titres not only in the textile range, but also coarse titres up to 80 dtex and even up to 1,000 dtex [7].

Before production can be started up on an industrial scale, several problems with this interesting process still have to be solved.

1.4 Aftertreatment

The next process in fibre manufacture is the aftertreatment. It is a complex procedure and involves stretching, scouring, softening, drying, crimping, in some cases cutting and finally packing the spun material.

In the wet-spinning process, the filaments run direct to the aftertreatment. With dry spinning, the filaments coiled in cans are put together into slivers of 40 — 100 g/m and are aftertreated with several slivers at a time.

Scouring. Residual solvents and salts are washed out with hot water. Scouring is frequently performed before drawing, because the time spent in the scour baths is then, because of the relatively slow sliver speed before stretching, long and the scouring process accordingly intensive.

Stretching. The fibres spun at the usual spinning velocities have a high level of deformability in the unstretched state because of the low orientation of the chain molecules. One of the most important aftertreatment processes is therefore the drawing, which gives the fibre the necessary strength while reducing at the same time the elongation at break and titre of the individual fibre. Through the drawing operation, the chain molecules are oriented in the longitudinal fibre direction — a process which, during conventional spinning, was introduced through the draft. During the stretching process, the degree of order of the fibre structure also increases.

Wet-spun filaments are stretched to a greater degree than dry-spun filaments. The draw ratio generally lies between 1 : 2 and 1 : 10. After one or multi-step drawing, the fibres have a shrinkage at the boil, which, depending on the draw ratio and drawing temperature, lies between 15 and 45 %. This behaviour is utilized for manufacturing shrinkable fibres. Hot water is the preferred stretching medium. Also used are steam, godets and higher boiling liquids, e.g. glycerin.

Finishing. The aim of this finishing process is to prevent electrostatic charges building up during further processing of the fibres and to give the surface the right amount of adhesion and smoothness. Normally, anionic compounds are applied to the fibre from an aqueous medium, e.g. ethoxylated fatty acids, salts of ethoxylated sulphonic acids or phosphoric esters of long-chain aliphatic alcohols. The concentration of finishing agent is 0.2 — 0.5 %

Crimping. The type of crimp is important for the processing of the fibres because of its effect of increasing adhesion, but it is also important for the appearance and the handle of the yarns made out of the fibres. The crimping is generally undertaken in stuffer boxes before or after drying. Its nature is determined by the comonomer content of the polymer, the presence of softening substances, e.g. water, the crimping temperature and the stuffing pressure.

Drying. In the drying process, the fibres are dried to a moisture content of 1 — 2 %. When dried under tension, the fibres must subsequently be subjected to a relaxing operation, which generally involves steaming. Where the fibres are dried without tension, e.g. when drying loosely coiled slivers or cut fibres, the shrinkage of the fibres is released and thereby eliminated. By steaming, the effectiveness of the shrinkage process of the fibres is increased.

Cutting and packing. For producing continuous tow for processing on stretch-breaking machines, the crimped and dried slivers are laid into cardboard boxes and packed. For producing staple fibres, they are normally cut into lengths of 40, 60, 100 or 150 mm, depending on the intended application. The cut fibres are pressed into bales on baling presses and then packed.

Having dealt in detail with the production technology, let us have a look at the properties of acrylic fibres.

2. Properties

It is not possible to directly deduce what the quality of the spun fibres will be from the production process. It is, in fact, the details of the manufaccturing process (type of comonomer, polymerization conditions, spin-drawing and aftertreatment etc.) which basically determine the overall properties of the end-product. For this reason, it is also difficult to compare the properties of wet-spun and dry-spun filaments. This is because the general technological properties of the fibre can, in some cases, be varied considerably even within one particular process.

There are nevertheless some points which are characteristic of the individual processes: because of their cross-sectional form, dry-spun fibres generally have a higher opacity, higher bulk, better recovery and a fuller handle than the wet-spun types. The latter, on the other hand, are somewhat softer and fluffier. This applies particularly to fine titres from 1.5 to 3.3 dtex. Coarse titres of more than 20 dtex are predominantly wet-spun, because dry spinning of such coarse titres produces problems and the fibre also takes on a softer handle — a factor which compensates a little for the greater rigidity caused by the cross-section. As regards the dyeing properties (basic, acid) and shrinkage behaviour (S - shrinkage fibre, HS - high-shrinkage fibre), in other words the properties relating to the substrate, wet and dry-spun yarns behave virtually the same.

Before discussing the technological properties, we should first look at the various acrylic types.

2.1. Classification of the acrylic fibres

There are certain aspects which are normally taken to classify the range of acrylic fibres.

The *chemical composition* governs special properties which are used for classification :

basic-dyeable
deep-dyeable
acid-dyeable
self-crimping
flame-retardant

Other characteristics such as bright, dull, brightened and dope-dyes are also usual.

A subdivision into *staple fibre* and *tow* takes into account the different possibilities for processing: staple fibres for the processes of carded wool spinning, cotton spinning, worsted spinning and OE-spinning, tow for processing on the stretch-breaking machine with the subsequent spinning process.

From the classification according to *titre* and *staple*, the processor can select the most suitable type for the particular article he is making. On the basis of wide-ranging tests and a considerable amount of experience, manufacturers have developed particular recommendations for certain fields of applications as far as the choice of types and method of processing are concerned.

The range of titre (in dtex) covers

1.6; 2.2; 2.6; 3.3; 5.0; 6.7; 11.0; 15.0; 17.0;

Very recently, ultra-fine fibres with a titre of around 0.5 dtex have also been manufactured.

Staple lengths (in mm) are

28, 40, 50, 60, 80, 100, 120, 150.

Physical modifications, which are important for the properties of the final article, are also used for classification purposes

As far as fibre shrinkage is concerned, a distinction is made between

N-fibre (shrinkage 0 — 2 %)
s-fibre (shrinkage approx. 20 %)
HS-fibre (shrinkage approx. 40 %)

Shrinkable fibres are primarily manufactured from tow by stretch-breaking on the stretch breaking machine. Generally speaking, the fibre shrinkage obtained on the stretch-breaker lies between 15 and 24 %. By taking special measures during production of the tow and stretch-breaking, it is also possible to produce fibre shrinkage of between 24 and 40 %.

Shrinkable staple fibres are generally with two levels of shrinkage: S-fibres with approx. 20 % shrinkage and HS-fibres with 35 — 40 % shrinkage.

Shrinkable fibres are frequently blended with non-shrinkable fibres to give high-bulk yarns, which are noted for their high volume. High-shrinkage fibres are also used as underhair in fur imitations, for multistage plushes and in felts.

The required level of shrinkage in the production of shrinkable fibres can best be set through the appropriate choice of draw ratio and drawing temperature, followed by careful drying. Care must, however, also be taken that the shrinkable fibre is free of cavities so that no electrostatic problems can arise during further processing and no changes in colour or lustre can occur in the processed fibre. Good technological data are also required. Criteria for a cavity-free structure are negative birefringence and a density above 1.180 g/cm^3.

The type of *crimp* is also a criterion which affects the characteristics of the final material. Qualitative data concerning crimp.contraction anc crimp stability (light, medium, strong) are used for the purpose of characterization.

Bicomponent fibres. Whereas the form of a mechanically crimped fibre is more of a pointed arch, it is possible with bicomponent crimp to achieve a three-dimensional crimp effect. The various types of crimp are shown diagrammatically in the next picture (Fig. 8).

Of commercial importance is the "side-by-side" type, in which the two components are positioned eccentrically in the cross section and run along the entire fibre (Fig. 9). It is the differing shrinkage of the two components forming the fibre which causes the three-dimensional fibre crimp. This difference in shrinkage between the two components is brought about by varying the content of comonomers. If there is a difference between the two components in the concentration of hydrophilic, generally ionic groups, the result is a reversible crimp. By this, we mean a crimp that can be removed by washing and regenerated by drying. Where the concentration of hydrophilic groups in both components is more or less the same, the crimp will be irreversible or permanent. The shrinkage of the fibre, and thus the crimp, can be triggered off during production of the fibre by drying or steaming or during the processing, e.g. when dyeing the fibre or yarn.

Bifilary fibres are made both in the form of staple fibres and in the form of tow. Knitted fibrics made from these yarns are noted for their good volume, their pleasant, woolly handle and their clearly defined stitch pattern. Bifilary fibres are also used for carpets because of their covering power [8].

Producer-dyed fibres. The manufacture of dyed fibres is of interest where large quantities have to be made in one colour. In dope or spin-dyeing, the dyestuffs are added to the spinning solution before it reaches the spinneret. Use is made of soluble cationic dyestuffs and, where maximum fastness requirements are made, of pigment dyestuffs. Other possible additives are titanium dioxide for delustring and optical brighteners.

Another method is to dye the fibres after the spinning process in an aqueous dyebath. This process is particularly advantageous in the case of wet spinning, since the highly swollen gel filament produced in wet spinning permits rapid pickup of the dye. Dry-spun filaments can also be dyed, although the rate of dye adsorption has to be increased by taking suitable measures.

Absorbent fibres. With the aim of manufacturing fibres with higher wear comfort, fibre producers have attached considerable importance to the development of water-absorbent fibres. A fibre of this kind must be able to absorb moisture from the air and water, either due to a large swelling capacity or by means of a pore system inside the fibre. In the case of acrylic fibres, the formation of a pore system has proved to be particularly favourable. The important point is that the pore system is protected by a sheath of suitable thickness to ensure unproblematical processing. The sheath must possess a large number of fine channels which are able to carry the water to the porous inner fibre. The overall properties of a fibre of this kind include high absorption, no swelling, high moisture perception threshold, rapid moisture transport, fast evaporation, low density [9].

Fig. 10 shows a model and a scanning electron micrograph of an absorbent polyacrylinitrile fibre. Absorbent fibres can be produced either by the dry-spinning or the wet-spinning method. Where dry spinning is used, a suitable precipitating agent can be added to the spinning solution. This causes a sheath to form around the filament being spun, which is rich in solvent and precipitating agent; a polymeric pore system is produced. With wet spinning, it is initially highly swollen, pore-rich filaments that are formed on coagulation in the precipitation bath. Watersoluble substances can be made to diffuse into these filaments, the filaments dry and, after washing out the water-soluble compounds, a pore system is formed. By skilfully coordinating the production conditions, it is possible with wet spinning to retain the pores right through to the end-product.

Fibres with a high swelling capacity are accessible through the incorporation of comonomers with hydrophilic groups. Comonomers of this kind are, for example, acrylic acid, methacrylic acid or dimethylaminoethylmethacrylate. The saponification of comonomers on the fibre is also used for producing hydrophilic carboxy groups [10].

The next illustration (Fig. 11) shows the increased absorption of the this fibre, which has since been brought onto the market by Bayer AG under the name Dunova®, compared with cotton, wool and normal acrylic fibre.

The modacrylics are an important class of acrylic fibres.

Modacrylic fibres contain less than 85 % and more than 50 % bound acrylinitrile. The comonomer which makes up the 100 % is generally a monomer containing a halogen.

The main advantage of the modacrylic fibres is their reduced flammability. Whereas polyacrylonitrile fibres melt in the flame, inflame and continue to burn after removal of the flame, the modacrylic fibres are extinguished when the flame is taken away. Another point is that there is none of that undesirable dripping of the melting fibre. The burnt residues are solid and black. One disadvantage in the case of fire is the formation of hydrogen chloride. The fibres with vinyl chloride are even less flammable than those with vinylidene chloride.

Modacrylic fibres were, however, not developed because of their fire properties. One of the major factors leading to their production was that modacrylic polymers can be spun from the readily accessible and cheap solvent, acetone. In 1948, the UNION CARBIDE CORPORATION introduced Vinyon N in filament form, and in 1950, Dynel introduced it as a staple fibre. Both consisted of the same copolymer with 40 % acrylonitrile and 60 % vinyl chloride. In 1956, TENNESSEE EASTMAN introduced

Verel onto the market, a fibre which consists of an acrylonitrile/vinylidene chloride copolymer. Vinyl chloride and vinylidene chloride are the most used comonomers containing halogens. In addition to, or instead of these, monomers containing bromine, such as vinyl bromide or vinylidene bromide, are sometimes used. Developments have also been tried with polymerizable phosphorus compounds. In addition to acrylonitrile and comonomers containing halogens, the modacrylic fibres generally contain comonomers which are intended to improve the dyeability of the fibres. They are usually monomers with acid groups, such as Nastyrene sulphonate or Na-methallyl sulphonate. Neutral comonomers can also be incorporated, such as alkyl acrylamides. They improve dyeability by loosening up the fibre structure.

The production of modacrylic fibres basically follows the same pattern as the production of polyacrylonitrile fibres.

Because of the type and high proportion of comonomers, the modacrylic fibres have a high degree of plasticity, which becomes evident in a low bonding temperature or increased shrinkage. Recent developments are endeavouring to eliminate this disadvantage by reducing the halogen content of the polymer and incorporating additives into the spinning solution, which act synergistically as regards reduced flammability. Additives of this kind are antimony trioxide, organic antimony compounds or halogen compounds.

The number of combinations from the various characteristics amounts to several hundred for the basic-dyeable staple fibre alone. If we take into account that the processor can call on more than twenty different types with their differing properties, that polyacrylonitrile fibre types can be blended with each other or with other manmade or natural fibres in order to obtain special properties and that the appearance and characteristics of the final product are very much determined by the large number of possible yarn and article constructions, then we can obtain an idea of the extremely wide variety of possibilities for using this synthetic staple fibre.

The next table (Table 6) shows the industrial consumption of acrylic fibres for the main fields of application in the Common Market in 1980 in %. It can be seen from the table that about 50 % of production is sold as knitted goods.

2.2 Textile characteristics

Articles made of acrylic fibres have a pleasant handle. By using fine titres, the handle becomes softer, while coarser titres make it crispier. The high bulking power and low density compared with natural fibres means that the textiles can be made lighter, airier and also have good recover, heat retention properties and good covering power. Since acrylic fibres do not swell, articles made from them remain permeable to air even when damp.

The tensile strength of acrylic fibres and the chafing resistance of articles made from them is greater than with natural fibres.

The fibres available on the market have different dye affinities and dye absorption rates. For light shades, use is made of disperse and basic dyes, whereas only basic dyes are used for dark shades. Dyeing temperatures generally lie around 100 °C. The dyeings are noted for their brilliance and good fastnesses. The level of lustre is governed by the choice of type (bright or dull).

Articles made of acrylic fibres are easy-care. Their water absorption is low, they can be washed at medium temperatures and dry quickly. they are resistant to a number of organic solvents and stains are easy to clean. They do not felt.

Their weathering and light stability are outstanding and are unmatched by any natural or manmade fibre. This makes these fibres particularly suitable for outdoor use, e.g. for awnings. Acrylic fibres are not attacked by bacteria fungi or insects, nor do they rot.

2.3 Chemical properties

Acrylic fibres are resistant to most mineral acids. They have good stability to weak alkalis and moderate resistance to strong alkalis.

Their good chemical stability, and particularly the resistance to hydrolysis of the homopolymer, means that they can be used for technical applications up to temperatures of 140 °C in a damp atmosphere, e.g. for filter cloths and acid-proof clothing.

2.4 Technological and mechanical properties

The most important technological properties are summarized in Table 7. Of these, particular reference is made to the high initial elasticity modulus, the good dimensional stability, the low specific weight, the low water absorption and the high light stability, which exceeds that of all synthetic fibres. The way in which these technical properties affect the appearance, handle and overall performance properties of the final textiles has already been discussed.

The next table (Table 8) summarizes these product properties one again. Nearly all these product properties can, taking the same chemical composition of the fibre substance, be influenced by modifying the production and aftertreatment conditions, in other words by taking technological or physical measures. Is it also possible to explain these product properties right down to the last detail? We must not disguise the fact that there are some aspects which still have to be explained. Let us consider, for example, the light stability of the acrylic fibres, which is unmatched by any other type of fibre. According to the present level of know-how, there is no explanation for this particular quality. Another point is the highly valued crispy handle of these fibres, which is regarded as an "inborn" property and which can barely be influenced by subsequent finishing processes.

Since it is possible to draw important conclusions about the processing and performance properties of acrylic fibres from their stress-strain diagram and thermoplasticity, I shall deal in more detail with these technological and mechanical properties. To describe the deformation behaviour, use is frequently made of σ,ε diagrams at various temperatures and thermomechanical analysis.

Figure 12 shows the basic curve below and above the glass transition temperature. The σ,ε diagram of acrylic fibres is characterized below their glass transition temperature (50 — 95 °C with decreasing water content) by a steep, glass-like starting zone "A", followed on the other side of the elasticity limit by a zone "B" of greater resilience triggered off by "stress softening". Above the glass transition temperature, zone "A" does not exist any more; the fibre is more extensible against a resistance which is gradually increasing again, until it reaches a yield stress σ_c, where structural resistances to plastic slip processes are overcome [11].

The next diagram (Fig. 13) shows the real path between 21 and 140 °C. At elevated temperatures above the glass transition temperature there is not steep increase in the force in the region of low strains. The flow or yield zone, in which plastic deformation occurs with a decrease in the recovery stress, is clearly recognizable.

Fig. 14 shows how the degree of drawing affects the σ,ε diagram. Other factors influencing the σ,ε behaviour are the type and quantity of comonomer, the molecule mass and molecule mass distribution, the spinning conditions and the thermal influences during aftertreatment. I shall be dealing with the latter point later when discussing the physical structure of acrylic fibres.

Information about the mechanical resilience of a fibre under thermal load is provided by thermomechanical analysis (TMA). The next diagram (Fig. 15) shows the thermomechanical deformation of acrylic fibre tow for three different types. Above 90 °C, two types are more thermoplastic than the third, in which elongation of the filaments is hindered by the release of shrinkage stresses. It can be concluded from this that types 1 and 2 were more intensively shrunk than 3 during manufacture.

In principle, any mechanical property can be the subject of a TMA analysis. Also of interest, for example, is the force which is generated on isometric heating. Frozen deformations are then expressed in shrinkage forces, which can be observed as a function of temperature. Since shrinkage contributions cannot provide any information about the level of the causal force, the size of the shrinkage force provides additional information.

Shrinkage force measurements carried out on filaments and fibres enable conclusions to be drawn on preceding drawing processes, especially the thermal breakdown of recovery stresses that had occurred. They can also be used for assessing the practical shrinkage of processed fibres, in other words e.g. the shrinkage inhibited by frictional forces. The next illustration (Fig. 16) shows the shrinking force of three acrylic fibres pretreated at different temperatures as a function of temperature. It can be seen that — depending on the intended application, it is possible to obtain fibres with latent shrinkage as well as fibres in virtually fully shrunk form.

It is these overall properties of acrylic fibres which makes them suitable for such a wide variety of applications in the clothing and home textiles industry as well as the technical sector. Some of the most important are:

knitted articles
furnishing fabrics
curtains
upholstery fabrics
car upholstery fabrics
blankets and rugs
carpets
lining and toy plush
wall coverings
technical uses (filters)
protective clothing

From what has been said so far and from Fig. 1, it can be seen that the production of acrylic fibres involves clearly defined stages such as polymer production, dissolving, spinning, drawing and aftertreatment. The number of variables process parameters which have to be taken into account during these processes is, however, very much larger. The complex relationships between these parameters become clearer if we trace back the fibre properties not to the individual process parameters, but to molecular and supra-molecular structural data of the fibre, which differ as a result of the varied production conditions. Whereas, during the initial phases of manmade fibre production, the interrelationships between the morphological structure and the performance properties of manmade fibres could be determined primarily through a subsequent systemization of existing facts, fibre manufacturers and further processors are nowadays more in a position of being able, through the specific creation of certain fibre structures, to influence the textile properties of the manmade fibres in the desired direction, and finally to establish a correlation between the physical structure and performance properties of the fibre [12].

3. Physical structure

It should be evident from Figure 17 why we believe that research into the physical structure of the fibre is also of major significance. If we start with a given chemical substance and consider the technological properties, which goes beyond the production process and physical structure. It is the physical structure which finally determined the overall properties and consequently the fields of application of the fibres, although it must, of course, not be forgotten that, as has already been discussed, natural limits are set by the choice of chemical starting material.

Following on from the two terms "physical structure" and "technological properties", I would like to describe in a little more detail what we understand by these two expressions. Table 9 summarizes this information.

Both the left-hand and the right-hand side of the table could be extended and improved, but it is intended simply to express the fact that it is impossible for us here to discuss the entire range of properties of textile fabrics, but that we have to concentrate on the property data of filaments and fibres which can be determined easily and, above all, reliably.

There are various methods available for studying the structure of polymers, and some of these are summarized in the next table (Table 10). The interpretation of mechanical behaviour has already been dealt with when we discussed the technological properties of acrylic fibres.

Since x-ray wide-range-angle scattering can provide information on the state of order and state of orientation of the better-ordered regions, and dye-kinetic measurements can provide details on the packing of the macromolecules in the less ordered regions, a brief mention should be made of the results obtained in tests using these two methods. The next diagram (Fig. 18) shows x-ray wide-angle curves of unstretched (a), stretched (b) and stretched and thermally aftertreated (c) acrylic fibres. From this x-ray analysis, we can conclude — without going into detail — that, as with other synthetic fibres, drawing brings about an increase in orientation (compare Figs. a and b). Although, on the equator of the x-ray diagram, sharp crescent-shaped crystal reflexes can be seen (Fig. b), which are due to trouble-free lattice planes parallel to the chain direction, there are, besides these, only diffuse "amorphous" intensity distributions, since there are apparently no defined lattice planes perpendicular to the chain direction. The main reason for this is the high dipole concentration, which causes irregular chain conformations.

An evaluation of the x-ray diagram of an annealed acrylic fibre (Fig. c) shows — as with all other crystal structures — a widening of the lateral chain spacing. This means that polyacrylonitrile behaves like an amorphous chain packing as far as the absorption of free volume is concerned. The conventional polyacrylonitrile does not therefore have any clearly marked crystal structure which can be defined by x-ray analysis [13].

Studies of the dye diffusion are particularly suitable for recognizing changes in the more amorphous regions of a fibre that have greater accessibility for the dyestuff. This is because there is no room in the better-ordered regions for the relatively large dye molecules. The dyestuff absorption rate of the fibre is affected by even minimal changes in the structure.

Since the synthetic fibres are frequently subjected to heat treatment during further processing, it should be established whether structural changes occur during these processes or not. The next illustration (Fig. 19) shows the change in the dyestuff adsorption rate from a saturated steam treatment carried out at 110, 130 and 140 °C. It can be seen that, with increasing temperature, the dyeing rate increases considerably. The same effect is also found with the corresponding treatment of fibres made of semi-crystalline polymers, e.g. polymides [14].

With the aid of dyeing-kinetic analysis, the assumption is thus reinforced that although the crystalline/amorphous two-phase model cannot be employed for characterizing the structure of acrylic fibres, their structure is nevertheless built up from differently ordered paracrystalline regions [13].

4. Future problems

Finally, I should say something about the development work that is still likely to be carried out on acrylic fibres. Work is at present directed towards modifying (diversification) and improving the products and processes. The next picture (Fig. 20) gives a summary of the various possibilities of modification [1]. It can be seen from this that, with this class of synthetic fibres, further possibilities still exist of modifying and in some cases improving the highly interesting properties of acrylic fibres and of subsequently offering them to the consumer.

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year fibre group	1960		1970		1980	
	t	%	t	%	t	%
polyester	123	17,5	1 620	34,0	5 130	44,5
polyamide	407	58,0	1 870	38,0	3 130	27,1
polyacrylic	109	15,5	1 000	20,0	2 080	18,0
others (with olefins)	64	9,0	400	8,0	1 200	10,4
total :	703	100,0	4 890	100,0	11 540	100,0

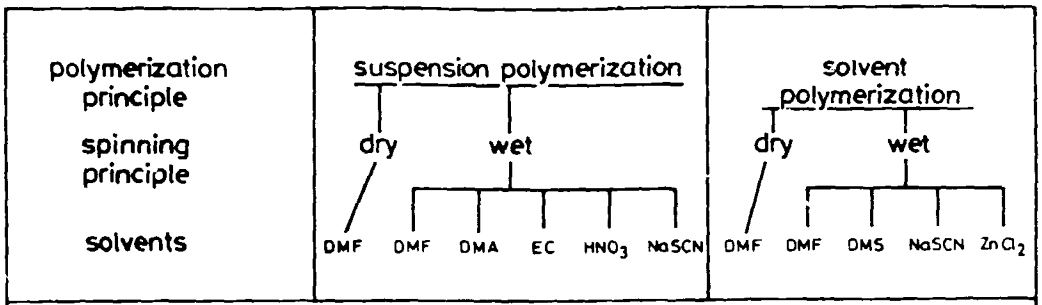
Tabl. 1 : World production of synthetic fibres in 1 000 t and %.

	price $ / lb	change from 1981 in %
dimethylterephthalate	0,37	+ 4,6
terephtalic acid	0,36	+ 4,6
ethylene glycol	0,30	+ 1,7
caprolactam	0,73	+ 1,4
AH salt	0,72	± 0
propylene	0,23	+ 21,1
acrylonitrile	0,43	+ 10,1

Tabl. 2 : Raw material prices for manmade fibres (as at end of first quater 1982)

organic solvents	70 %	inorganic solvents	30 %
of which DMF	39 %	of which NaSCN	18 %
DMA	27 %	$ZnCl_2$	3 %
DMS	3 %	HNO_3	9 %
EC	1 %		

Tabl. 3 : Proportion of the various solvents used in the worldwide production of polyacrylic fibres



DMF = dimethylformamide

DMA = dimethylacetamide

DMS = dimethylsulphoxide

EC = ethylene carbonate

Tabl. 4 : Polymerization, spinning and solvent variations for the production of acrylic fibres.

18,2 %	in	dimethylformamide solution	
10,6 %	in	conc. NaSCN solution	(51,5 %)
9,1 %	in	conc. HNO_3 solution	(65,0 %)
7,9 %	in	conc. $ZnCl_2$ solution	(60,0 %)
14,9 %	in	dimethylsulphoxide	
11,6 %	in	ethylene carbonate	(87,0 %)

Tabl. 5 : Spinning dope concentrations of equal viscosity with various solvents.

		%
Spun yarns	wovens	22,5
	knits	48,9
	carpets	8,2
	others	10,0
Non-spun fibres	felts	0,8
	filling material	0,4
	nonwovens	9,2
		100,0

Tabl. 6: Industrial consumption of acrylic fibres (EEC, 1980 in %)

Specific gravity	(g/cm^3)	1,18
Tenacity	(cN/tex)	23 - 27
Initial modulus	(cN/tex)	500-700
Breaking elongation	(%)	35 - 50
Loop breaking force relation	(%)	50 - 60
Loop breaking elongation	(%)	25 - 30
Moisture absorption (20°C and 65% rel. humidity)	(%)	1 - 2
LOI - value (Oxygen index)		18 - 19
Softening point	(°C / °F)	230 / 446

Tabl. 7: The most important technological properties of acrylic fibres.

Lower specific weight than natural products

Easy care: rapid drying, good shape retention, no swelling on becoming wet

Maximum light stability

Bulky or flat yarns, as desired

Brilliant shades with high fastnesses

Mothproof, rot-resistance

Tabl. 8 : **Specific properties of acrylic fibres which affect the final textiles.**

PHYSICAL STRUCTURE	TECHNOLOGICAL PROPERTIES
crystal structure crystallinity	mechanical properties (strength, elongation, moduli, elasticity)
supramolecular structure	thermal behaviour
colloidal structure	dyeing
morphology	shrinkage, friction behaviour, handle
structure of the non-cristalline regions	optical properties
orientation	processing properties

Tabl. 9 : Loose relationship between physical structure and technological properties.

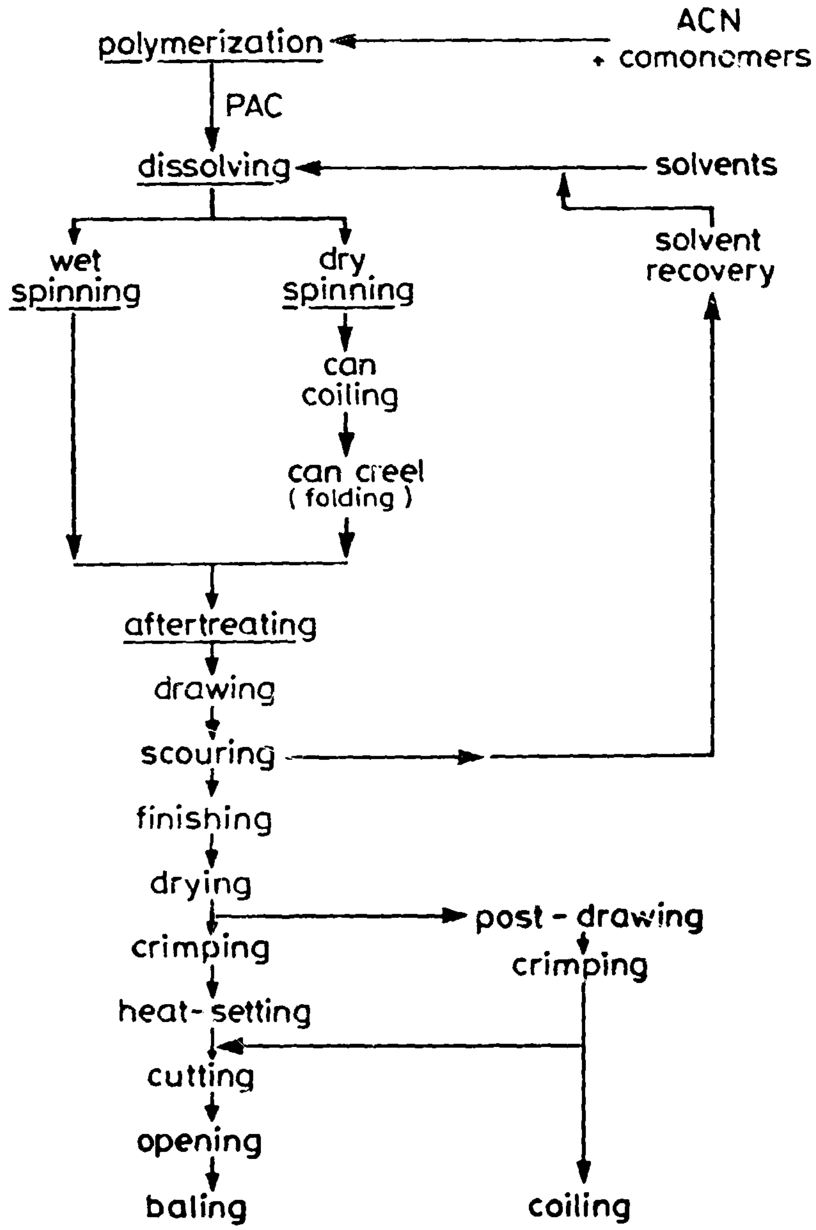


Fig. 1 : Flow chard for the production of polyacrylic filaments .

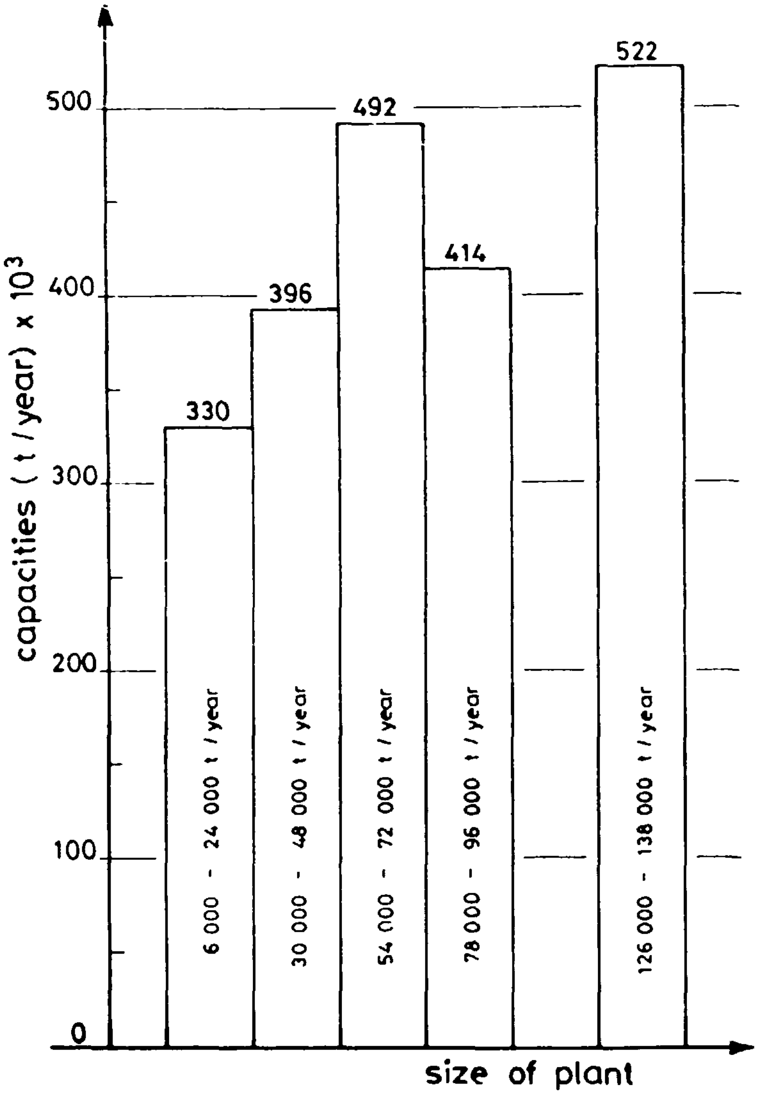


Fig. 2 : Capacities available in certain sizes of plant (t / year).

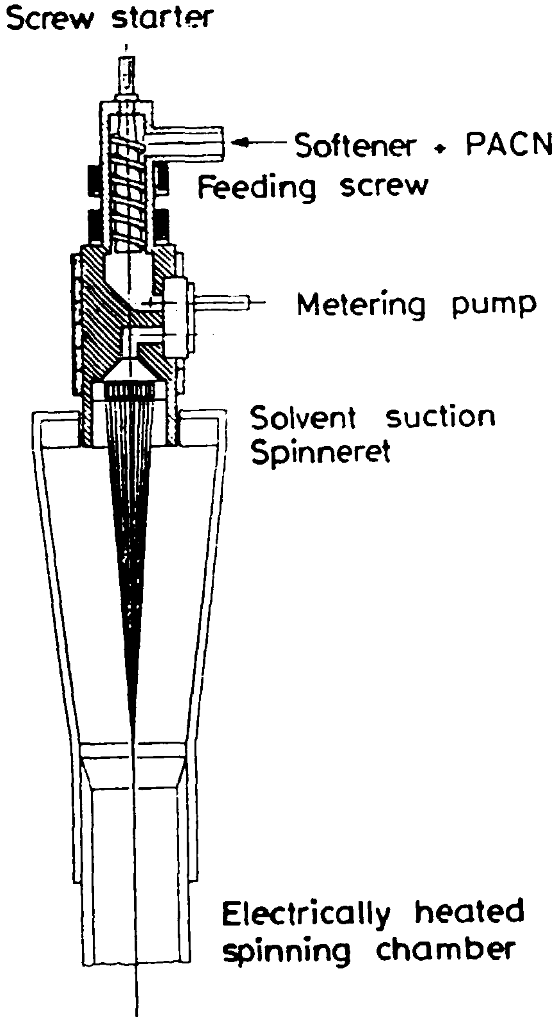
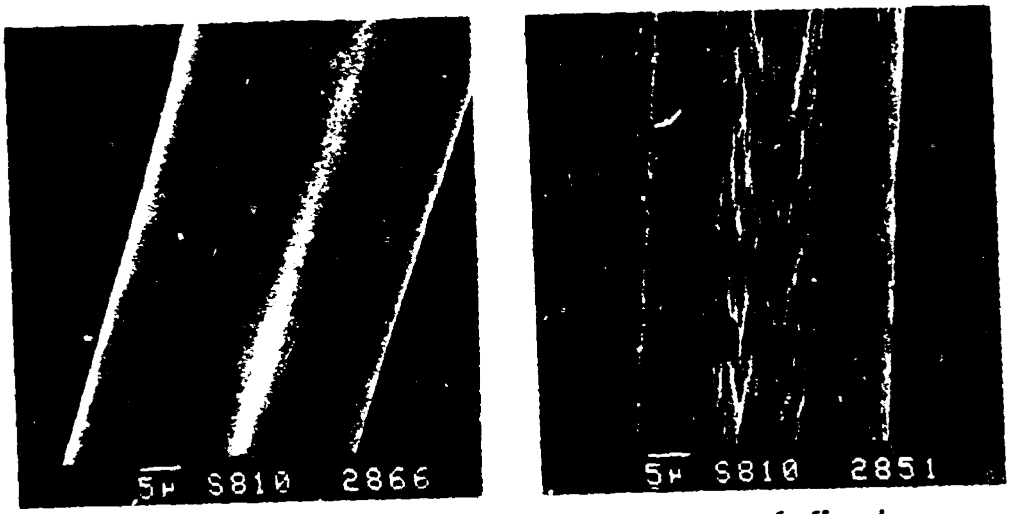
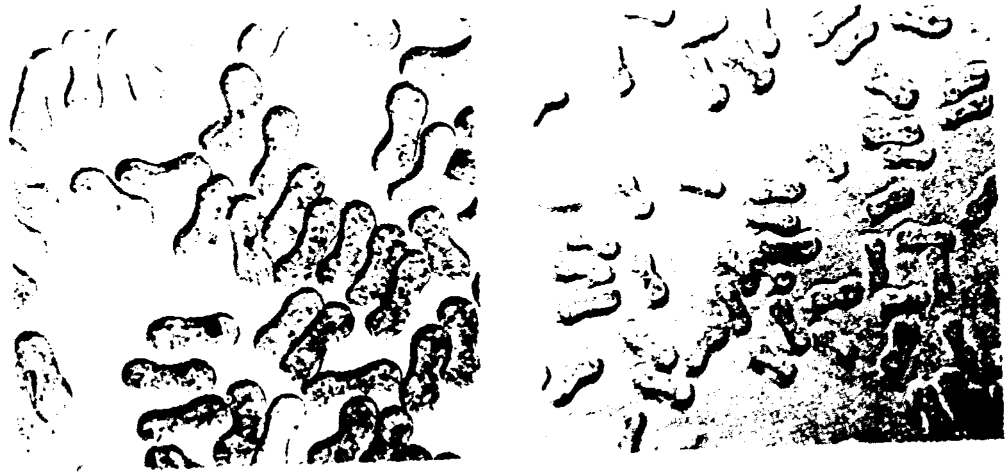


Fig. 3 : Diagram of a dry-spinning head.



surface of unstretched dry-spun fibres

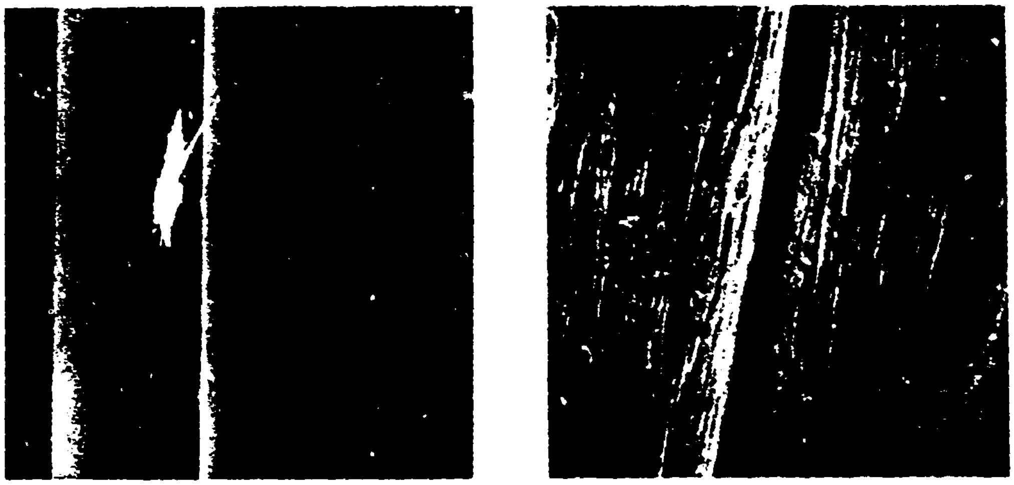
surface of final dry-spun fibres



cross-section of unstretched dry-spun fibres

cross-section of final dry-spun fibres

Fig. 4: Micrographs of acrylic fibres



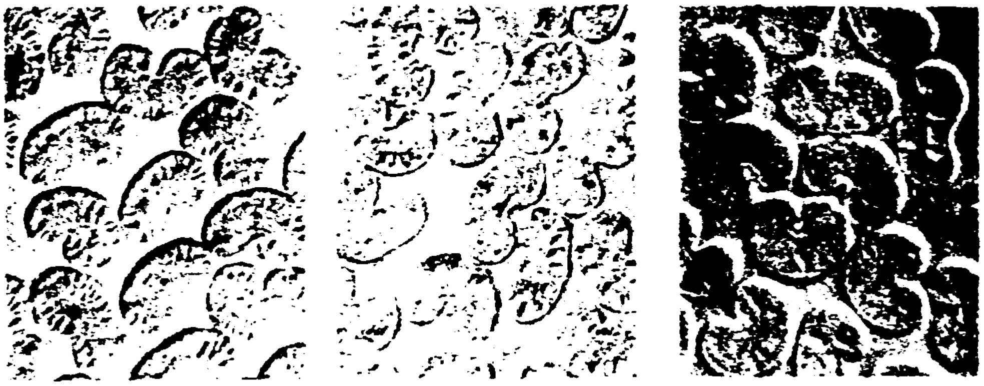
surface of unstretched wet-spun fibres

surface of final wet-spun fibres

cross-section of unstretched wet-spun fibres

cross-section of final wet-spun fibres

Fig. 5 : Micrographs of acrylic fibres



a
20 %

b
25 %

c
27 %

Fig. 6 : Reduction of the cavities in acrylic fibre by incraesing the dope concentration.

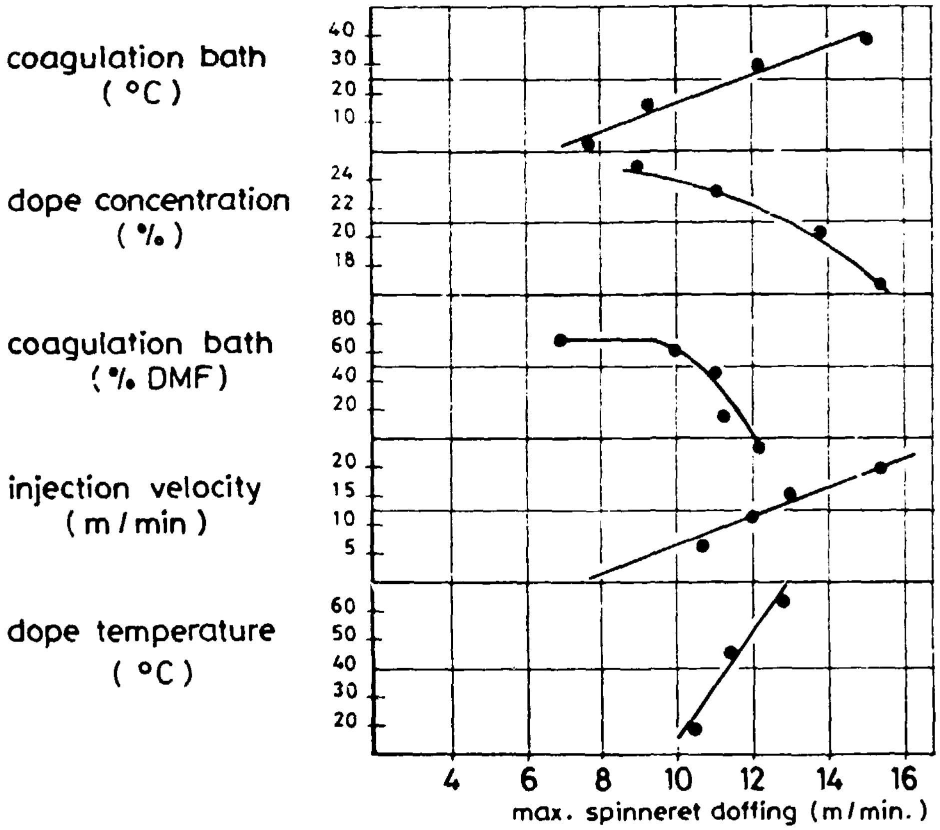
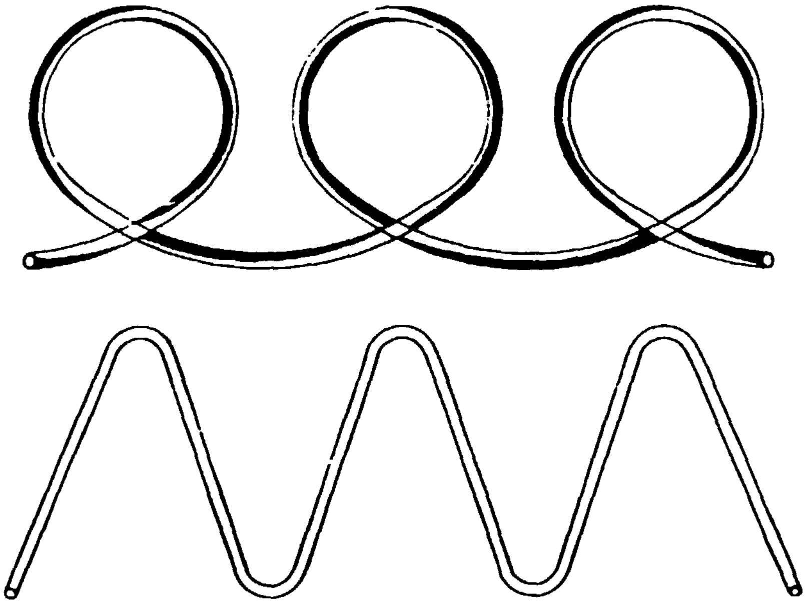


Fig. 7 : Relaxation between max. spinning velocity and selected spinning parameters.



a) wavy crimp

b) mechanically produced stuffer - crimp

Fig. 8 : Diagram showing crimp forms.

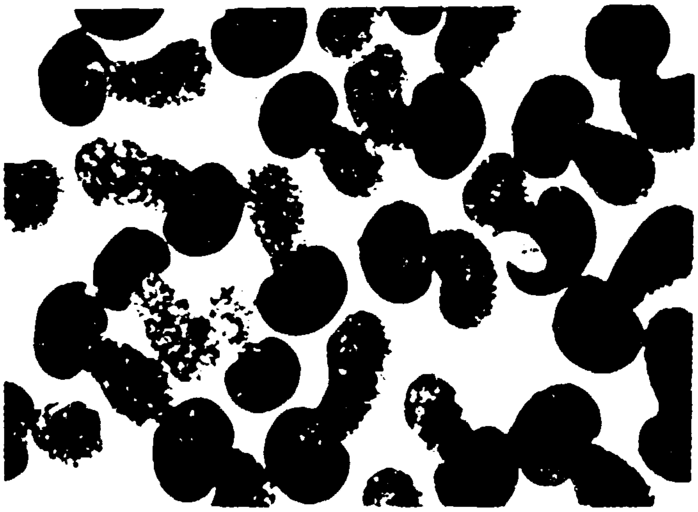


Fig. 9: Cross-sections of acrylic bicomponent fibres

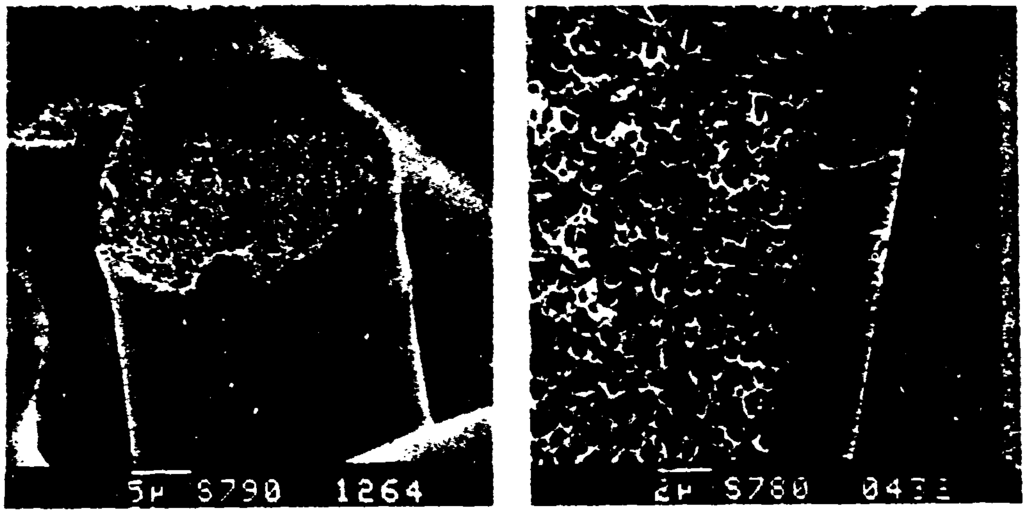


Fig. 10: Pore structure of Dunova

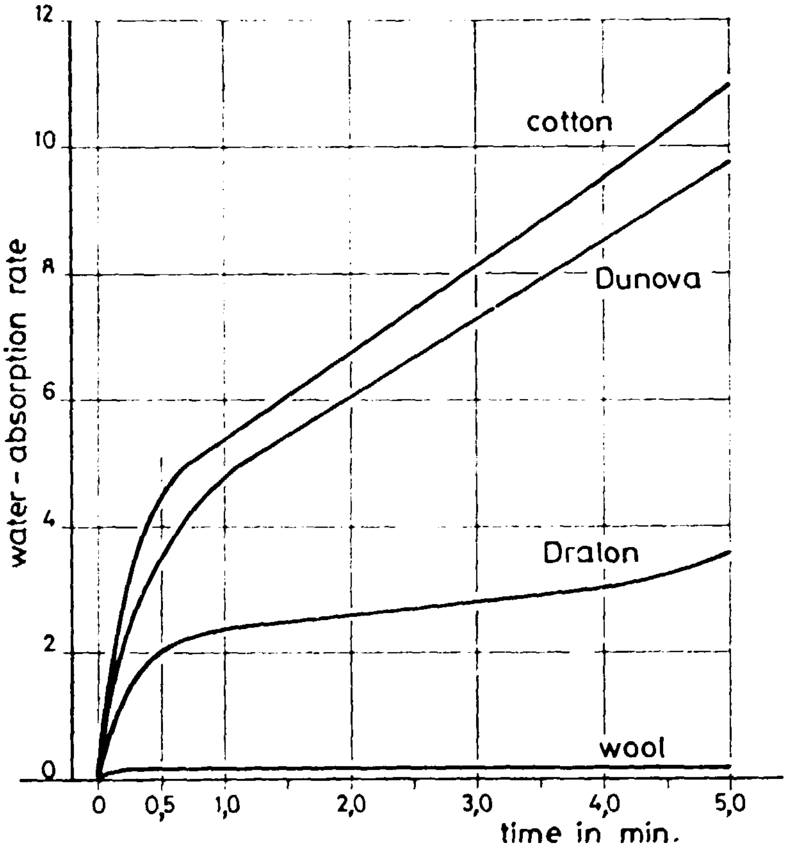
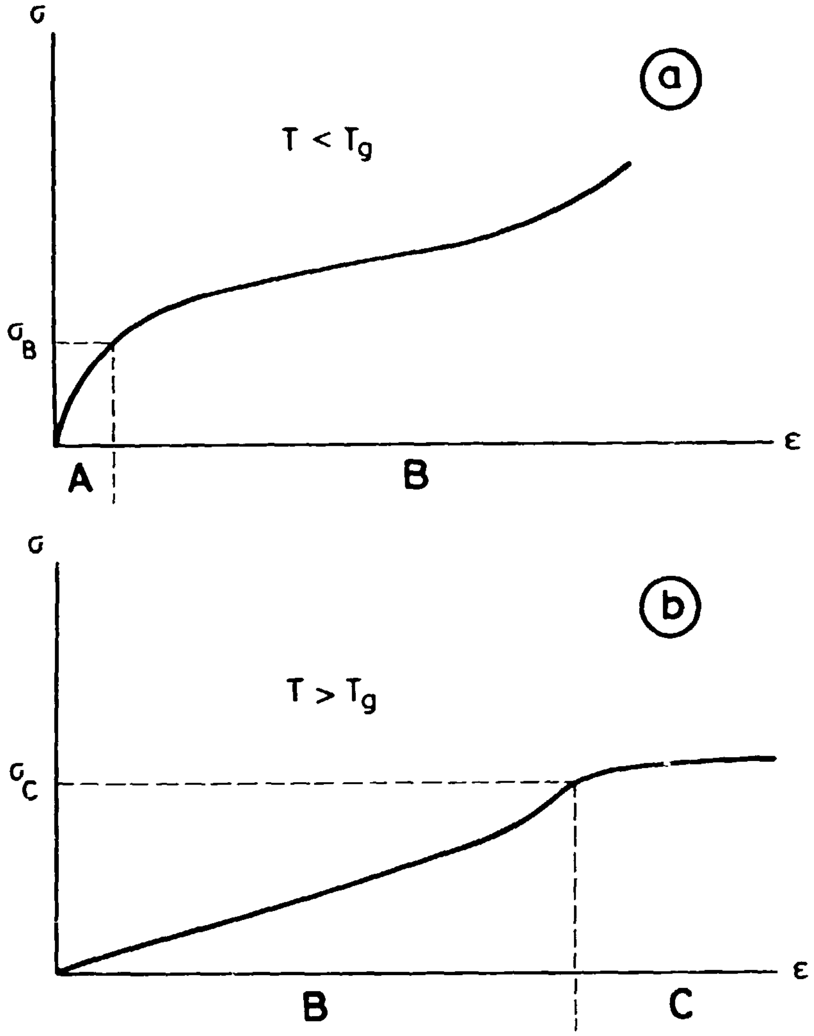


Fig. 11: Absorption of various fibres
at room temperature.



ⓐ below the glass transition temperature

ⓑ above the glass transition temperature

σ_B σ_C yield points

Fig. 12: Stress-strain diagrams σ, ε of acrylic fibres

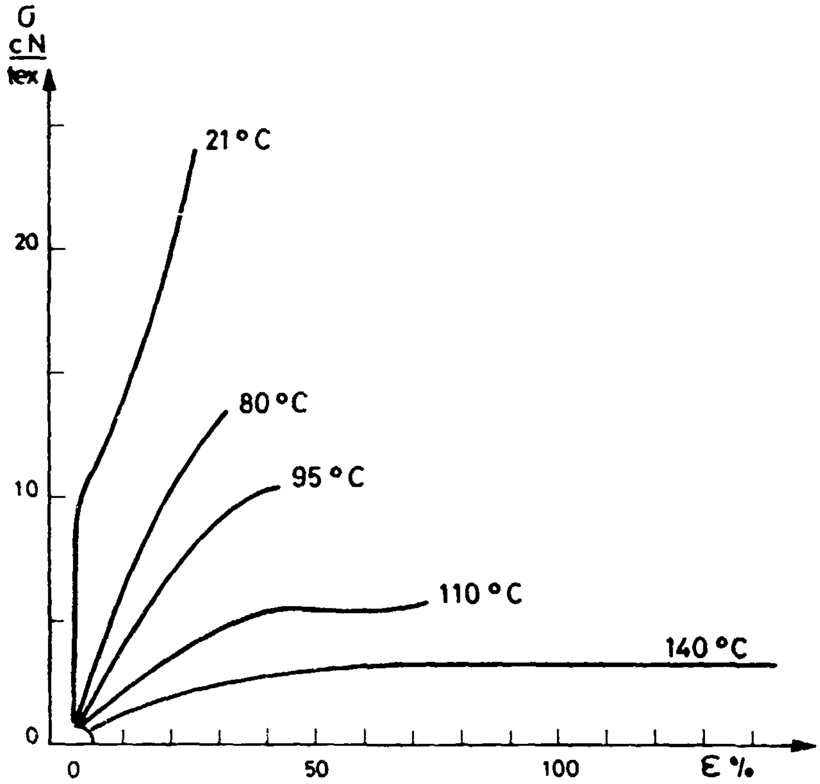


Fig. 13 : Relationship between the σ, ε characteristics (10 % /s) and the strain temperature 21 - 140°C.

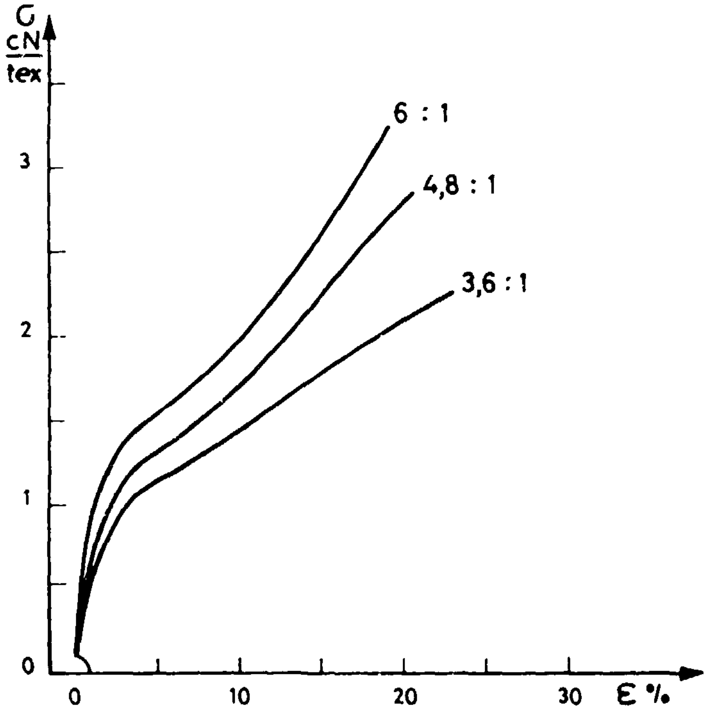


Fig. 14 : σ, ε curves at different pre-stretch levels, draw ratios 6 : 1; 4,8 : 1; 3,6 : 1.

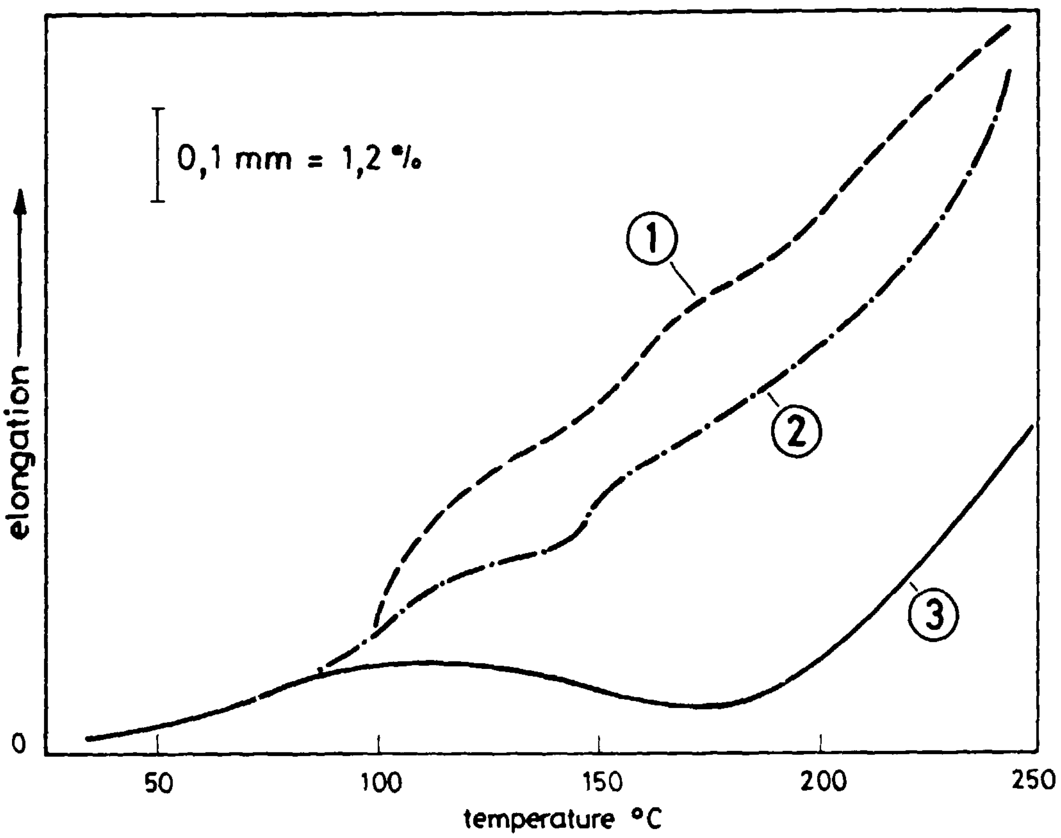


Fig. 15 : Thermomechanical deformation of acrylic fibre tows for three different types (pretension 0,015 cN / dtex ; heating - up rate 10 °C / min).

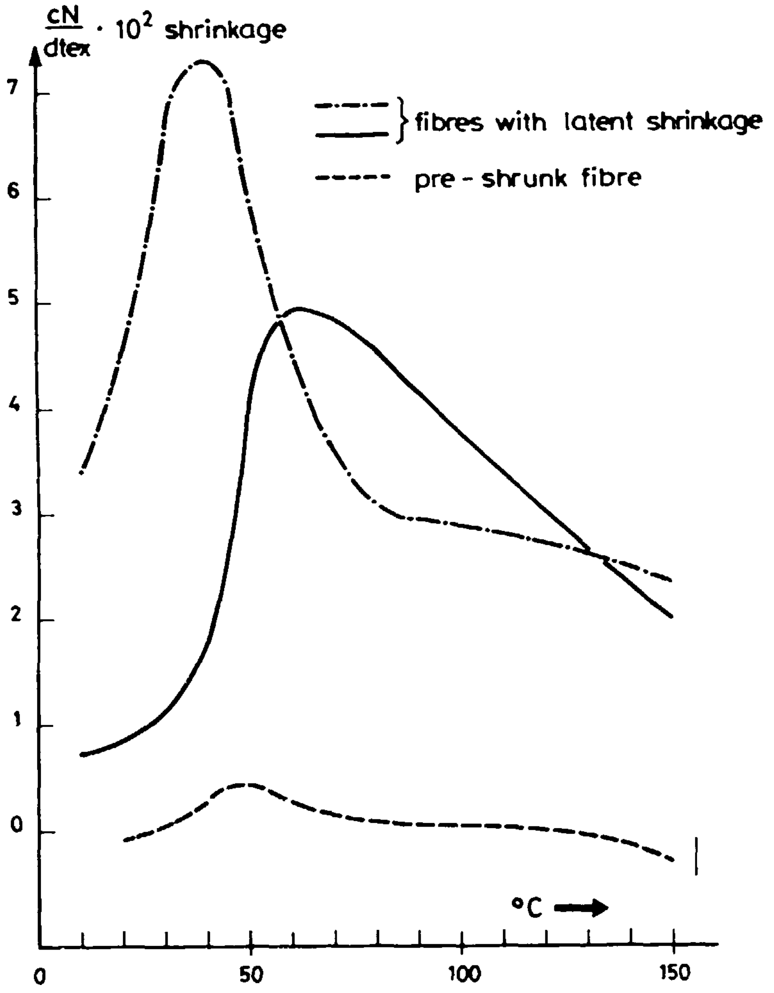


Fig. 16 : Shrinkage force of various pretreated acrylic fibres.

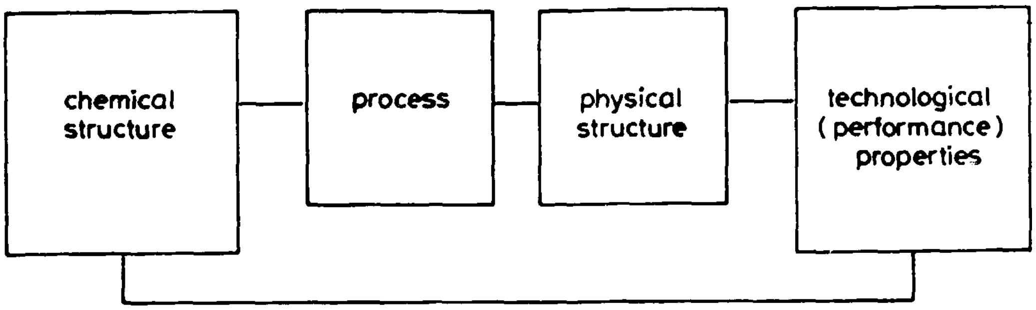
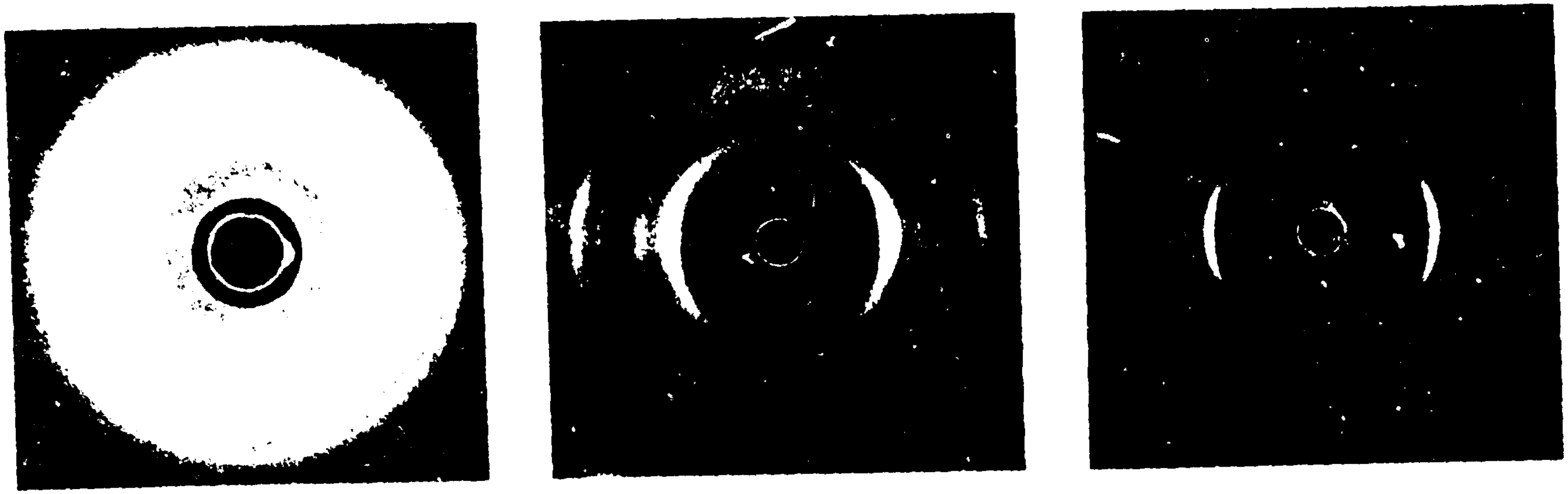


Fig. 17 : Relationships between structure and properties of polymers.



undrawn drawn 1 : 6,8 heat - treated

Fig. 18: Wide-angle diffraction patterns of PAC-fibers

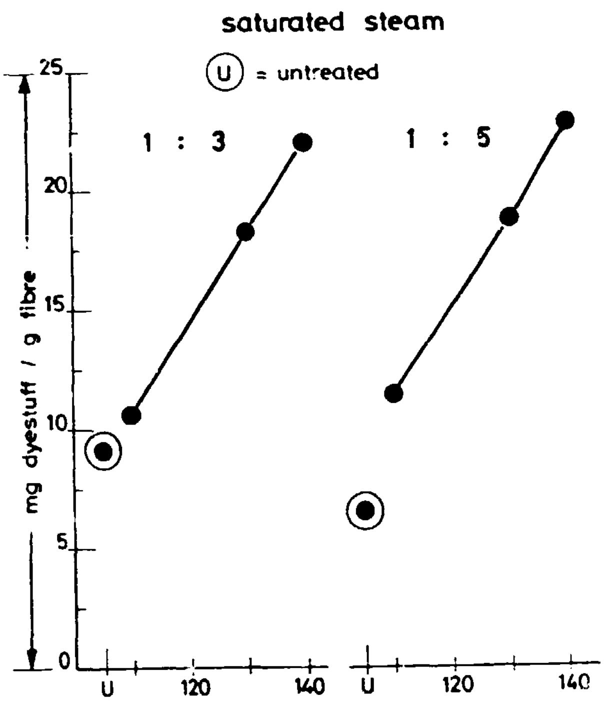


Fig. 19 : Effect of heat-setting on dyeing rate

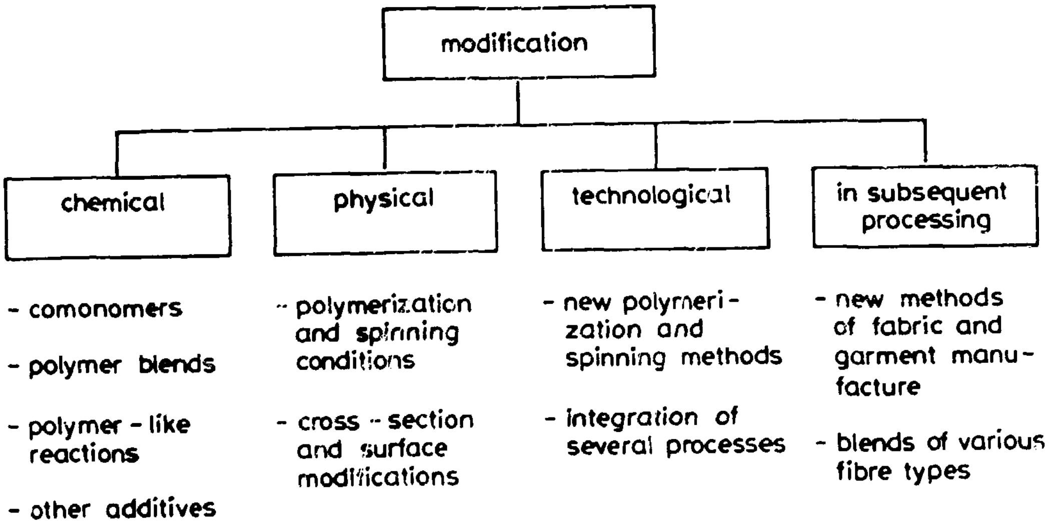


Fig. 20 : Possibilities for modifying acrylic fibres

sasmira

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FIBRE AND TEXTILE RESEARCH IN INDIA

Miss Madhury D. Bhavsar, *SASMIRA*

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Synopsis

Research in the field of man-made fibres and textiles carried out by Scientists in India mainly during the last five years has been reviewed to throw light on the research trends in India. The contributions cover fibre research and research involving steps to convert fibres to finished fabrics.

FIBRE AND TEXTILE RESEARCH IN INDIA

Miss Madhury D. Bhavsar, *SASMIRA*

Before the advent of man-made fibres, textile research was mainly confined to natural fibres involving steps dealing with collection of fibres and conversion of fibres to finished fabrics. Cotton, a cellulosic fibre played major role compared to the protein fibres wool and silk. In the beginning of this century the first man-made fibre appeared initiating new ideas and approaches in the field of textiles. This was followed by the interesting development of the first synthetic fibre and thus entire new field of synthetic fibres came into being.

After the entry of man-made fibres the number of which has grown considerably and has been still growing to some extent, the textile research has assumed greater importance and attained a very broad base in which utilisation of various branches of science and technology has become possible and necessary.

India a developing country spends much less on research than the developed countries, but the awareness of research is growing with the increasing competition from the outside market.

In old days when science was in its primitive stages and scientific and technical approach did not exist, people handled textiles as craftsmen and it was the art and craft which initiated people to develop beautiful textiles using the then available fibres, dyes and other facilities all from nature. One can say that was also the result of research and development or may be plain search involving trials for new and better things, which did exist in India as a result of which beautiful textiles were made by our craftsmen in old days and are being still made in various small scale sectors supporting several families.

Indian textile industry is very old. When man-made fibres made their entry in the field of textiles, Indian industrialists also diverted their attention towards these new entrants, as a result in the beginning man-made fibres were imported and then fibre manufacturing units were set-up. Thus we have today 12 viscose rayon plants, 11 nylon manufacturing units, 15 polyester producing companies, 2 acrylic plants, one acetate rayon plant and one unit for polypropylene[1]. Simultaneously the mill industry also grew to handle exclusively man- made fibres and it is this expansion of the sector handling man-made fibres which had initiated the establishment of Silk & Art Silk Mills' Research Association (SASMIRA) a co-operative research organisation.

The manufacture of fibres and conversion of fibres to fabrics involves various aspects including chemical, mechanical and analytical and therefore textile research will fall into following main categories dealing with all these aspects :

1. Fibre research involving development of better and/or new fibres and other R & D pertaining to fibre manufacture.
2. Research involving conversion of fibres to yarns and fabrics.
3. Research involving processing of grey fabrics to finished fabrics ready for marketing.

Research will also fall into two broad categories namely basic research and applied research. However, basic research must serve some useful purpose for the advancement of applied research, otherwise one may not like to label such basic research as textile research because textile field is an applied field.

The organisations involved in the fibre and textile research are:

1) Co-operative Research centres established for textile research
2) Technical Institutions conducting courses in textiles
3) University departments conducting courses in textiles
4) Other industrial research centres run by (a) Government
   (b) private industrial concerns, including fibre manufacturers.

Each fibre has its own indentity depending on its source of supply or origin and its chemical and physical properties. It is necessary to take this into consideration from the point of view of industry as well as R & D activities.

As far as the textile industry is concerned, there are separate sectors based on the type of fibres they deal with. Thus there are three main sectors each dealing with each of the three main natural fibres namely cotton, wool and silk and the fourth main sector dealing with man-made fibres. This sectors again has been divided into various sectors depending on the type of the fibres handled and the end products produced etc. Thus it becomes apparent that textile research can be general as well as more specific to serve only a particular sector.

The textile industry being very old in India, and India being an agricultural land, early attention has been paid to the natural fibres cotton, wool and silk. There are separate research organisations looking after the development of these three natural fibres which mainly deal with the agricultural and biological aspects along with some textile research. In addition all the three industrial sectors have their private as well as cooperative or government research organisations which are pursuing textile research dealing with spinning, weaving and processing of cotton, wool and silk. The Silk and Art Silk Mills' Research Association is the only one, unique institute established in the country to fulfil the task of research in the field of man-made fibres and textiles. However, it is a well known and well established fact that blends or mixtures of fibres are becoming more popular because such combinations of fibres at times provide more advantages as compared to each of the single fibre used for the blend. Therefore the industry as well as researchers working with the natural fibres alone have now taken up R & D work in the field of man-made fibres.

Based on the above background, now I will review major contributions made by Indian Scientists towards R & D in the field of man-made fibres and textiles mainly during the last five years to give an idea of research trends in India.

This review has been prepared in a very short period and it was not possible to collect and include all the published work by Indian Scientists. It is likely that I might have missed some major contributions.

Fibre Research

When man-made fibres made their entry, viscose being the first such fibre followed by nylon and then polyester, initially India remained an importer of these fibres. But ultimately industrialists in the country decided to set up plants for the manufacture of these fibres indigeneously and did this with the help of foreign know how or collaboration, because we did not have our independent know how. This has happened in case of practically all the man-made fibres.

However, once the manufacture of a particular fibre had started, the manufacturer all well as the policy makers in India thought for lessening the amount of dependence on others in any form including imports whether of raw materials or of machineries and other items required to run the plant satisfactorily. This has initiated research and development to achieve import substitution for various items and also involved attempts to solve day to day problems. This led to setting up of new industries to cater to the needs of the man-made fibre manufacturing industry. This in turn created further scope for research and development in these new industries and ultimately scientists and technologists turned their attention to the fibre research. So the point is we are late beginners in the field of fibre research.

Fibre research would fall under three categories :

1. Synthesis of new fibres.
2. Modification of known fibres at the manufacturing stage
3. Modification of known fibres (Polymers) at a suitable stage after production.

In addition fibre research involves other R & D pertaining to the entire operation of fibre manufacture. Information collected regarding the activities of scientists in India in these fields are given below.

Polyethylene terephthalate (PET) fibres have various useful properties. As a result they have been able to outrank other synthetic fibres in their utility. In spite of this, there are certain limitations such as low moisture regain, pilling problem, etc. which encourag further research on this fibre. One approach tried for improving the properties involves preparation of co-polyesters either by mixing another acid with dimethyl terephthalate or by mixing another glycol with ethylene glycol during polymerisation. Such a study on the synthesis of co-polyesters by melt condensation of dimethyl terephthalate with different quantities of ethylene glycol and 1, 6-hexane diol in the initial monomer feed has been reported[2]. Properties of 100% PET fibres and random copolymers containing ethyelene and hexamethylene units in the polymer chain have been compared. It was observed that melting point was lowered continuously with increase of hexamethylene units in the copolymer. Also the thermal stability decreased due to introduction of hexamethylene units. Fibres were spun from the copolyester having 5 mole % of hexane diol which showed slight decrease in tenacity and increase in % elongation.

At times fibres are modified by chemical treatment. Also during processing, fibres have to undergo certain chemical treatments. Therefore information regarding effect of chemicals on fibres is very important. In this connection nature of degradation taking place in polyester films due to acid and alkaline hydrolysis as well as aminolysis has been investigated to throw light on the effect of these chemicals on the polyester fibres[3]. It has been observed that a change in the number of hydroxyl and carboxylic acid end groups and IR crystallinity results. Also random depolymerisation takes place in the case of hydrochloric acid hydrolysis.

Polyamide fibres are modified for several reasons by research workers. Modification of nylon 6 fibres has been reported by reacting them with sulphuryl chloride in benzene[4]. The reaction variables were studied and the increase in the weight of the polymer as a result of modification was measured. Physical properties of the modified fibres were compared with those of unmodified fibre. It has been observed that modified fibres showed slight improvement in the thermal stability. Also some increase in the density and moisture regain was observed with increase in add-on, but breaking strength and modulus showed some decrease.

A study of cross linking of nylon 6 fibres with a bifunctional reagent to improve their properties has also been reported.[5].

A theoretical study of grafting of methyl methacrylate on nylon 6 fibres in presence and absence of fructose using different solvent media and by initiating the reaction by irradiation with carbon arc lamp has been reported[6]. The thermal properties of the grafted fibres is reported to be inferior to that of the ungrafted nylon 6 fibre, but the fibre diameter and density was found to increase continuously with increase in the graft add-on percentage.

In another investigation thermal stability of radiation induced acrylic acid grafted nylon 6 has been reported[7]. Acrylic acid was graft copolymerised on nylon 6 fabric using gamma-ray irradiation technique and the effect of heat on the mechanical properties of the modified fabric was investigated which showed that the thermal stability had improved considerably as a result of grafting. Grafting technique to modify fibres has been explored by scientists in India and there are other publications in the subject, all of which are not included here.

Modification of polycaprolactam has been reported by reacting it with o-chlorophenol in cyclohexane as a solvent in presence of benzoyl peroxide[8]. The modified polymer was then spun into fibres and the properties of the modified polymer and the fibre spun from it were investigated. The mechanism of reaction of o-chlorophenol with polycaprolactam leading to its modification is discussed and linking of the phenyl ring with the polymer with chlorine as well as without cl. has been proposed to take place. The modified nylon 6 fibres showed higher moisture regain, higher density, higher melting point as well as 3 to 4% increase in the limiting oxygen index (LOI) value when tested for flamability. The dye uptake of disperse dye showed decrease probably due to increase in the density and compactness, but the uptake of basic dye showed increase. However, there was no significant loss in strength of the polymer.

Fibres with good thermal resistance are required for special applications and polyimide fibres belong to this category. Therefore the effect of structure on the thermal properties of polyimides has been reported to be investigated by changing the backbone structure of the polymer[9]. The structure variation in polyimides was obtained by polymerising different molar ratios of p,p'- diaminodiphenyl ether with pyromellitic dianhydride followed by cyclodehydration of the resulting polyamic acids. Homopolymers from both the diamino-monomers were also prepared. The structure elucidation as well as properties of the polymers are reported. The thermal stability of the copolymer has been found to decrease with increasing amount of p, p'-diphenyl ether groups. The homopolymer from pyromellitic anhydride and p,p'-diaminodiphenyl ether was wet-spun into fibres, cyclodehydrated to polyimide and the mechanical properties of the fibres were investigated after cold drawing.

Indigenous development efforts for high performance rayon yarn of polynosic/HWM type are reported by a rayon manufacturing unit[10]. The pilot plant was designed, fabricated and erracted indigenously except the spinning pumps and spinnerets. The fibres produced are shown to compare well in their physical properties with a typical polynosic and a typical HWM fibre. Yarns and fabrics were prepared from the fibre as well as from the blend of the fibre with polyester, cotton and wool. These have been evaluated for their properties and performance characteristics. The findings have shown the fibre to be promising.

Scientists of the same manufacturing concern have investigated the use of sodium zincate in viscose rayon manufacture as viscose additive as well as for recycling waste rayon fibres[11], [11a]. Addition of sodium zincate to viscose rayon during its manufacture has been reported to provide certain advantages. Therefore the effect of addition of sodium zincate to viscose solution on the properties of the solution as well as on the yarns spun from it has been studied.[11] The strength of the yarn was found to improve without any adverse effect at any stage of the process. During the rayon manufacture, some waste rayon fibres (about 2%) are reported to be produced. Therefore in another study the possibility of recycling of viscose rayon waste fibres for spinning after dissolving in sodium zincate has been investigated and the advantages and limitations of the process have been assessed.[11a]

In addition, acetylation of these waste fibres by solution method has been reported to be studied under various conditions and it has been observed that di- and tri-acetate derivatives of desired D.P. and acetyl value could be obtained satisfactorily to be suitable for appropriate end uses[12]. Further investigation on vapour phase acetylation of rayon fibres has been reported in which the viscose rayon fibres have been converted to cellulose acetate by vapour phase reaction without any significant effect on D.P. or mechanical properties[13]. It is claimed that cellulose acetate with better tenacity than that obtained in the normal process has been obtained.

Benzoylation of viscose rayon yarn for possible modification has been tried at Sasmira[14]. The benzoylation was studied in presence of alkali as well as pyridine as a base. Alkali was found to give better results compared to pyridine. Mono-, di-and tri-benzoylation was attempted by varying the amount of benzoyl chloride and it was observed that with increasing amount of benzoylation the affinity for direct dyes decreased, whereas the affinity for disperse dyes increased and was very good for the highest degree of benzoylation achieved.

From another rayon manufacturing concern, sulphur recovery from waste slag of rayon has been reported[15]. Two processes for recovery have been studied extensively with a view to develop a simple process which would be economical and give pure product. One is a chemical process in which reaction of the slag with lime produces sulphur compounds of calcium from which pure sulphur is recovered by hydrochloric acid treatment and the other is vaporization method in which sulphur is distilled off by heating the slag in a suitable distillation set up. The latter process has been reported to be found more suitable and economical.

Apart from normal textile applications, various fibres are also used for several non-textile applications. Such applications demand certain special properties not possessed by normal textile fibres necessitating development of special materials and polymers. A brief mention of such work will not be out of place. For example work has been reported on development of composite materials using glass fibres reinforced with polypropylene[16]. With the use of good adhesive materials such as silane coupling agents, composite materials having good thermal and mechanical properties have been developed.

Also synthesis of polyester resins having good thermal, flame and chemical resistance has been reported for strategic applications[17]. The polyester resins are reported to be prepared by step-wise condensation of isophthalic acid, chlorendic acid, and maleic anhydride with propylene glycol by changing the molar ratios of the first two reactants. The properties of the polyesters were studied with a view to develop polyester with satisfactory properties.

It can be mentioned that the materials group at Vikram Sarabhai Space Centre (Trivandrum) is engaged in research and development on polymers for textile and non textile applications for space research and applications. As a result we anticipate development of speciality fibres lessening our dependance on imports and providing good boost to our own R & D work. Sasmira has always rendered possible service to this centre.

The entry of synthetic fibres and certain major differences in the properties of natural and synthetic fibres have introduced keen competition between these fibres and created a very interesting situation encouraging research work in which scientists try to modify natural fibres to impart some of the desirable properties of synthetic fibres and also try to modify synthetic fibres to impart some of the desirable properties of natural fibres.

One approach of modification of cellulosic fibres in general and cotton fibres in particular by graft copolymerisation has been studied by Indian scientist.[18-22] India being a cotton growing country and cotton being blended widely with polyester, this work assumes considerable importance. The work involves applied as well as theoretical aspects.

In one paper grafting of cotton fabrics with binary and ternary mixtures of vinyl monomers containing acrylamide, then methylolation of the polyacrylamide grafts followed by crosslinking is reported.[19] The treatment is reported to impart good wrinkle-recovery property without any appreciable adverse effect on mechanical properties except in case of acrylamide-acrylonitrile grafts. However, when crosslinking was carried out using N-methylol crosslinking agents, strength loss was observed except when mixtures with ethylacrylate were grafted at higher add-on. Also first crosslinking through polyacrylamide grafts followed by grafting with monomers imparted good abrasion resistance but moderate crease-recovery.

In another paper acrylonitrile has been reported to be graft copolymerised on cellulose (cotton) backbone using various initiating agents.[20] The grafted chains of polyacrylonitile were separated by hydrolysis of the cellulose backbone and the molecular weight of the grafts were determined after fractionation. Also the solubility behaviour of the grafted samples in cadoxen solvent (cadminum in ethylenediamine referred to later in detail) has been investigated. The study throws light on the molecular weight distribution as well as solubility behaviour at different add-on for different initiators.

The graft copolymerisation methods for cellulosic fibres are not very simple or cheap for commercialisation. Therefore, an attempt to develop a more suitable method has been reported in which pad-dry-cure method has been experimented with using polyester-viscose blended fabric and acrylic acid, acrylamide and their mixtures as monomers.[22] The in-situ polymerisation of the monomers has been achieved with the help of suitable catalysts added in the padding recipe. The physical and mechanical properties of the graft-finished fabrics have been investigated and it was observed that, without any adverse effect on the mechanical properties, the modified fabric had acquired Soil release property as well as transfer printability with disperse dyes.

Research involving conversation of fibres to yarns and fabrics

When we come to the subject of conversation of fibres to yarns and fabrics spinning and weaving are the two major operations, involved. Apart from these two conventional operations of spinning and weaving, other operations such as blending of different fibres, crimping/texturising and heat setting have assumed importance with the advent of synthetic fibres and are essential to get variety of fabrics. All these operations are not very simple and provide enough scope for research and study. Therefore technologists associated with industry, universities, technical institutions and research organisations have made contributions in these fields.

In a blend at least two types of fibres are mixed, the properties of which would not be similar. Therefore, a systematic study of fibre interactions and inter-relations in blends has been reported using various blended yarns in which one of the components is high or medium tenacity polyester and the second component is cotton, viscose, polynosic or acrylic fibre all produced in India.[23] Various physical properties as well as whiteness, dyeability etc. were examined at the fibre stage and then at the yarn stage in order to examine the role of intrinsic properties as well as surface properties of each type of fibre in governing the properties of the yarns obtained from these fibres either 100% or after blending. Detailed examination of strength characteristics, dyeability, feel etc. has been carried out to throw light on translation of the fibre properties to yarns as a result of yarn formation and blending.

The subject of fibre interactions in blends and dependance of yarn properties on fibre properties is important and similar studies have been conducted by several others.[24-26] For example a theoretical study on the prediction of bundle strength from single fibre test data[24], and an attempt to quantify the translation of fibre bundle tenacity into yarn tenacity are reported[25]. Also effect of processing factors and fibre properties on the arrangement of fibres in blended yarns has been studied, because the fibres differing in physical properties when blended take up preferential arrangement.[26]

A study has been reported by another group of scientists on the mechanical properties and performance characteristics of polyester-cotton blended yarns and suiting fabrics obtained by blending a variety of polyester fibres varying in denier, tenacity, initial modulus and surface properties with a few selected variety of cotton.[27] It has been observed that tenacity of polyester fibres plays important role in determining certain mechanical properties.

Apart from inter-relations between properties of fibres and resulting yarns, various mechanical steps and factors involved during blending and conversion of fibres to yarns are important in influencing the properties of the yarns. These have been investigated by technologists. For example, investigation of the drafting force characteristics during roller drafting of polyester-viscose blended slubbings by means of a sensing probe in the drafting zone has been reported so that optimization of process parameters can be achieved to get better yarns[28].

In another investigation, effect of drafting speed at ring-frame on yarn and blend irregularities has been studied both of which are not found to be similar.[29] Effect of drafting speed on yarns made from fibres of high as well as low extensibility and on yarns made from polyester-acrylic, viscose-acrylic, and polyester-polynosic blends has been studied to give useful information to reduce yarn irregularities as well as blend irregularities.[29]

Winding conditions would affect the properties of the yarn such as hairiness, strength characteristics etc. Therefore effect of winding conditions on the properties of polynosic-cotton blended yarns has been reported to be investigated using two types of winding machines so that operation of winding can be controlled to get yarns with satisfactory properties.[30]

Yarn hairiness affects the fabric quality and creates problem during conversion of yarns to fabrics. Therefore, effect of various parameters involved during preparation of polyester-cotton blended yarns on hairiness has been investigated.[31]

Draw twisting, winding and unwinding are important operations in the production of synthetic filament yarns. Tension variation during winding operation will affect the ultimate yarn structure due to uneven relaxation process. The resulting variation in the yarn structure will affect the dyeability of the yarns giving rise to defects like barreness etc. Therefore to get uniform yarns with homogenous properties, winding tension has to be controlled. In this connection mechanics of winding tension on draw-twisting machine has been reported to be studied.[32] Sfpecific winding operation has been analysed to throw light on the mechanism and guide lines have been provided to control the winding operation.[32]

Crimping and texturising of synthetic fibres is very important. Therefore this subject has received considerable attention from scientists in India. A theoretical study on stuffer-box texturing process for thermoplastic fibres such as polyamide and polyester and designing of stuffer-box crimper are reported.[33] Also effect of process variables on yarn characteristics using nylon 6 multifilament yarn as well as crimping of polyethylene terephthalate(PET) multifilament yarn are reported to be studied.[33] In another study fabrication of edge crimper is reported according to which carbide edge was prepared first and the edge crimper was fabricated from it.[34] Nylon multifilament yarn was crimped changing few variables and the properties of the yarns were evaluated to throw light on the edge-crimping process and the effect of process variables on the crimped yarns.

A study on air-texturing of nylon 6 multi-filament yarn is reported in order to see the effect of filament characteristics and processing variables on the characteristics of the textured yarn.[35]

Also air-texturing of fine denier polyester and nylon 6 filament yarn was reported in which variables have been examined.[36] It was observed that it is possible to produce air-textured yarn with desired bulk, stability and strength by controlling the parameters involved such as air pressure, pretwist, overfeed etc. The evaluation of the properties of these yarns indicated their suitability for dress material.

The influence of certain texturing parameters on bulk and resilience of nylon 6 yarn textured by false-twist texturing has also been reported to be studied.[37] Such yarns would have inherent torque the effect of which will depend on texturing parameters. This has been investigated and the effect of combining various textured yarns on the spiralities in knitted goods has been studied. It has been concluded that by selective use of combination of various yarns it is possible to obtain variety of fabric effects.[38]

A theoretical study on creep and creep recovery behaviour of nylon 6 monofilaments using commercial sample which was heat-set under different conditions is also reported.[39] The orientation of the filaments appeared to play an important role.

An interesting study of influence of draw ratio and drawing temperature on false twist textured nylon 6 multifilament yarn has been reported.[40] Crimp regidity, tenacity and dye uptake have been assessed to study the effect and it has been observed that the properties of the textured yarn depends on the feeder yarn, as the yarn retains the memory of the previous drawing history.

A comparison between conventionally textured and draw-textured polyester yarns has been reported in which the physical characteristics of the fully oriented yarn (FOY) textured by conventional method and partially oriented yarn (POY) textured by draw-texturing were examined.[41] Also the yarns were evaluated for weaving, dyeing and finishing etc. It was observed that the draw-textured POY yarns had several advantages over the conventionally textured FOY yarns such as more bulk, more flexibility during processing, attractive feel, better crease-resistance, and better dyeing behaviour. These advantages are indicated to ultimately benefit the consumers who would get better fabrics.

A comparative study of the properties of the fabrics from conventionally textured polyester yarns as well as from draw-textured polyester yarns both used in the weft on polyester-viscose and polyester-cotton warp has been reported which showed that the mechanical properties such as tensile strength, tear-strength, crease-resistance, abrasion resistance, pilling and stiffness were same for both, but the fabric from draw-textured yarns as weft had lively handle and gave darker shades.[42]

In another paper of similar nature, fabrics from air textured polyester filament yarn and those from flat yarns, both used as weft on same (polyester-cotton) warp have been compared for tensile strength, pilling, air-permeabiliy etc.[43] The fabrics with air textured weft showed bulk, flexibility and air permeability all of higher order than that from flat yarn.

A new method of texturing thermoplastic yarns with the aid of solvents is reported.[44] Polyester, polyamide and acetate yarns were torque textured by chemo-mechanical method using suitable solvents and their properties were analysed. The method is reported to offer good promise for texturing tri and secondary acetate yarns.

Thermoplastic fibres can be textured by heat treatment, but viscose rayon, a non-thermoplastic fibre will require special method for texturing. Therefore, textured viscose rayon was reported to have been produced by using crosslinking agents such as dimethylol-dihydroxyethylene urea (DMDHEU) and epichlorohydrin and backtwisting the crosslinked yarns.[45] The cross-linking was carried out by curing under tension and without tension and the properties of the textured yarns have been evaluated. It has been observed that curing under tension improved tenacity.

Texturing of polyester-viscose blended yarns is a two-step process as conditions for texturing both the fibres are different. Therefore, development of a single stage rapid cure technique has been reported in which texturing is accomplished by heat-setting of polyester and cross-linking of viscose using commercial resin precondensates based on DMDHEU and ployfunctional urethane.[46] The cross-linking of viscose was carried out by a single-stage rapid-cure technique which helped setting the deformation on viscose to achieve texturing. Effect of variables on the crimp rigidity, crimp stability and other properties of the crimped yarns have been examined.

A investigation of physical and mechanical properties of texturised filling fabrics has been reported from Sasmira.[47]a

Core spun yarns are special yarns in which one can have core of one type of fibre and sheath of another type of fibre, a combination of which can be utilised with some advantages for certain purpose. A variety of core spun yarns have been therefore reported to be prepared and studied. Majority of these are made with cotton as sheath and man-made fibre as core material. However, there are few exceptions.

Luxurious appearance of silk and its aesthetic appeal are well known. Therefore a project was undertaken at Sasmira to investigate the possibility of core-spinning of silk for obtaining furnishing fabrics, in which silk is used as a covering with a suitable man-made fibre as a core, the combination of which would provide some advantages.[47]b Three varieties of core-spun yarns were made on ring-frame using silk (mulbery type in top form) as a covering material and crimped nylon filament, viscose rayon filament and viscose staple as core materials. A fourth variety was prepared using sheath of silk-polyester blend with viscose filament as core. Fabrics were woven using these core-spun yarns as weft with viscose rayon filament as warp. Various physical properties of the yarns as well as of the fabrics were investigated and it was observed that the strength of the yarns appeared to depend more on the long staple silk cover than on the core fibre. Therefore cheap core material such as viscose will give cheap material with no apparent disadvantage. Also dyeing of such material was possible and attractive single and multi-colour effects could be obtained.

Core spun yarns with multi-filament nylon yarn as core and cotton as sheath are reported to be obtained on a modified ring frame from four to five types of cotton fibres having different staple lengths.[48], [49] From each grade of cotton three core-spun yarn samples were obtained by varying core-sheath ratio, twist factor etc. and their properties were examined. From the results it was concluded that single thread strength and tenacity of yarns increase from short staple to long staple cotton. Also yarns with longer staple length of cotton have the advantages of regularity, evenness, less hairiness and decreased extension. Reduced cotton sheath content has been found to improve yarn tenacity, extension and evenness, but yarn regularity was found to improve with increased sheath content. In general core spun yarns have improved strength and regularity but they also have snarling tendency which can be reduced by steam setting. It is also reported that core spun yarns of different counts and having different twist factor were made on a ring frame with nylon multifilament as core and cotton as sheath which showed improved strength and evenness.[50]

Fabrics were also made from these core spun yarns. It was observed that most advantageous use of nylon multi-filament core with cotton sheath can be made for optimum functional performance of fabrics.[51] These fabrics were found to possess higher tensile strength, better extension, improved abrasion resistance and better crease-recovery, but lower bending modulus and less air premeability as compared to similarly designed cotton fabrics. The amount of twist in the core yarns influenced the properties appreciably.

Core spun yarns using nylon monofilaments of different denier as core and Indian cotton of medium and long staple variety as sheath were prepared and the strength characteristics were measured.[52] Fabrics were woven from these yarns and their properties were also investigated. Core spun yarns are reported to show improvement in general and give fabrics with satisfactory performance.

In another paper, effect of spinning conditions on the tensile properties of core spun yarns with medium tenacity nylon filament core and cotton as well as polynosic rayon covering has been reported.[53]

Core-spun yarns were reported to be prepared by using textured nylon multifilament as core having different geometrical disposition and cotton as sheath.[54] The effect of certain variables on tensile properties of the yarns has been evaluated.

Also core spun yarns from high-density polyethylene (HDPE) monofilament covered by jute sheath fibres for common packaging materials have been reported to be obtained which showed spinning efficiency of jute improves by introducing HDPE at the core.[55] Such yarns are found better for retention of strength after prolonged soaking in water and have higher extensibility.

Polyester-cotton has been established as a very popular blend all over the world. It is known that upto 1974 mainly imported Cotton from Egypt, U.S.A. and Sudan was used for blending, because the Indian cottons were found to have inferior quality compared to the imported varieties when blending trials were taken.[56], [57]. However, from 1970 onwards number of new hybrid varieties of cotton have been developed and therefore scientists from various institutions have reported work undertaken by them to study the blending properties of these new varieties of cotton with polyester fibres.[58-64] Variables involved in the blending operation and the properties of the blends obtained were investigated to assess the performance of the new Indian cottons in blends. A recent report on such investigations indicates that the new varieties of Indian cottons provide good scope for blending when the blend contains at least 50% polyester.[65]

Though 67/33 polyester-cellulose blend has been established as a superior blend, the blend ratio can be varied to any extent. In a country like India, fabrics with high polyester content would be more costly due to high price of polyester and climatic condition would also favour lesser amount of polyester and higher percentage of cellulosic fibre in a blend which would provide more comfort. Therefore, several researchers have studied various factors affecting the blend as well as effect of blend ratic on the properties and performance characteristics of the fabrics and explored the possibility of reducing the polyester content in the polyester-cellulose blends to a satisfactory level.[66], [67] In this connection mechanical properties of polyester-cotton blends have been reported to be studied using conventional (67/33) blend and blends with low percentage of polyester upto 20% including reverse blend of 67 cotton and 33 polyester.[66] The comparison of various properties of the different blends gave useful data and indicated that fabrics with satisfactory crease-resistance property and strength could be obtained with low polyester content.

In another paper changes in some mechanical properties of polyester-cotton suiting have been reported to be examined for blends in which polyester content was kept below 67%.[67] The examination of various parameters indicated that for obtaining satisfactory crease-resistance property and strength when polyester content is low, it is necessary to take certain remedial measures such as selection of weave, choice of raw material followed by appropriate processing steps such as heat-setting, resin finishing etc.

However in another paper it has been shown that the wear-life of a polyester-cotton blended fabric suffers when polyester content is lowered below 50%.[68]

High twist polyester blend (HTPB) yarns are found useful for certain fabrics, but pose some problems during fabric preparation. As weaving of such yarns satisfactorily is very important, a study has been reported which has arrived at certain guide lines to be followed from twist-setting to weaving steps while handling such HTPB yarns.[69] Proper twist setting, satisfactory sizing and precautions and controls for other processing parameters are discussed to provide guide lines to obtain fabric without any defect or damage.

As viscose is a cheap fibre, properties of polyester-cotton, polyester-viscose and polyester-cotton-viscose (triple blend) blended fabrics have been reported to be studied with a view to find out the extent of viscose that can be used with polyester, without affecting the physical and aesthetic properties of the fabrics to a significant level.[70] It has been found that the fabric properties were not adversely affected in a blend with polyester-cotton-viscose of 50-33-17% composition.

Properties of blended textiles depend on various factors. Therefore, effect of different twist multipliers on polyester-cotton (50 : 50) blend has been investigated with a view to establish optimum conditions for obtaining fabrics with satisfactory properties.[71]

Two or more types of fibres are blended for various reasons. Due to high price and shortage of cotton, multifibre policy has been now introduced in India and as a result cotton is required to be mixed with at least 10% of regenerated cellulosic fibre. With a view to throw light on the properties of cotton-polynosic blends of different composition and to find out the optimum blend percentage having satisfactory properties, a study has been reported by Scientists in which the mechanical properties of yarns and fabrics obtained from various blends of cotton-polynosic are studied.[72]

Also a study has been reported on successful blending of wool-polyester and wool-polyester-viscose on cotton system with some advantages including cost saving.[73]

Khadi fabric is a speciality of India in which hand spun yarn is hand woven and as a result a large sector known as Khadi and Village Industries exists which supports families living in villages (rural areas) encouraging them to carry out various types of handicrafts apart from making Khadi. So far khadi has been made only from cotton. But recently utilisation of synthetic fibres like polyester has been thought of in order to improve certain performance characteristics of the Khadi fabric. At Sasmira, Scientists prepared Khadi material using polyester-cotton blend with a view to improve the properties of the fabric such as durability and impart wash and wear characteristics.[74] Four types of cheaper variety of cotton was blended with polyester to get 67 cotton-33-polyester blend and the yarns were hand spun. The yarns were then woven on a hand-loom. The properties of the yarns-and fabrics were then investigated. It was observed that the Khadi look of the fabrics was preserved, but the fabrics were superior in durability and wash and wear properties. Thus if cheaper cotton is mixed with polyester on which exemption is granted from the excise duty, then polyester-khadi can be brought within the reach of common man.

An analysis by CAFI in this regard has indicated decline in the production of 100% cotton Khadi due to lack of easy-care properties and other related factors. The analysis deals with statistics, cost figures and other factors pertaining to the problem and suggests blending of polyester-cotton for the khadi production to revive the industy.[75] The suggestion is based on the fact that CAFI's experiment with spinning of polyester-cotton blended yarns on Amber Charkha and weaving of this yarn on conventional hand-looms has been successful in uplifting the income of spinners and weavers. Ambar Charkha is a modified yarn spinning machine to get hand-spun yarn with better quality and in better yield. CAFI has analysed the problem of production as well as processing of such blended fabrics by the hand-loom sector in detail and done good amount of promotional work.

Apart from polyesters and polyamides, acrylics have become the third most important group of synthetic fibres. Acrylic fibre is manufactured in India since 1979 under the trade name "Cashmilon" by M/s. Indian Petro-Chemicals Corporation Ltd. Also J. K. Synthetics has started to manufacture this fibre. The fibre is well utilised in the woollen sector, but its use in other sectors needs to be promoted by trials. Therefore development of acrylic-viscose blended suiting and shirting fabrics has been reported by one of the manufacturers.[76] A blend of 65% acrylic and 35% high tenacity viscose has been developed, spun and woven into fabrics which have been then processed chemically and dyed. The sequences of operations involved are outlined and other details are given. Also details regarding dyeing procedure and dyeing behaviour as well as finishing treatments are given. Finally evaluation of the fabric properties and cost analysis to compare the acrylic-viscose blend with polyester-viscose blend are given. The findings indicate that the performance of the blend is satisfactory and such fabrics would be cheaper than polyester-viscose blends having upto 48% polyesters.

As in the previous case of Khadi, Promotion of jute fibre applications has been visualised by blending of this fibre with other fibres including man-made fibres. India is a producer of considerable amount of jute fibres which are mainly used in packaging and floor-covering items. As jute is a relatively cheap and strong fibre, the feasibility of spinning viscose-jute blended yarns on cotton system has been investigated at Sasmira.[77] The findings indicated that the viscose-jute blended yarns having upto 33% jute can be satisfactory spun.

In addition, Indian Jute Research Association (IJIRA) also thought of blending of jute fibres with man-made fibres and develop fabrics which may offer advantages over all jute materials and which may be suitable for other end uses.[78], [79] Also it was felt that the blended yarns may be suitably utilised by the handloom sector for producing furnishing materials and variety of other items. Therefore, attractive blended yarns of jute-viscose rayon, jute-wool and jute-polypropylene (PP) have been developed by IJIRA scientists using jute system.[78], [79] The study indicates that the blended yarns could be processed and dyed satisfactorily and found useful for tufted carpets, or could be woven on jute-looms or handlooms into decorative fabrics, blankets and carpets. The fabrics from blends are found to have improved performance characteristics and better strength properties as the disadvantages associated with jute were minimised or removed. Also union fabrics produced by weaving jute yarns in one direction and HDPE/PP tapes in the other direction were found to be lighter in weight and therefore would be suitable for packagings and carpet backing.[78]

Silk is known for its aesthetic appeal but it lacks in certain properties such as strength, durability and crease-resistance. Therefore a study of blending of mulbery silk with polyester fibres was undertaken at Sasmira with a view to obtain dress fabric with appearance of silk but with improved performance in some respects.[80] Silk fibres were blended with polyester fibres of different denier on cotton system to obtain silk-polyester 33-67% and 50-50% blends. Apparel fabrics were woven successfully using 33-67 blend both in warp and weft and 33-67 blend in warp and 50-50 blend in weft. Properties of the yarns and fabrics have been assessed and the results appeared promising.

Aakra plant is a wildy growing desert plant. Its fruits give silk-like cellulosic fibres which may be used as textile fibres. Therefore, a study was undertaken at Sasmira to explore the possibilities of finding useful applications of Aakra fibres.[81] Initial attempts to spin 100% Aakra fibres were not successful due to brittle nature of the fibres. Therefore, blends of Aakra fibres with viscose rayon were experimented with. A blend of 33% Aakra fibres with 67% viscose rayon was found more suitable. It was spun into yarn and woven into fabric. The properties of the yarns and the fabric were then investigated. The yarns were found to be weak and therefore more suitable for hand weaving. However, the yarns and fabric produced had the silky look and therefore may be useful for fashion wear. It was found that the fabric could be successfully processed like cellulosic textiles and the finished fabric has a soft feel and attractive appearance. Aakra fibres are cheap and can be developed further in the rural areas for providing work as well as cheap fabric to the weaker section.

Apart from research work on weaving aspects and woven textiles one can find publications on knitting aspects.

Parachutes are very important items for defence purpose and requirements of parachute canopy fabrics are very rigid. Therefore a study was reported in which various parameters involved in weaving and processing of parachute fabrics made from high tenacity nylon 6 yarn in lower denier were assessed and their effect on the fabric properties at various stages of the manufacture was studied to provide useful guidelines.[82]

Air permeability of parachute fabric plays very important role in the reliability of opening, stability and rate of descent of a parachute. Therefore, functional properties of parachute textiles have also been reported to be studied.[83]

In addition, relation between fabric pore size and air permeability has been studied with the help of photomicrographs of parachute fabrics made from high tenacity yarn.[84]

Sizing of yarns before weaving is an essential step. With the development of new fibres and blends, sizing requirements have also been changing to suit the type of the yarns being handled. In an interesting paper, development of a new acrylic size named as Catacryl size suitable for polyester and polyester blends has been reported.[85] The catacryl size developed is a novel acrylic polymer containing various ester groups such as ethyl, butyl, and others together with free carboxylic acid groups so that certain desired properties can be derived from these groups. The properties of this size and of its mixtures with starch were examined and compared with that of other sizing agents or sizing recipes. Also the performance of this new size has been assessed against polyvinyl alcohol size and cost analysis is presented. It has been concluded that the Catacryl size is very economical and has excellent performance for polyester blends when used in blends with etherified, thin boiling starches.

Organisation of a seminar on the subject at Delhi I.I.T. indicates the importance of sizing and interest of Indian Scientist in the subject.

Research involving processing

Processing of woven fabrics is very important and involves various chemical and mechanical treatments. Research and development work in this field has also been reported from time to time.

The conventional processing steps to convert grey polyester-cotton blended fabric to white fabric prior to whitening or dyeing are energy and water consuming steps. To save time, water, electricity, steam and man-power a study has been undertaken by a leading mill to combine some of the operations such as desizing, scouring and bleaching into one single operation.[86] Trials have been taken using various recipes for the combined process and the results obtained were compared with that of the standard process. It was observed that simulteneous desizing, scouring and bleaching of polyester-cotton blended fabrics can be carried out by using a chemical system comprising hydrogen peroxide, sodium silicate, soda ash, potasium sulphate and non-ionic wetting agent to achieve satisfactory results identical with that by the commercial four step bleaching process. The cost and other benefits are also outlined.

Textile chemists are familiar with the pretreatments needed for polyester-cellulosic blends. However, one may find it logical as seen in the previous paper, to re-examine various processes with a view to achieve some saving in energy as well as cost. Such a study has been undertaken and reported in which a single stage bleaching process on jig as well as pad-roll system has been developed.[87] The process is short but imparts good whiteness and absorbency to fabrics and therefore accepted by industry. The possibility of using J-box for this process is also indicated.

Mercerization of cotton-viscose blend results in loss of viscose and therefore barium number fails to indicate efficiency of mercerization in such cases. Therefore proper care or precautions are required to be taken otherwise the blend does not offer any advantage. A study has been reported in this connection.[88]

We are all aware that cellulosic textiles or cotton textiles would be found more comfortable in a country like India due to climatic conditions. However, due to rising price of cotton and several other factors, blending of cotton with regenerated cellulosic fibres is becoming more common. The fine structure and physical and mechanical properties of cotton and regenerated cellulosic fibres are not similar. Also cotton textiles need and can stand severe alkaline treatments which is not the case with regenerated cellulose. Therefore, realizing the necessity for modifying and standardising pretreatments such as scouring and bleaching for blends of cotton-regenerated cellulose, a study has been reported to be undertaken.[89] Various types of blended and 100% single fibre fabrics were subjected to a set of pretreatments both mild and severe and the mechanical properties of the fabrics were assessed to estimate loss in tensile strength, weight etc. From the investigation, suitable conditions for pretreatments for various blends have been arrived at and recommended.

An interesting investigation has been reported to throw light on the deterioration of mechanical and aesthetic properties of polyester-polynosic-cotton blended fabrics during processing.[90] Each step of processing namely shearing, cropping, singeing, desizing, scouring, chemicking, causticization or mercerization, dyeing and printing, reduction clearing, resin finishing, soaping, drying etc. was investigated for its effect on the fabric properties. It has been observed that the strength loss occured during various stages in which alkali was involved and therefore steps to reduce the severity of the action of alkaline liquors have been outlined.

Polyvastra-means Khadi fabric made from polyester-cotton blends, has been already referred to in the earlier section. The processing aspects of polyvastra are reported to be studied, taking into consideration their applicability and suitability to small scale sector of Khadi. The processing sequences followed by industry involves various machines such as jigger, padding mangle, stenter, heat setting and singeing arrangements etc, whereas the Khadi fabric is only given ordinary bleaching treatment and Dhobi wash (means washing by washerman).[91] The study involves comparison of the performance characteristics of the polyvastra after dhobi wash with that of the fabric processed by the conventional method involving heat setting and singeing. It has been observed that the dhobi washed polyvastra showed satisfactory strength, demensional stability and crease-recovery property, indicating that a simple dhobi wash would be adequate eliminating the need for heat-setting or singeing operations not very suitable to small scale sectors. The point is stressed that heat setting and singeing would give somewhat smarter appearance to the fabric which would be more significant in thick materials, but the objective of improving the wear life and dimensional stability by blending would be achieved without these operations. Also dyeing of polyvastra by the usual process for khadi dyeing was found satisfactory and therefore for pale shades high temperature-pressure dyeing facilities would not be essential.

A similar study on polyester-cellulosic blended fabric was undertaken at Sasmira to investigate simplified processing sequences for grey material to obtain white fabric, which can be suitable to and therefore recommended to handloom sector thus encourating it to handle polyester blended material.[92] The study involved processing of the fabric by the conventional mill process and by the simplified process eliminating the heat setting step and avoiding the use of machines and comparison of the properties of the fabrics obtained by both the processes. The findings indicated that the simplified process gave comparable results with the mill process and can be recommended to the handloom sector.

Amongst the various steps of wet processing, dyeing and printing are two very important processes for all types of fibres and blends.

Inspite of variety of dyes being available and number of processes being known for their application on all types of fibres, there are problems and limitations attracting the attention of the scientists to carry out applied and basic research in the field so that better understanding of the dyeing and printing processes and better results could be obtained.

When polyester fibres came into the market, the old concept of dyeing from aqueous solutions of dyes had to be modified leading to the development of disperse dyes and dyeing from acqueous dispersions of the dyes. Actually the credit for the development of dyeing from dispersion of dyes goes to acetage fibres. Acetylacted cellulose loses affinity for water soluble dyes otherwise applicable to cellulose, as a result new dyes were developed which could be applied from dispersions to not only cellulose acetate, but also to polyamide fibres. Later on, the polyester fibres gave a large boost to the development of disperse dyes and their application methods. With the development of thermoplastic fibres, another factor which assumed importance during wet processing steps is heat treatment or heat-setting, texturing etc.

It is a well known fact that dyeing properties of polyethylene terephthalate fibres depend on the manufacturing conditions as well as conditions of heat-setting, texturing etc. Therefore, a fabric made from yarns having different thermal and manufacturing history is likely to show uneven dye uptake. To differentiate between polyester fibres which may produce barre effect on mixing, a study has been reported to be undertaken to develop a quick method of detecting difference in dyeability of different fibres.[93] The study involves heat-setting of polyester filament yarn at different temperatures and examination of the samples for shrinkage, critical dissolution time, solvent swelling, X-ray diffraction and dye uptake at 130° C, so that the structural changes on heat-setting and dye uptake can be correlated. In addition, the heat-set samples as well as selected samples having difference in dyeability were dyed from solvent mixtures at room temperature to study the staining effect which may provide quick method to detect difference in dyeability. The high temperature dyeing as well as staining with dye solutions in solvent mextures gave useful information. It has been observed that the dye uptake decreases as setting temperature increases from 120 to 140° C, remains same between 140 to 170° C and then again show increase when the setting temperature is raised from 170° C to 220° C. The dyeability has been shown to be governed by the order factor and orientation as indicated by the X-ray data as well as on the dye because it was observed that different dyes showed different dye uptake and therefore the difference was well marked with some dyes but was less prominant with others. Though the effect of staining from solvent mixtures was observed to be prominant on samples heat set upto 160° C, the polyester samples known to have difference in dyeability showed significant differential staining from such solutions when appropriate dye was used, thus providing a quick method to differentiate polyester fibres having difference in merge numbers.

In a similar study dyeing of polyester filaments after heat-setting at different temperatures has been reported to be investigated using trichloroethylene, water and water-trichloroethylene mixture to throw light on dyeing mechanism.[94] It has been observed that the dye uptake initially decreases and is minimum in the range of 170-200° C setting temperatures, but increases at setting temperatures above 200° C irrespective of the dyeing medium. Thus it is indicated that the dyeing mechanism is similar in all the cases and can be explained by the free volume theory.

In other investigation, effect of heat setting under different conditions on the structure, mechanical properties and dyeing behaviour of flat and textured polyester yarns has been reported.[95] It has been concluded that for flat yarn setting under constant tension at constant temperature is necessary to obtain yarn with good mechanical properties and uniform dyeability. Also the effect of setting temperatures on the dye uptake is similar for flat as well as textured PET yarns and the dye uptake which initially decreases upto 170-180° range of setting temperature starts increasing above 180° C. It has been observed that the post-texturing heat treatment plays important role in case of textured yarn. Same observations were made earlier and temperature of texturing was shown to play important role.[96]

Fabrics from polyester and polyester-cellulosic fibre blends are normally dyed after heat setting and heat setting temperatures are known to affect the dyeing properties of polyester fibres, few publications on which have been already referred to above. Therefore effect of heat setting temperatures on dyeability of polyester in 67 : 33 polyester-cotton blended fabric is reported to be investigated.[97] The fabric was heat set at four different temperatures, namely 160°, 175°, 190° and 205° C for 30 secs. and dyed at 130° C using 15 commercial disperse dyes which were selected for the study. It was observed that nearly all dyes showed poor uptake for heat setting temperature of 175°C. However, for heat setting temperature above 190°C and upto 205°C, some dyes showed higher uptake at 205°C setting temperature whereas some dyes showed higher uptake at 190°C setting temperature which was decreased at setting temperature of 205°C i.e. the trend was reversed. Normal heat setting temperature in the textile industry is 190°C, but some textured and knitted goods are heat set at 160°C. Therefore lower limit of heat setting was studied. It was observed that for setting temperature of 160°C some dyes showed lower uptake but some dyes showed higher uptake compared to that for setting temperature of 190° C. On the whole different dyes showed different behaviour, but the findings indicate that 190° C is the most suitable heat setting temperature at which most of the dyes showed good pick-up. Also maintenance of uniform setting conditions are essential.

In a theoretical study, polyester fibres are reported to be modified by grafting with polyvinyl acetate and polyvinyl alcohol using gamma ray irradiation, and the effect of grafting on morphological parameters such as crystallinity, orientation etc. as well as the effect of morphological structure on dyeing characteristics when the modified fibers were dyed with disperse dyes at boil and at high temperature were investigated.[98] It has been observed that the grafting with polyvinyl acetate slightly decreases the moisture regain, but the saturation dye uptake increases upto a particular graft content and attains an equilibrium whereas in case of polyester grafted with polyvinyl alcohol the saturation dye uptake initially increases with polyvinyl alcohol content and then decreases, but the moisture regain increases with the graft content due to hydrophilic nature of PVAL. This data indicates that the behaviour of both these modified fibers differ from that of PET fibers modified with acrylic acid.

A study of the effect of fine structure of the preswollen nylon 6 fibers on dyeing and mechanical properties has been reported. Nylon 6 filaments, undrawn and of different-draw ratios were preswollen in solvents like benzyl alcohol, acqueous phenol and acqueous formic acid.[97] The structural parameters of the preswollen fibers, such as crystallinity, molecular orientation, [illegible] were assessed and their dyeing and mechanical properties were also investigated in order to study the influence of the fine structure of the fibers on these properties. The main effect produced by the solvent treatment was increase in the lateral order of crystallinity without any appreciable reduction in orientation. Also increase in dye uptake, little reduction in tenacity, but increase in elongation at break were observed which were assigned to increase in void volume.

In another paper, nylon 6 monofilament has been reported to be graft copolymerised with acrylic acid and acrylamide using ceric salts as initiators and the dyeing behaviour of modified nylon was investigated.[100] The basic dye uptake of acrylic acid grafted nylon showed increase compared to that of unmodified nylon 6 due to introduction of carboxylic acid groups, but the dyeability of the acrylamide grafted nylon 6 was not altered for acid dye compared to that for unmodified control.

Modification of polyamides and[101] studies in dyeing of polyamides are reported in which various aspects have been studied.[101, 104]. For example in one study polyamide filaments were modified by blocking amino groups using a condensation product of cyanuric chloride with sulphanilic acid named as C-S compound.[101] Substantivity of the polyamide fibres towards cationic dyes is reported to be improved by this modification. Blocking of amino groups also improved the resistance towards heat and light degradation. Also differential dyeing properties could be imparted by printing with the C-S compound and its fixation[102]. The modified fibres could be dyed satisfactorily with cationic dyes. Also it was observed that the condensation product C-S blocked amino groups and partially blocked samples showed better resistance to thermal degradation compared to fully blocked samples. The investigation was further pursued to study the thermal stability of nylon filaments dyed with cationic dyes without any modification, dyed after modification with C-S compound and modified after dyeing with cationic dye.[103] The cationic dyes alone were found to give some protection against thermal degradation, but when the amino groups were blocked by modification prior to dyeing not only the protection imparted against degradation was higher, but the thermal fading of cationic dyes was also retarded. This indicates that the amino groups probably catalyze the degradation of fibres as well as cationic dyes both of which can be controlled by blocking these groups.

As cationic and basic dyes show poor light fastness on polyamide fibres and wool respectively, the effect of modification of polyamide fibres on light fastness by grafting the predyed fibres with acrylonitrile as well as acrylamide using gamma ray irradiation technique has been reported to be investigated.[104] It was observed that with low add-on of the graft, light fastness was improved considerably in case of acrylonitrile, but the acrylamide graft showed only limited improvement.

Mass colouration or dope dyeing technique is used for synthetic fibres to get very fast, uniform and deep shades otherwise difficult to obtain in some cases. The process involves incorporation of colouring material prior to spinning of fibres at a suitable stage during or after polymerisation. Mass colouration of flat nylon 6 yarns is reported to be studied by using various known techniques, because it is difficult to use conventional yarn dyeing procedures.[105] The flat coloured nylon yarns obtained were found to have satisfactory mechanical properties, and exhibited uniform shades with good fastness properties, The study indicated that the coloured yarns can be satisfactorily texturised by usual methods to get coloured textured yarns without any barreness whereas it is difficult to get such uniform shades by the normal process of texturising followed by dyeing. It is further shown that twisting of two coloured yarns will give multi coloured effect and yarns can be used for weaving or knitting to produce multi coloured effects. Also grey yarn produced by this method can be redyed with a suitable dye to produce variety of tertiary shades.

In an interesting paper, advantages and disadvantages of continuous dyeing of polyester-cellulosic blends have been discussed and two new dyeing systems have been reported. The first study is based on removing some of the difficulties encountered due to alkaline conditions required for fixing the reactive dyes during dyeing with conventional disperse-reactive system.[106] The study reports the conversion of a procion dye to N-methylol derivative through ammonolysis to replace halogen group by amino followed by methylolation with formaldehyde to obtain a reactive dye which can be fixed with acid catalysis. The polyester-viscose blend was dyed satisfactorily with disperse-methylolated reactive dye using acid catalyst based on aluminium complex. The light and washing fastness were found to be good and there was no appreciable loss in mechanical properties. The methylolated reactive dyes were also applied on cotton with cross-linking agents having similar reactive groups to achieve simultaneous dyeing and finishing.[106,106a] The second method investigated, involves the use of basic dyes to dye both the polyester and viscose components with the help of mordants.[106a] Tannic acid was used for mordanting viscose, but polyester was mordanted with another suitable mordant reported to be complexing agent to impart dyeability with the basic dyes. It was found that the basic dyes showed good washing and drycleaning fastness both on the blend and 100% polyester obtained by carbonisation but light fastness was not very satisfactory. However, further study is reported to be in progress and new cationic dyes may be found to have better performance, thus opening up the new approach to dye polyester-cellulosic blends satisfactorily.

With a view to achieve economy by saving time, manpower and energy, modified dyeing techniques for polyester-cellulosic (cotton, polynosic and cuprammonium rayon) blends are reported to have been studied in comparison with the conventional method.[107] In one modification inverse dyeing technique has been explored using disperse-reactive system in which cellulosic component was dyed first followed by the polyester component so that intermediate washing-off, reduction-clearing and drying operations are eliminated. Suitable dyeing conditions have been established for this process and all the aspects such as fastness properties, relative colour value, tensile strength etc. were studied in comparison with the conventional method. Full scale plant trials of the process showed that the results were comparable with the conventional process with additional advantage of cost benefits due to saving in time, energy etc. Another approach to modify the process involved modification of polyester by solvent treatment and modification of cellulosic (cotton) portion by treatment with urea. It has been found that the solvent pretreated polyester gave higher colour yield and could be dyed in half the normal dyeing time to obtain same colour yield as that of the untreated control due to intermolecular structural changes produced by the solvent. Also the chemical modification of cotton by treatment with urea which introduced carbamate groups was found to increase its affinity and reactivity towards reactive dyes resulting into higher colour yields.

In one paper, problems pertaining to dyeing of polyester-wool blends have been discussed and common dyeing faults are attributed to improper selection of disperse dyes.[108] In this connection several commercial dyes available in India have been evaluated for certain properties and parameters which play important role during the dyeing procedure such as build up property, saturation value, sensitivity to heat setting differences in polyester, to pH, to reductive degradation, bath stability, and compatibility with wool dyes and dyebath auxiliaries, as well as resistance to degradation by wool decomposition products. The study explains the practical importance of all these properties of disperse dyes and suggests ways to define these properties so that proper selection of the dyes would be possible.

In order to overcome the limitations involved in dyeing of textured polyester-viscose blends fabrics, a novel process for simultaneous dyeing and texturing of polyester-viscose (50 : 50) blended yarns has been reported to be studied by pad-thermosol-alkali shock treatment.[109] The yarn samples were treated in single bath containing a mixture of suitable pairs of disperse and vinyl sulphone reactive dyes, dimethylol-dihydroxy-ethylene urea (DMDHEU) as a cross-linking agent and an acid catelyst followed by padding drying and curing at 210° C for 2.5, 5 and 30 secs. on Scragg Mini Bulk machine and then alkali shock treatment at 90° C for 15 secs. The simultaneously dyed and textured yarns when compared with the only textured yarn by back or false twisting showed satisfactory crimp rigidity and mechanical properties. Also the colour yield of these samples was compared with that for flat yarn dyed without any crosslinking agent and with that for false twist textured yarn dyed and given padalkali shock treatment and was found satisfactory.

Apart from actual dyeing process, other aspects such as kinetics of dyeing, exhaustion of dyes, mechanism of dyeing, shade matching, analytical aspects involving estimation of dyes and even synthesis of new dyes are important. Indian Scientists have made contributions in these fields and few papers are quoted below.

A method of evaluating the exhaustion of disperse dyebaths during dyeing of polyester fabrics has been reported.[110] The method involves comparison of two consicutive dyeings carried out in the same bath and by measuring the dye concentration of the two dyeings spectrophotometrically. The ratio of the dye concentrations of the two dyeings provides a measure of residual concentration of the dye in the dye bath. The method may be useful for obtaining exhaustion ratings of disperse dyes.

Also studies in dyeing from organic solvents has been reported.[111] In continuation in another paper, kinetics and equilibrium of the dyeing process have been reported to be studied by applying reactive disperse dyes on nylon 6 and nylon 66 from perchloroethylene at 121° C and by sublimation transfer process.[111a]. Also the effect of different pretreatments given to polyamide fibres on the dyeing has been examined and the results are compared with those for cellulose triacetate and polyester fibres. The work was extended to transfer printing of polyamide fibres.

Computerised colour matching is gaining importance due to certain advantages, because colour matching is becoming more challenging with the advances made in the field of fibres and dyes. Therefore, computerised colour matching has been reported to be investigated for dyeing of polyester-cotton blended fabrics with disperse-reactive and disperse-vat dyes.[112] It is reported that a method has been developed by which satisfactory matchings were obtained in several shades in the first computer shot. The method has been investigated for the possible quick change over to new recipe for shade matching with considerable amount of saving in the production cost.

A solvent cadmium ethylene-diamine complex known as cadoxen has been reported in literature for the dissolution of cellulose. The solvent has been reported to be modified and its uses for the estimation of dyes on cellulosic fibres,[113], [114] for the determination of molecular weight of cellulose, [115], [116] as well as for the quantitative blend analysis of cellulosic and synthetic fibres have been reported.[117-119]

Cadoxen is prepared by the addition of cadmium oxide to ethylene-diamine under controlled conditions, its final composition being 5 + 0.1% cadmium, 28 + 1% ethylene-diamine and 0.5 M + 0.01 M NaDH.[113-115].

The solvents was successfully used to estimate direct and reactive dyes on cotton giving comparable results with the conventional methods.[113] Further a new method has been reported to be established for the estimation of direct, reactive and vat dyes on cellulosic fibres and disperse dyes on cellulose acetate fibres using modified cadoxen solvent in which the dyed material is dissolved followed by colorimetric estimation of the dye.[114] The method is found to be more convenient and accurate than the conventional methods.

In continuation of this study a standard method to dissolve cellulosic materials dyed with different types of reactive dyes was reported to be developed using modified cadoxen solvent and viscosity measurements of the solution of cotton showed no anamolous behaviour. However, viscose rayon dyed with bifunctional reactive dyes showed higher viscosity values when measured immediately, but the values became constant end identical with those of undyed material after storage for 24 hours indicating no influence of the dye. Also the use of cadoxen for the determination of molecular weight of cellulose has been reported.[115-116].

Also dissolution of cotton dyed with bifunctional and polyfunctional reactive dyes, in cadoxen has been studied. The kinetics of dissolution in both the cases were found to be different.[120] This study of rate of dissolution has been reported to be useful in detecting the presence of crosslinks and other aspects of dyeing.

A study on behaviour of bifunctional and polyfunctional reactive dyes applied on cotton has been reported using variety of reactive dyes and techniques such as electron microscopy, surface area determination and swelling in cadoxen.[121] It throws light on the morphology of the dyed material which is shown to depend on the amount of dye present in the fibre and conditions of application. Also positive evidence of formation of cross-links between adjacent cellulose chain has been obtained.

A theoretical study to illustrate the effect of various cations on the adsorption of a direct dye such as Chlorozol Sky Blue FF by viscose rayon has been reported.[122]

Reactive dyes for cellulosic fibres are well established in the market, but reactive dyes for synthetic fibres such as polyamide and polyester is a recent development. Synthesis of reactive dyes containing sulphonylazide, carbonylazide, arylazido and azidoacetamido groups which would react chemically with synthetic fibres such as polyester, polyamide and cellulose acetate has been reported.[123] Their dyeing and fastess properties have been studied. Evidence for chemical bonding of azido dyes with fibres has been established. Also mechanism of fixation of sulphonazido dyes on polyester has been proposed and it has been shown that covalent bonding takes place between the dye and the polyester fibres.[124]

In another earlier paper, incorporation of reactive sulphonazido groups in various chromophoric systems such as azo, anthraquinone etc. has been reported.[125] These dyes were then applied on various fibres such as polyester, polyamide, protein, cellulosic, cellulose acetate, acrylic, polypropylene and their blends. The dyes were fixed on fibres at high temperature after dyeing from dye baths and were found to link with fibres through covalent bonds.

Structure of fibres and structure of dyes play important role during the dyeing process which is not a simple process. As a result mechanism of dyeing and fastness properties of dyes have been studied by scientists, and Indian scientists have also made contributions which are briefly referred to here.

Planarity of dyes plays important role in being substantive to fibres. Therefore relation between planarity of dyes and their substantivity towards cellulosic fibres as well as synthetic fibres has been reported to be investigated by selecting dyes having planar and nonplanar structures and studying their dyeing behaviour.[126],[127]

Also mechanism of dyeing of polyamide fibres with acid dyes [128] as well as mechanism of dyeing of hyrdophobic fibres with disperse dyes[129] have been reported to be studied.

Studies in dyeing of polyester and polyester-cellulosic blends with disperse dyes in connection with adsorption of dyes, their migration as well as transfer from one substrate to another etc. are reported to be studied leading to further studies in the field of transfer printing and some developments in the field which are referred to in the next section.[130-134]

Printing

Thermoplasticity of synthetic fibres has introduced several new concepts and brought about new developments. One such development is that of transfer printing. Transfer printing is a recent development which has drawn attention of Indian Scientists.[135] In this connection, while studying the "Thermosol" process of colouring polyester-cotton blends it has been shown that the dye which is initially evenly distributed on both the fibres. undergoes migration from cotton to polyester as a result of sublimation during thermo-fixation.[130-133] During this investigation mechanism of dye transfer has been studied and it has been shown that disperse dyes can be transferred from filter paper to synthetic textiles.[130] It has also been shown that cellulose adsorbs disperse dyes at elevated temperatures[132],[134] amd any non-ionic disperse dye can be transferred from paper to polyester, the rate of which is controlled by the vapour pressure of the dye.[136] Thus dyes having low sublimation fastness and high vapour pressure are more suitable for transfer printing. The behaviour of dyes during vacuum transfer has been studied in which it was observed that though initial vaporisation and condensation is fast, the diffusion of the condensed dye in the fibre is slow.[137] All these observations led to the development of wet transfer printing process for cellulosic textiles with reactive dyes.[138] The fabric, padded with alkali, salt, urea and other auxiliaries is placed on a hot plate and covered with a paper prepared with reactive dye and urea or some other hydrotropic compound which in turn is further covered with a perforated plate. On heating the water evaporates from the fabric and condenses on the paper dissolving the dye. The dye solution thus formed returns to the fabric which picks up the dye and the process continues till the fabric is dry. Very sharp prints are claimed to be obtained.

A random printing process was also developed making use of the fact that at high temperatures dye from cellulose can migrate to polyester.[139] The process involves placing of dyed filter paper pieces cut into various shapes at random on polyester fabric followed by heat fixation. If the fabric is padded with a disperse dye and dried prior to printing, then two colour or multicoloured effect can be obtained. Also by using textured paper, textured print effects can be produced.

It is stated that due to poor fastness of disperse dyes on nylon, transfer printing of nylon is difficult. Therefore, extensive work on transfer printing of nylon using reactive dyes has been reported according to which it was found possible to use reactive dyes if an acid binding agent is present on nylon.[135],[136]

The conventional method of sublimation transfer printing did not give satisfactory results on carpets. The factors behind the poor penetration of the dye were examined and a novel method has been reported to be developed to give satisfactory results in which penetration of the dyes can be achieved within few seconds at 180-210° C.[140] For the study model compounds and commercial disperse dyes on filter paper and cotton voile as substrate were used. It has been observed that the penetration was not influenced by the load on the carpet-paper assembly and other factors, but the penetration was a function of vapour pressure of the dye and was significantly improved by the transpiration process in which a hot gas was sucked or pushed from high to low dye concentration by using cotton voile or any other porous substrate as a dyesubstrate for transfer print.

The study was further extended to transfer printing of commercial disperse dyes from filter papers to polyester staple and 67-33 polyester-cotton blended fabrics and assessment of their fastness properties before and after reduction clear treatment.[141] The washing and light fastness were not affected, but the sublimation fastness showed slight improvement after the treatment.

Transfer printing of polyester-cellulosic fibre blends has been reported to be studied by modifying cellulosic portion (cotton or rayon) by resin (such as DMDHEU) finish as well as solvent treatment such as polyethylene glycol or clycol ether, so that the cellulosic part can develop reactivity for the disperse dyes used for transfer prints.[119] It has been shown that both the treatments alone or when used together gave good prints with satisfactory fastness properties.

It has also been reported that when polyester-viscose blended fabrics are modified by grafting with vinyl monomers such as acrylic acid, acrylamide and their mixtures by a pad-dry-cure method resulting into in-situ grafting, the modified fabrics acquired transfer printability with disperse dyes as well as soil release property.[22]

Blend analysis and fibre identification

With the introduction of variety of fibres in the textile field as a result of development of man-made and synthetic fibres, mixing of two or three types of fibres have assumed importance. Therefore, analysis of blends and identification of fibres are two important aspects for which appropriate methods are essentials for everyone concerned.

Use of cadoxen solvent for blend analysis has been already referred to in the earlier section. The use of cadoxen with alkali and without alkali has been further explored for the quantitative analysis of blends of cellulosic with synthetic fibres,blends of cotton with regenerated cellulosic fibres as well as tertiary blends of cotton, polynosic and polyester.[117-119].

It has been shown that cadoxen-I (with cd 5%, ED 30% and 0.5 N NaOH) is suitable for dissolving cellulosic component and can be used to analyse binary blends of cellulosic fibres with various synthetic fibres, the results being comparable with the other known methods.[117] Further study using cadoxen solvent with varying amount of cadmium and alkalinity has been reported for the development of a method for analysing blends of cotton with regenerated cellulosic fibres.[118] The solubility of cellulosic fibres with different D. P. was found to depend on the composition of cadoxen.[117-119] Thus, it has been shown that cadoxen-II (with 4.6% cd, 30% ED and no free alkali) dissolves only viscose and polynosic rayond but not cotton. Based on this a method has been reported for the analysis of tertiary blends of polyester-cotton-regenerated cellulose (viscose or polynosic) in which cadoxen-II is used to dissolve regenerated cellulose, followed by dissolution of cotton in cadoxen-I.[119] Reliable results are claimed to have been obtained, establishing cadoxen as a versatile solvent useful for various purpose.

When we come to the subject of blend analysis, considerable attention has been paid to it by Indian scientists and there are contributions reported to develop better methods. For example the effect of 5% alkali on acrylic fibres which has been used in quantitative analysis of wool-acrylic blends has been investigated and discrepancies in the method were analysed.[142] A suitable alternative method using dimethyl-formamide has been standardised to overcome the discrepancies encountered in the alkali method.

With the introduction of multifibre policy triple blends containing polyester, cotton and regenerated cellulosic fibres have become more common. The properties of a fabric depends on the blend composition and therefore accurate information is essential. Though there are number of methods known for blend analysis they do exhibit variations in the estimation. Therefore, first of all it is necessary to have reliable test method or methods to determine the blend ratio with minimum error and secondly to recommend feasible tolerance limits for the possible blend variation in various blends. A study has been reported with this view and various blends of polyester-cotton have been taken and analysed by various known methods in order to compare the extent of variation obtained by each method.[143] Also the effect of various processing sequences on the blend ratio tolarance has been examined to throw light on the magnitude of variable factors. In addition effect of blend ratio variations on the various physical and mechanical properties of the fabrics has been examined. The paper emphasises the fact that it is necessary to have suitable test method for quick and accurate determination of blend composition with minimum cost. Also blend composition is to be balanced to achieve desirable performance characteristics and lastly to have awareness and acceptability of the tolarance limits by parties concerned is important for the purpose of exise, trade, etc.

A similar study has been undertaken at Sasmira to evaluate the accuracy of known methods for blend analysis of polyester-cellulosic fibres. Yarns of standard blends were analysed by various methods and results have been compared to throw light on the usefulness and limitations of these methods.[144] Destructive methods using sulphuric acid, sodium hypochlorite, nitrobenzene and monoethanol amine as solvents to dissolve one of the compound were studied and all were found to give results within the range of ± 2%.

A non-destructive method for quantitative analysis of fibre blends has been reported to be investigated which is based on the measurement of moisture regain of the blend and its component fibres.[145],[146] The study involves analysis of cotton-polynosic, cotton-viscose, polyester-wool and cotton-wool blend by the moisture regain method as well as by standard chemical methods and comparison of the results obtained by these methods. It has been observed that moisture regain of a blend can be obtained by linear combination of the moisture regains of its constituent fibres.

Apart from quantitative analysis, quick fibre identification has assumed importance with more and more fibre varieties being found in the market. Staining agents reported in literature are not easily available in India. Therefore, with a view to develop staining agents suitable for identification of fibres, work has been carried out at Sasmira in which mixtures of various types of dyes were investigated for differential staining of fibres. Interesting result have been obtained based on which dye mistures have been developed which can be used to identify different fibres.[147]a

Identification of different cellulosic fibres is important, therefore use of infra-red spectra for the purpose has been reported from Sasmira recently.[147]b.

Due to almost non-availability of commercial staining agents in India for qualitative identification of fibres, development of a staining agent Fibre-Stain ACH has been reported which is shown to clearly distinguish between different fibres and serve the purpose.[148]

Finishing

All fabrics are not dyed and all fabrics are not printed, but all fabrics, either undyed, dyed or printed undergo some finishing before being marketed. The finishing treatments are either normal and simple or special involving application of variety of chemicals or modification of fibres in the fabric from (or at any suitable stage) etc. to achieve special effects and modify or impart certain properties. Research papers at times involve investigations of more than one aspect of wet processing. Therefore some of the papers already reviewed will be found to include the finishing aspect.

Considerable interesting work has been carried out by Indian Scientists on resin finishing of cellulosic and polyester-cellulosic blended textiles, for improving crease resistance etc. which being of the conventional type including study of catalyst systems and other aspects has not been reviewed as the review has already covered many aspects.

When we come to the subject of resin finishing, properties and chemistry of fibres come into the picture. Cellulosic fibres are chemically reactive and can be modified by certain chemical treatments. Finishing of silk poses different problems due to its special structure and aesthetic appeal.

We all know that silk fabrics crease badly on washing and need ironing. Attempts to obtain a synthetic fibre resembling silk have not met with complete success. One would like to have silk fabrics with all the advantages of silk, but with its draw backs such as property to crease on washing being removed.

With a view to develop a recipe for finishing of silk fabrics to impart easy-care or wash and wear property work has been carried out at Sasmira.[149] Silk fabrics mainly of mulbery silk were finished with locally available resins based on urea-formaldehyde, melamine formaldehyde, dimethylolethylene urea, etc. and crease-resist property and mechanical properties of the finished fabrics were studied. After several trials, a recipe based on melamine-formaldehyde applied by pad-dry-cure method was found to improve the crease-resistance of the silk fabrics to some extent (about 10% increase). The finish was found to be fast to washing and had no appreciable adverse effect on strength of the fabric. It was also observed that fabric construction and uniformity of the fabric were important factors. More uniform a fabric better the effect of the finish.

Preparation of polymers and copolymers from acrylic monomers to obtain soil-release finishes for polyester and polyester-cellulose blended fabrics and their evaluation has been reported from Sasmira.[150]

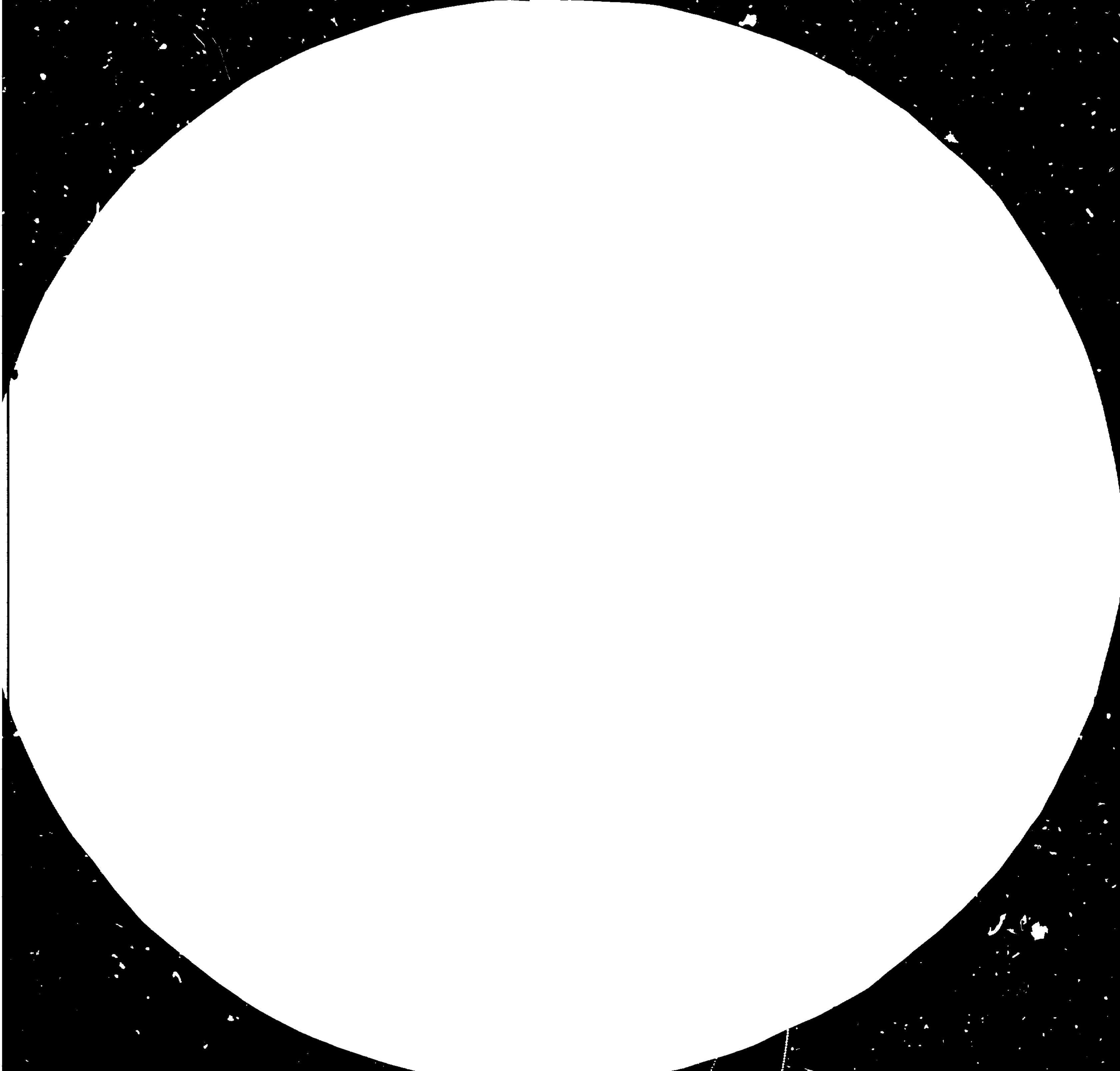
Synthesis of dyes having reactive azido groups has been reported in the earlier section.[125] The azido groups are also reported to be introduced in finishing agents such as long chain alkyl compounds to obtain carboxylazide and sulphonazide derivatives like steroyl and cetyl sulphonazides.[125] These reactive finishing agents when applied on natural and synthetic fibres are reported to impart durable finishing effects. Thus it would be possible to obtain durable finishes on various fibres such as water repellency, oil repellency, soil resistance, antistatic effect, fire retardancy and crease-resistance depending on the nature of the finishing agent.

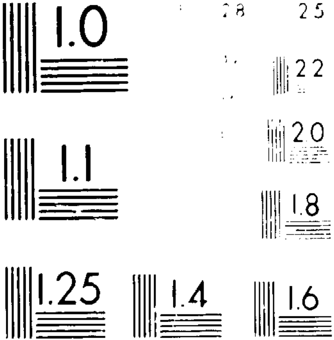
The common textiles in use are all flammable to some extent and in case of fire accidents pose serious hazard to human life. Therefore, advanced countries have enacted legislation to prevent marketing of flammable textiles for certain purpose such as children's wear, thereby compelling the manufacturers to make certain fabrics much less prone to catch fibre. As a result fire-retardant chemicals and fibres have been developed in these countries on a commercial scale, and further research in the field has been pursued.

Indian scientists have also started work in this field so that fabrics used in the areas where there is more fire hazard such as for defence purpose and sarees used by housewives while cooking can be made less flammable. Recently, number of interesting papers were presented at a symposium on the subject giving useful information on the work being done in India.[151], [151a-l]

In the keynote address during the symposium theoretical aspects pertaining to the subject are discussed and information on flammability of various polymers including synthetic fibres is given.[151a] Also various flame-retardant systems are discussed and application of a recipe based on tetrakis-(hydroxymethyl)-phosphonium chloride (THPC) on cellulosic textiles has been reported. In addition interesting work on various esters of cellulose including halo-esters to impart non-flammability has been reported.

A paper has been presented in which application of various flame-retardant finishes on cotton and polyester/cotton blended fabrics has been reported.[151b]. The finishes used were based on compounds containing halogen and phosphorus, compounds containing nitrogen and phosphorus, and halogen compounds in conjunction with antimony oxide. Durable press finishes (N-methylol resins) were also applied together with




1.0
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flame-retardant finishes. The study also involves phosphorylation of cellulosic part as well as graft copolymerisation of vinyl and alkyl phosphorus compounds. The finished fabrics were evaluated by limiting oxygen Index (LOI) for flame retardancy. Various other data on percentage add-on of the finish, nitrogen, phosphorus etc. is given and also synergism of phosphorus by nitrogen is confirmed. The paper reviews various flame-retardants for polyester/cotton blends.

In another paper, development of durable flame-retardants for cotton, 100% polyester and polyester/cotton blends has been reported.[151c] It has been shown that durable flame retardency can be produced on polyester and polyester/cotton blends by single stage application process with decabromo-diphenyl-oxide (DBDPO) and by two stage process with application of N-methylol-diethyl-phosphonopropionamide (NMDEPPA) followed by application of DBDPO. Both the systems are found effective, but two stage process is reported to be more beneficial. In addition phosphonopropionamide compounds were found to impart durable flame retardancy to cotton fabrics.

A detailed examination of these two types of finishes on various polyester-cellulosic blends has been reported.[152] NMDEPPA along with trimethylol-melamine was found to impart durable flame retardancy to cotton but not to polyester. Similarly DBDPO with antimony trioxide was found effective flame retardant for polyester alone. Therefore for polyester-cellulosic blends, especially in case of thinner fabrics and having higher percentage of one of the fibres, single treatment with any one finish would not be effective and it is necessary to finish both the fibres with respective flame retardant in a two stage process.

In order to develop flame-retardant finishing agents for textiles, theoretical information regarding mechanism of combustion and mechanism of flame inhibition or retardance is important. Therefore, mechanism of flame-retardancy of cotton and polyester/cotton blended fabrics has been discussed to emphasise the fact that the flame inhibition mechanism depends on the combined system of flame-retardant plus substrate.[151d]

Evaluation of flame-retardancy by a suitable method is also very important. Therefore development of a model testing method which has been considered more reliable and applicable to all types of fabrics has been reported.[151e] Various testing methods and standards for the assessment of flammability of various textile materials have been reviewed in order to throw light on the new procedure which is reported to be not too mild or severe and involves evaluation of the fabric in a bidirectional burning condition, that is vertical as well as horizontal.

Man-made fibres are polymers which are reported to be rendered flame-resistant by additives added during polymerisation or melt spinning. Therefore, a paper needs to be mentioned in which investigation of action of fire-retardant compounds on polymer combustion has been reported taking polystyrene as a model polymer and selecting simple fire-retardants such as ammonium phosphates, ammonium halides, ammonium sulphate and few organic bromine compounds as additives.[151f] The study reveals that the selection should be based on the intended use of the product.

Flame-retardance of PVC coated fabrics which have been used in some engineering applications of Defence is important. Therefore a study on the subject is reported.[151g] It is stated that PVC does not burn as such but most of the plasticizers used to plasticize PVC impart flammability to PVC films except phosphate plasticizers which are being used to impart flame-resistance. However suitability of plasticizers depends on various factors. Therefore, formulation of suitable plasticizer composition with flame-retardant property has been found essential. Keeping various aspects in mind a well balanced PVC composition has been reported to be developed which gave PVC coated fabrics with very good flame-retardancy. Also light is thrown on the limitations of usefulness of various test methods of Western countries in our country and it has been proposed to lay down standards and formulate methods suitable to our needs.

It is desirable or even essential that certain textiles used in the field of Defence have durable flame-retardant property. Therefore, evaluation of two well known fire-retardant finishing agents namely tetrakis (hydroxymethyl) phosphonium chloride (THPC) and tetrakis (hydroxymethyl) phosphonium hydroxide (THPOH) for imparting flame-retardancy to cotton textiles for Defence use has been reported.[151h] It has been indicated that the results obtained were satisfactory but production of necessary chemicals and their applications are not yet commercialised in India, though the Defence would like the flame-proofing of certain fabrics.

Application of tetrakish (hydroxymethyl) phosphonium chloride (THPC) and tetrakis (hydroxymethyl) phosphonium sulphate (THPS) on cotton has been also studied by other researchers.[151i] They have established the superiority of these finishes over other fire-retardants and found ammonia-cure technique to be better than heat cure method.

In another paper a study has been reported on the effect of various phosphoramides on the flame-retardancy of cotton including the effect of reaction of triethyl phosphoratriamide. [151j]. Also the effect of known systems namely THPOH-NH_3 and diammonium phosphate-urea were compared. The former system deposits a polymer containing phosphorus and nitrogen, whereas the latter system produces phosphorylated cellulose in order to impart flame-retardancy.

A leading mill has reported work leading to a patented process for imparting durable fire-retardancy to cotton fabrics. [151k] The process is based on utilising stannate salts and diammonium phosphate together with other chemicals easily available to produce acceptable finish with durable fire-retardancy.

Jute fibres have various applications some of which may demand fire-retardancy, one example being that of brattice cloth for coal mines. Therefore, development of fibre retardant jute fabrics for various end uses has been reported by using known fire retardant systems such as urea-phosphate, borax-boric acid [151l] etc.

The above review is not a complete review to include all the contributions, but an attempt has been made to collect as much information as possible during the short period available. I would have liked to mention R and D efforts by our fibre manufacturers, but only very few of them respondend to my inquiry and there has been no ready information published by them which was available to include in this review except few publications.

As seen from the review, fibres and conversion of fibres to finished fabrics require raw materials and adequate machineries, chemicals and proper know how. If we remain dependant for various other requirements pertaining to textiles or textile industry as a whole, then the textile research in the laboratories alone would not serve much purpose. However, in include engineering, mechanical, chemical and other related aspects which would be more related to development work is beyond the scope of this review. Therefore I feel it is not out of place if I refer briefly to the progress made in India in other fields related to textile industry.

One would find information on progress made in India for development of plant and equipment necessary for production of synthetic fibres, production of raw materials for synthetic fibres, fulfilment of requirements for down stream textile industries which means facilities for conversion of fibres to yarns, yarns to fabrics and fabrics to finished goods by refering to the special article "Synthetic fibre industry in India" by a well known industrialists.[1]

Also I have witnessed as a student at the Bombay University, Department of Chemical Technology, how Indian Scientists joined hands with Indian industrialists to establish the dyestuff industry in India, dyes being very essential for textiles. Today we have well established dyestuff industry producing variety of dyes. In addition, auxiliary manufacturers of India have been bringing out variety of auxiliaries and chemicals necessary for fibres and textiles. Last but not the least, I can mention efforts for testing and quality control, as well as some of the testing equipments being now fabricated in India.

Conclusion

Textile research in India during the last five years, especially related to the field of man-made fibres and textiles, has been found to cover various aspects such as fibre research and research in the field of conversion of fibres to fibrics, to include texturising, blending, spinning, weaving and other aspects. The contributions also cover research in the field of conversion of fabrics to finished goods, wihch include all wet processing steps such as bleaching, dyeing, printing and finishing as well as analytical aspects. I hope this review would help Indian Scientists to get a collective view of textile research in India and embark on new projects. Also our foreign guests would get an idea of research trends in India. I thank Shri D. N. Shroff and Shri J. G. Parikh for giving me an opportunity to present this paper.

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Modern Plants for Synthetic Fibres
— Planning, Construction and Economic Efficiency —

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Introduction

In this lecture the economical as well as the technological viewpoints of modern Polyamide 6, Polyamide 66 and Polyethylene terephthalate processing will be examined. Figure 1 shows a survey of the processes we are concerned with starting from the monomers and ending up with various final products.

The main requirements of modern and economic polymer and fibre production plants are :

Table 1

- High capacity.
- Low raw material consumption.
- Low energy consumption.
- Reduced operation and maintenance personnel requirement.
- Minimised effluents and by-products.
- High product quality.

The result is the best possible production efficiency.

These requirements can best be met by the application of the following process technologies measures and prerequisites:

Section 1 Polymer Plants

The fast development in polymer and synthetic fibre production units is shown in figure 2.

In the past 15 to 20 years the capacities of production units have risen by more than the factor 10.

Table 3 shows today's high influence of raw material on the total production cost. This is mainly due to the strong increase in crude oil costs. The power and utilities cost increase could be partly balanced by using more effective systems as well as by using heat recovery units in the production plants. We can, therefore, state that this percentage did not change much during the recent years.

Personnel costs are based on European standard. For other countries with lower wages, this value could be lowered without influencing the total costs to an important degree. The comparatively low personal costs only apply to a polymerisation or polycondensation plant. For spinning and textile installations with a high demand for personnel, this cost factor is more important.

Apart from the advantages for continuous operating polycondensation plants, batch operation is still feasible in some cases. This alternative is always recommended if the following items are essential:

- Flexible production programme.
- Capacity smaller than 20 t/d for a polyester and polyamide 66 and 10 t/d for a polyamide 6 production respectively.
- First plant in a developing country with the normal difficulties in the backing of industrial production in respect to power and utility supply, trained personnel, basic infrastructure etc.

Table 2

- Proven technology.
- Large Production capacities.
- Energy saving heat recovery systems.
- High degree of automation and computerisation.
- Effective, integrated recycling and recovery units.
- Constant operating conditions.
- Well trained operating personnel.
- Trouble-free energy, utilities and water supply.
- Sufficient infrastructure of the plant location area (road, railway or sea transport possibilities).
- Experience in planning, construction and operating highly developed production plants.

Table 3

Typical production costs — split off based on a 100 t/d resp. 35,000 t/y PET Polycondensation Plant.

Raw material:	PTA and EG
Final product:	PET-chips
Depreciation (10 % linear) :	4 %
Raw materials :	88 %
Power and Utilities :	5 %
Personnel :	2 %
Total maintenance :	1 %
Total production cost :	100 %

Polyamide Plants:

In the field of polyamides we have two major alternatives polyamide 6 and polyamide 66. Both have gained essential market shares dependent on the specific market conditions in different parts of the world, mainly depending on the price situation and availability of raw materials. In the following we will perform a comparison of the PA6 and PA66 processes.

Firstly we treat the raw materials costs. The basis of our calculation is shown in figure 3 as block diagram for the PA6 process and in figure 4 for the PA66 process. In both cases optimal waste recovery was considered.

Table 5 shows the resulting main material flows and the compatible raw material costs althrough the price difference between caprolactam (CL) and AH-salt is only 7%. The raw material costs for the PA66 process are 29 % higher.

The reasons for the difference are beside the higher monomer price formation of 16 % water in the polycondensation reaction of AH-salt as useless by-product and less effective waste recovery in case of PA66.

The above figures are based on today's raw material costs in Europe. In the future drastic could take place, influenced by the general economic situation, supply and demand, aromatics and aliphatic feedstock development as well as more efficient processes for the production of HMD.

In table 6 some characteristic features are listed for both types of polyamides.

Table 5

Raw material consumption and costs for polyamides

Monomer input	970 kg CL	1,170 kg AH-salt
By-product of polycondensation reaction	—	162 kg water
Unrecovered waste	10 kg	48 kg
Water and spin-finish in yarn	40 kg	40 kg
Textile filament	1,000 kg	1,000 kg
Price relation CL/AH-salt CL set at 100 %	100 %	107 %
Monomer cost PA6 process set at 100 %	100 %	129 %

Table 6

Comparison of principle items referring to technology and economics of NYLON 6/6.6 — Polycondensation process

POLYAMIDE 6 (Continuous Polymerisation)	POLYAMIDE 6.6 (Continuous Polycondensation)
high monomer content chip spinning advisable	low monomer content direct spinning advisable
flexible capacity	small capacity flexibility
simple design	less simple design
easy operation	less easy operation
limited utility failures have only small influence on production and quality	constant utility supply essential
caprolactam cost lower	raw material cost higher
many caprolactam suppliers now and in the future	limited raw material suppliers (market control?)
melting point 222°C	melting point 260 °C advantages for high elastic low shrinkage and vulkanized material

There is a high monomer content in the PA6 after the polymerization of CL which has to be reduced before spinning. This is done most effectively by extraction of chips in water — a fact which excludes of course direct spinning.

The more sophisticated equipment in case of PA66 results mainly from the fact that during the polycondensation reaction water is formed which has to be removed during the reaction in liquid state to achieve the desired degree of polycondensation. Equipment which promotes diffusion processes and removes water by evaporation is necessary. At the polymerisation of Cl no by-products are formed.

PA66 is very sensitive to thermal cross-linking reaction which in a short time turns to gels or unmeltable solid products. Optimum flow conditions of the melt excluding dead corners are essential as well as the narrowest possible residence time spectrum. An optimal residence time spectrum is essential. This is the main reason for the comparatively low flexibility in capacity and the sensitivity to power failures. Because of the cross-linking reaction also frequent and laborious purification procedures have to take place for polycondensation and spinning equipment, this puts high demands on maintenance personnel.

The difference in melting point of PA6 and PA66 is important in some further processing stages where heat treatment at temperatures as high as possible is wanted. Heat setting of PA6 is limited to about 190 °C, whereas PA66 takes about 230 °C. This gives PA66 advantages for high elastic or low shrinkage yarns and for vulcanized products, whereby heat curing times can be reduced by higher temperatures and machine efficiencies can be raised.

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Polyester Plants :

When we look at the polyester production process, in particular the question arises which of the optimal monomers PTA or DMT should be given preference. From a manufacturing cost breakdown we have seen that the main cost factors are the raw material costs (see table 3).

We will perform a comparison of the raw material cost of the terephthalate (DMT) process.

The basis of this comparison is shown as block diagram in figure 5 applying optimum waste recovery. The result is given in table 7.

The advantages of the TPA process having 20 % lower raw material costs results from :

- low monomer cost
- higher conversion rate
- less by-product (methanol)

Advantages of the PTA process are :

Table 8

- Very low molecular ratio PTA:EG below 1:1.2.
- No esterification catalyst necessary.
- No catalyst blocking necessary.
- At least 15 % higher throughput.
- Higher reaction speed.
- No unwanted by-products (eg. methanol from DMT)

All these factors undoubtedly suggest the use of PTA as the starting material for an economical PET production.

The most economic way of producing polyester can be realised by using a continuously operated plant. Moreover, this technology provides the highest degree of product uniformity, lowest raw material and energy consumption as well as reduced operation and maintenance personnel, as already mentioned.

Table 7

Raw Material Consumption and Costs for PET

	TPA Process	DMT Process
Monomer input	875 kg TPA 345 kg EG	1,020 kg DMT 363 kg EF
By-product of polycondensation reaction	190 kg water	355 kg Methanol
Unrecovered waste	22 kg	49 kg
Water and spin-finish on yarn	10 kg	10 kg
Textile filament production	1,000 kg	1,000 kg
Price relation TPA/DMT TPA set to 100	100 %	112 %
Monomer costs TPA process set to 100	100 %	123.5%

Section II Recovery Plants

Figure 6 shows the block diagram for a modern plant design of a continuous polyester process with integrated recovery plant for glycol and solid wastes.

In the course of process developments in recent years it was possible to design the entire PET polycondensation system without aqueous by-products. The vaccum systems of the precondensation stage are preferable changed to glycol ring pumps. In the final polycondensation stage, glycol steam jet suction units are mechanical vaccum system (multi-stage roots pumps) are installed in place of the water steam jet vaccum units which were normally used in the past. The contaminated glycol from the above mentioned vaccum units is fed, together with the crude glycol accumulated in the processing to a glycol recovery plant, which can be operated batch-wise or continuously.

Furthermore, efforts are being made at the present time to reduce the loss of glycol with the by-product water as much as possible in the esterification of the PTA-PET process. For this purpose integrated rectification column system are used to directly reprocess the water/glycol vapours, the sump product glycol returning to the esterification reactor.

This applies similarly to the by-product methanol from the trans esterification of the DMT-PET process. Here the ;methanol is concentrated by integrated rectification columns so that no further distillation is required prior to certain re-use.

The gaseous by-products (eg. acetaldehyde) produced in the polycondensation are mainly found in the emitted air of the vaccum system, together with some glycol and water, or methanol and traces of oligomers. Due to the small concentration of these components in the carrier gas, burning off in the central heating system has proved to be the most favourable solution. The emitted air is added to the combustion air of the furnace by means of blowers via collector pipes.

The recovery of solid wastes from polycondensation as well as from spinning and further processing can be carried out using the solid waste recycling method which consists mainly of a waste fibre cutter, a specially designed fibre dryer, an extruder with force feeding system and a fine filtration system. The so recovered polymer-melt can be fed back either to the polycondensation or for certain application to the spinning facility.

Applying such an integrated recovery PET PLANT is shown in figure 6. TPA consumption can be reduced to 875 kg being only slightly above the theoretical consumption per 1000 kg filament.

Section III Textile Plants

An important factor is the question of to what extent synthetic filaments can be used as a substitute for natural products such as wool and cotton, and this especially in the light of the constantly growing shortage of these products.

In the synthetic fibre market there is a definite trend towards higher qualities, and the demand for fibre characteristics being more suitable for the individual applications is also growing. This development also includes the call for specialities (eg. high count yarns, yarn blends, high-module fibre, low-shrinkage types).

In this lecture the main emphasis is put on the influence of spinning systems on product quality and on the economical conditions under which such products are made, that is to say, on the development of modern and highly efficient production plants.

Melt distribution system

When approaching the question of how to achieve optimal productivity (operating speed) to produce high-quality material at the lowest possible capital investment and personnel requirements, the quality and efficiency of the respective spinning systems have an important influence.

Fig. 7 shows a 100 tons/day polymer production distribution line for polyester fibre production. The pump (3) is provided for building up the polymer pressure necessary to compensate the pressure drop in these product lines.

At point (6), the melt stream is divided to flow to the two spinning lines (8) and (9). The design also includes a bypass to convert some of the polymeric material into chips. The distribution line between point (6) and the inlets of the two spinning lines (each line has 3 manifolds) is designed according to the principle of uniform branching into 2 or 3 different side arms. Diameter and length have beenoptimised with respect to the stress and strain conditions and the need for polymer homogeneity (streaming profile and mixing).

With high output rates, the overall pipe length between the reactor and the spinnerets may come up to 40 or 50 meters.

Prior to designing the product distribution system, the polymer behaviour must be studied (see fig. 8). While with polyamides, viscosity proceeds as a function of the chips' water content and temperature, with polyester, viscosity largely depends on residence time and temperature. In view of these facts and especially in the event of high viscosities, certain temperature limits must be strictly observed. The change in product characteristics however does not take place uniformly as a function of time. It is rather influenced by the residence time and temperature spectra of the polymer inside the piping. Such influences are shown in figure 9. They are :

a) the flow profile in the straight pipe (a)

b) changes in the flow profile due to bends or branchings (b / c).

Branching is definitely the most favourable technical solution. In straight pipes, the flow profile pattern plays an essential part. It is therefore the technicians' task to determine the optimal polymer-specific flow profile at an acceptable pressure drop.

With long product lines, suitable measures must be taken to influence the residence time spectrum. While in the past, operation was based on the removal of inner pipe-wall film, modern techniques apply static mixers (see examples (d) and (e)).

Spinning manifold

Another piece of spinning equipment with high influence on product quality is the manifold.

For economic reasons, spinning positions with 900/1200 mm gauge must be able to handle up to 16 spinnerets which means producing 16 filaments of top quality.

Fig. 10 shows the schematic diagram of a common spinning position with its respective spinneret arrangements.

Example (a) explains the optimal utilization of the spinning surface. In example (b) the spinning surface is too small in proportion to the overall surface (heat balance). Example (c) has the disadvantage of a asymmetric blow-on pattern and, finally, example (d) is characterized by the disadvantage of asymmetric spinneret design. And there is another disadvantage of such a 900/1200 mm long position, the spinneret surface radiating heat to its surrounding atmosphere — as does the spinneret — will create the following problem (see fig. 11).

Due to unfavourable length to width ratio, therewill forcibly be a temperature difference between the spinnerets of one position. As shown in the example (PA 6 — 6-fold — 44/13 dtex — 5200 m/min) this phenomenon leads to an undesirably strong influence on the yarn quality. Thus, this solution is unacceptable, particularly with respect to delicate materials such a PA 66, 22/7 dtex or PA PET 55/48 dtex. The solution to the above problem is shown in figure 12.

Small size spinnerets are screened off. The large ones are oval shaped. The essential measure to be taken has been the installation of an active heating system betwen the spinnerets causing only an extremely small temperature gradient. This system can also be applied to large spinnerets producing staple fibres, technical yarns or carpet yarn. To materialise this concept, construction was required which had to be economic and safe from the heating point of view. The result of such efforts are shown in fig. 11 (bottom). There are constant temperature levels and constant textile data with respect to the breaking load.

Fig. 13 shows such a modern ZIMMER spinning unit. One unit consists of two positions comprising one dowtherm-vapour heated vessel with connections, vapour feed and condensate drain-off. It is constructed together with spinning pump drive units to one framework assembly. This unit is supplied complete and installed as such in the plant. Two to four of these units are connected together to one spinning manifold. The spinning manifold and product feed jacketed pipes are connected and heated both by a separate dowtherm boiler. Each spinning pump is provided with a drive unit consisting of synchron a.c. motor, reduction gear and pump shaft with overload protection.

Fig. 14 shows an arrangement of threadlines from the spinneret down to the winder. All threadlines wound on the same winder are completely separated from the other threadlines by separating buffs. With 16 ends per position, the maximum number of threads is limited to four at one section. In this way there are independent operating sections for each winder. During spin-pack change, spinneret cleaning, doffing, or in the event of filament breaks, one section could be operated without disturbing the other sections, that means that a maximum 4 threads are interrupted by operating one position. With 16-end spinning, one position consists of 4 sections, each with 4 threads, with 8-end spinning we have 4 sections each with 2 threads. In this case, the production risk involved in 16-end spinning per position will be reduced to the risk of 4-end spinning systems. The result of such a design will guarantee a high efficiency will low waste quantities and a high number of full bobbins (up to 96 % full bobbins for polyester for example). The denier programme is given in table 9.

Table 9

2spinnerets/position	staple fibre
2 ends/position	935 — 2700 dtex
4 ends/position	235 — 935 dtex
8 ends/position	17 — 210 dtex
12 ends/position	17 — 167 dtex
16 ends/position	17 — 110 dtex

Modern Synthetic Fibre Plant Design

A Textile Filaments

The characteristic feature of modern textile filament spinning is high production rates achieved with the most space saving machinery. An example of this philosophy is the compact design of a ZIMMER POY-spinning plant (see figure 15).

The plant is accommodated in a 2-stage building ;with the chip silo installed on the roof. The crystallization and drying units are both arranged next to the spinning section. The extruders are placed on the first stage together with the blow ducts. The winding section with its most varied arrangement of units to meet individual denier requirements is installed at 0 level.

The use of compact design, however, is limited for quality reasons, that means sufficient quenching, adequately long thread lines and the maximum allowed thread guiding angles.

Table 10 shows the textile-physical properties of 16-ends spinning PA 6 — POY, 44/13 dtex with winding speed of 5200 m/min.

This example shows the excellent uniformity of the figures obtained from such a modern spinning system.

Table 10

Titer	50.8 — 51.1 dtex
Breaking load	206 — 209 cN
cv "	3.1 — 4.1 %
Elongation	66.8 — 68.9 %
cv "	2.3 — 3.4 %
Uster normal	0.6 — 0.7 %
Uster half inert	0.5
Dyeing	abs. uniformed

Results after draw-texturizing with texturizing speed of 750 m/min are given in table 11.

Table 11

Titer	43.4 — 44.1 dtex
Breaking load	173 - - 182 cN
cv "	2.1 — 3.6 %
Tenacity	39.5 — 40.6 cN/tex
Elongation	27. 5 — 29.8 %
cv "	2.7 — 4.5 %
Crimp degree	58.5 — 60.3 %
Crimp removal	32.5 — 35.7 %
Crimp stability	92.8 — 95.4 %
Dyeing	abs. uniformed

Capacities for PA6, PA66 and PET depending on the denier are given in table 12.

Table 12

1. Technical Data

Filaments per spinning position	8	12	16
Filter area (cm2)	13-58	13-40	4.5/23
Titer range dtex	17-210	17-167	17-110

2. Capacity **POY on take up bobbins**

Polymer	Take up speed (m/min)	ends per pos. (dtex)	Throughput 6 Pos.	(kg/d) 8 Pos.
PA-6	5200	16 x 22/7	1726	2302
		16 x 33/10	2590	3454
		16 x 56/17	4400	5867
		16 x 78/24	6128	8170
PA-66	5200	16 x 22/7	1800	2400
		16 x 33/10	2691	3588
		16 x 56/17	4570	6094
		16 x 78/24	6364	8488
PET	3600	16 x 56/24	3812	5083
		16 x 84/24	5940	7920
		16 x 110/48	7508	10012
		8 x 167/34	6212	8282

B Staple Fibre Plant

Different types of PET fibres are in production adjusted to the corresponding natural blending partner fibres. The stress strain diagrams of the most important types are shown in figure 16. Figure 17 displays the schematic diagram of modern fibre lines. Fibre line 1 with 3 draw roller frames and 1 heat setting frame is suitable to produce all fibre types, as cotton-, wool-, carpet-, fill-types, from high modulus with highest tenacity to low modulus types. The HTM, HT cotton type, can be produced on only 1 with a capacity of up to 60 t/d. Fibre line 2 without heat setting frame is applied for the low modulus production of wool type fibre, with a capacity of up to 200 t/d.

C Spin-drawing plant for industrial yarns and tire cord

Figure 18 shows the schematic diagram of a spin-drawing plant.

In case of PET and PA66 it is preferable to apply a direct spinning process. For the chip spinning process it is preferable because of monomer extraction.

The spun yarn is directly led to the draw-winding machine through an annealer, a quenchduct and a spinning tube. For the production of high quality yarn, especially for low shrinkage yarn, drawing frames consisting of 4 pairs of heated godets should be used. The winder will change automatically and the doffing will be wasteless.

With such machines 2 ends per position at take-up speeds of approx. 3000 m/min with capacities from 700 kg to up to 1400 kg/d and position depending on the denier are produced (Table 13).

Plant Capacities

Spin-drawing Process

The usual unit are manifolds of four or six positions. The take-up speed is for low shrinkage yarns, 2,450 m/min, for other yarns 2,800 m/min.

The production of yarn on bobbins is:

	kg/day	per number of pos.	
Tire Cord Basic Yarn	1	4	6
PET 1,100 dtex 2-fold	814	3,280	4,880
1,450 dtex 2-fold	1,030	4,120	6,180
1,800 dtex 1-fold	670	2,680	4,026
1,800 dtex 2-fold	1.340	5,360	8,040
PA 940 dtex 2-fold	697	2,800	4,180
1,400 dtex 2-fold	1,058	4,230	6,350
1,870 dtex 1-fold	694	2,785	4,160
1,870 dtex 2-fold	1,387	5,550	8,320
Low Shrinkage Yarns			
PET 280 dtex 4-fold	355	1,420	2,130
550 dtex 4-fold	712	2,850	4,270
1,100 dtex 2-fold	712	2,850	4,270

D BCF plant

Figure 19 shows the schematic diagram of a spin-draw texturizing BCF plant. Displayed is a chip spinning plant where additives are added as side stream into the extruder. Such additives being for instance dye stuff master batches or antistatics.

In this case intensive mixing in the product line is necessary using static mixers.

For economic reasons take-up speed must be at least 2,000 m/min, processing two end per position. Such high texturizing speeds are only realizable with jet texturizing systems.

Plant capacities are given in table 14 being up to 1,500 kg/d per position depending on the denier. The resulting bobbins' running times in production are very low, going down to a minimum of 7 minutes. Therefore the use of automatically changing doffing winders is essential.

Plant Capacities for BCF-Production

Spin-draw-texturing Process

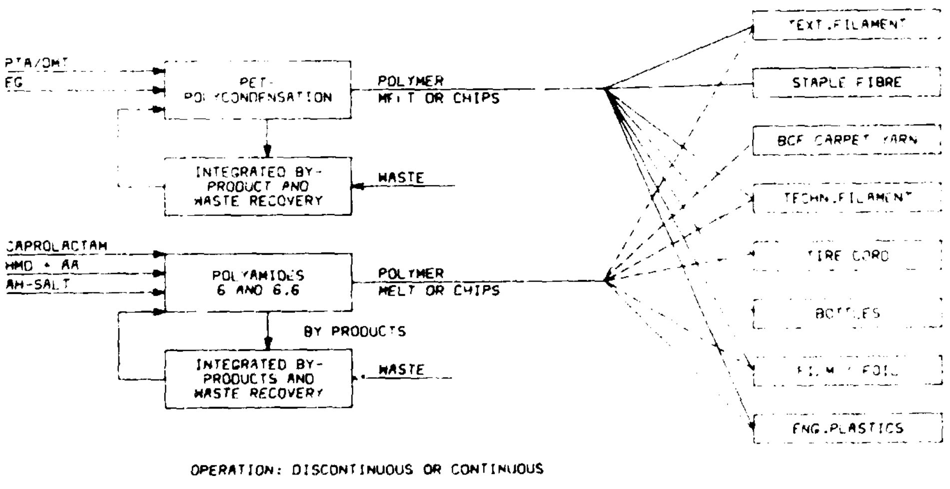
The usual unit are manifolds of four, six or eight positions. The take-up speed is 2.024 m/min. Depending on Denier the number of processed yarns per position is 1, 2 or 4.

the production of yarn on bobbins is :

	kg/day per number of pos			
	1	4	6	8
PA— 665 dtex-2-fold	362.5	1.450	2.175	2.900
655 dtex-4-fold	710	2.840	4.260	5.680
1330 dtex-2-fold	727.5	2.910	4.365	5.820
2670 dtex-2-fold	1.462	5.850	8.770	11.690
3670 dtex-1-fold	1.004	4.020	6.025	8.035

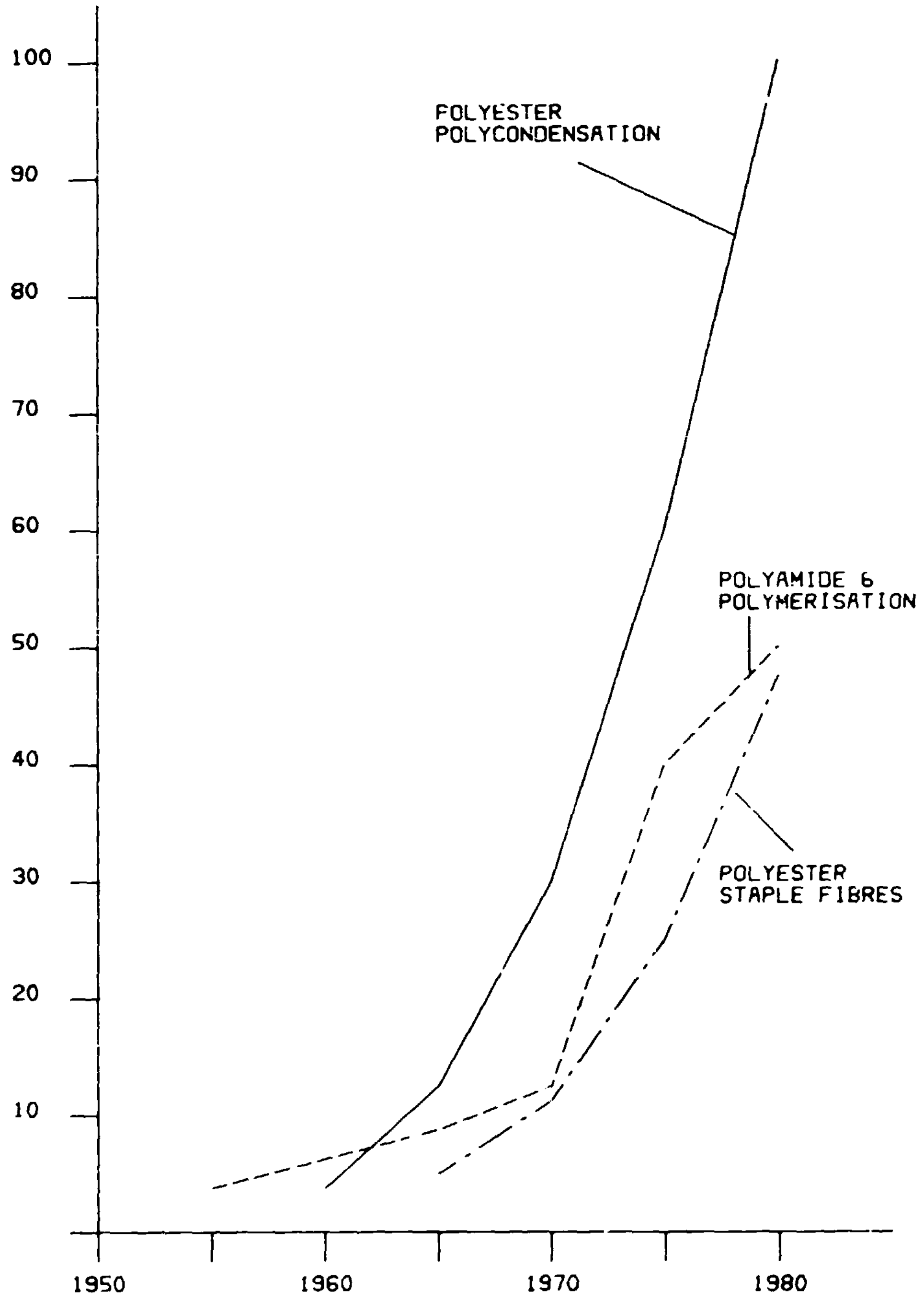
—o0o—

FIGURE 1



SURVEY OF POLYAMIDE AND POLYESTER PRODUCTION TECHNOLOGY
FROM THE MONOMERS TO THE FINAL PRODUCTS

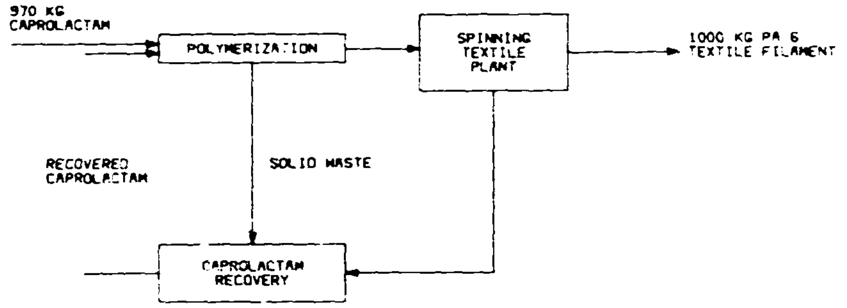
FIGURE 2



LAN005

DEVELOPMENT
IN SYNTHETIC FIBRE
PRODUCTION UNITS

FIGURE 3

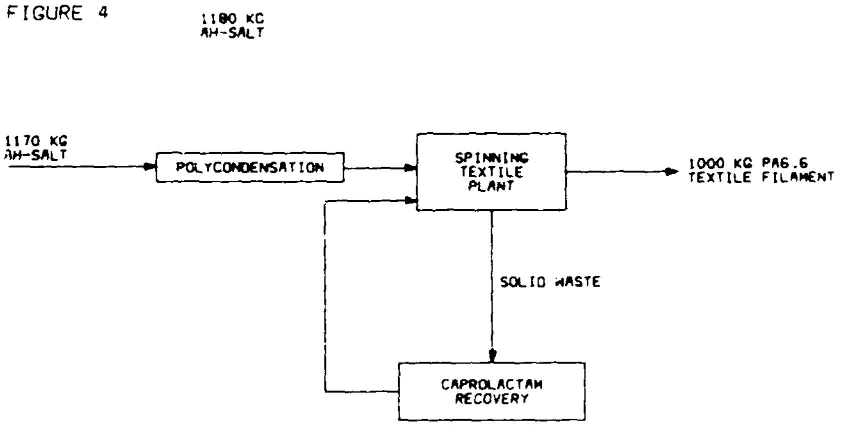


LAN002

Davy

POLYAMIDE 6 BASIS FOR EVALUATION RAW MATERIAL COSTS

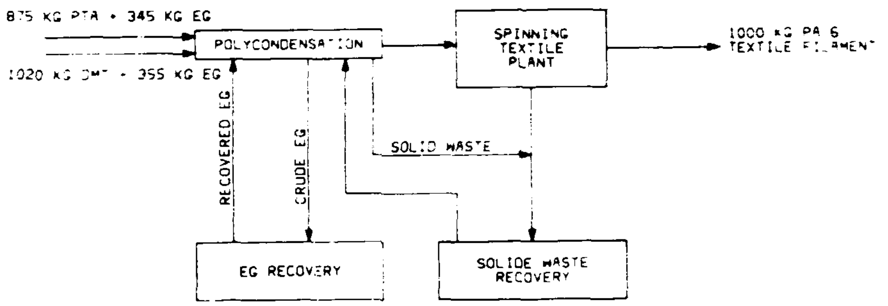
FIGURE 4



LAN003

POLYAMIDE 6.6 BASIS FOR EVALUATION RAW MATERIAL COSTS

FIGURE 5



AN004

<u>PET</u> BASIS FOR EVALUATION RAW MATERIAL COSTS

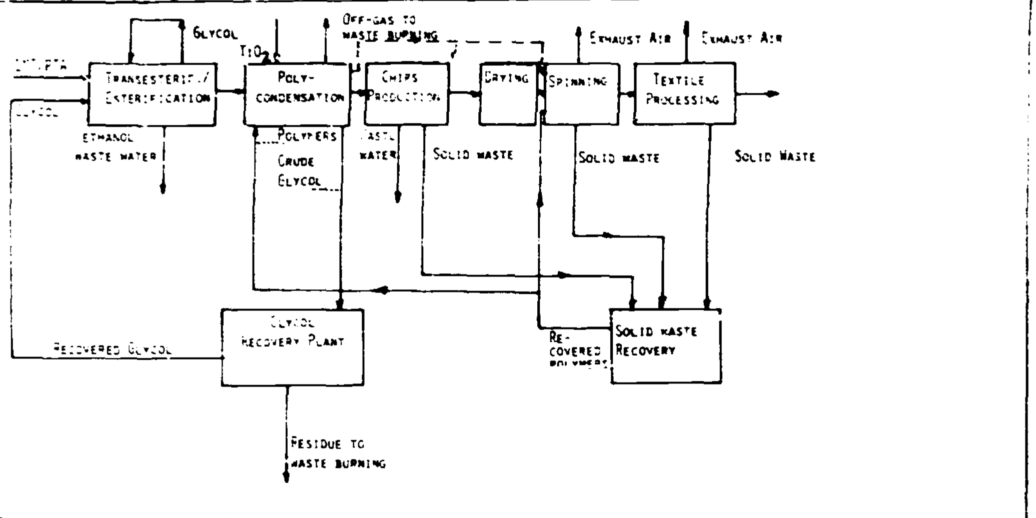
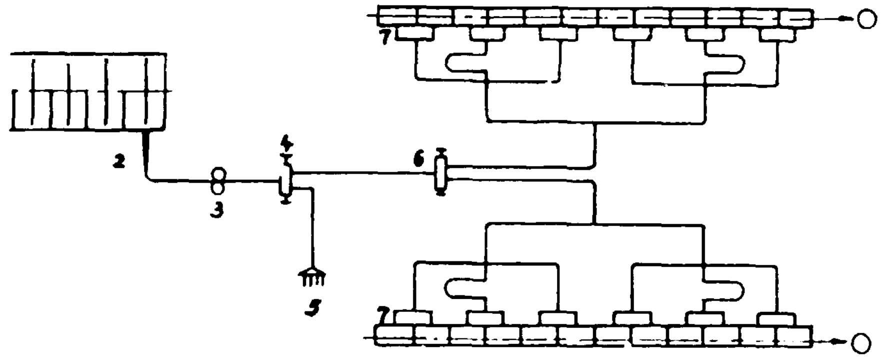


Fig 6 Block diagram for continuous PET-process with integrated recovery plants



1 Reactor inlet
2 Reactor outlet
3 Booster pump
4 - 6 Valves

5 Chip granulating
7 Spinning manifold inlet
8 - 9 Spinning and take-up lines

Fig. 7: Polymer transfer line (100 t/day PET staple fibre)

P E T

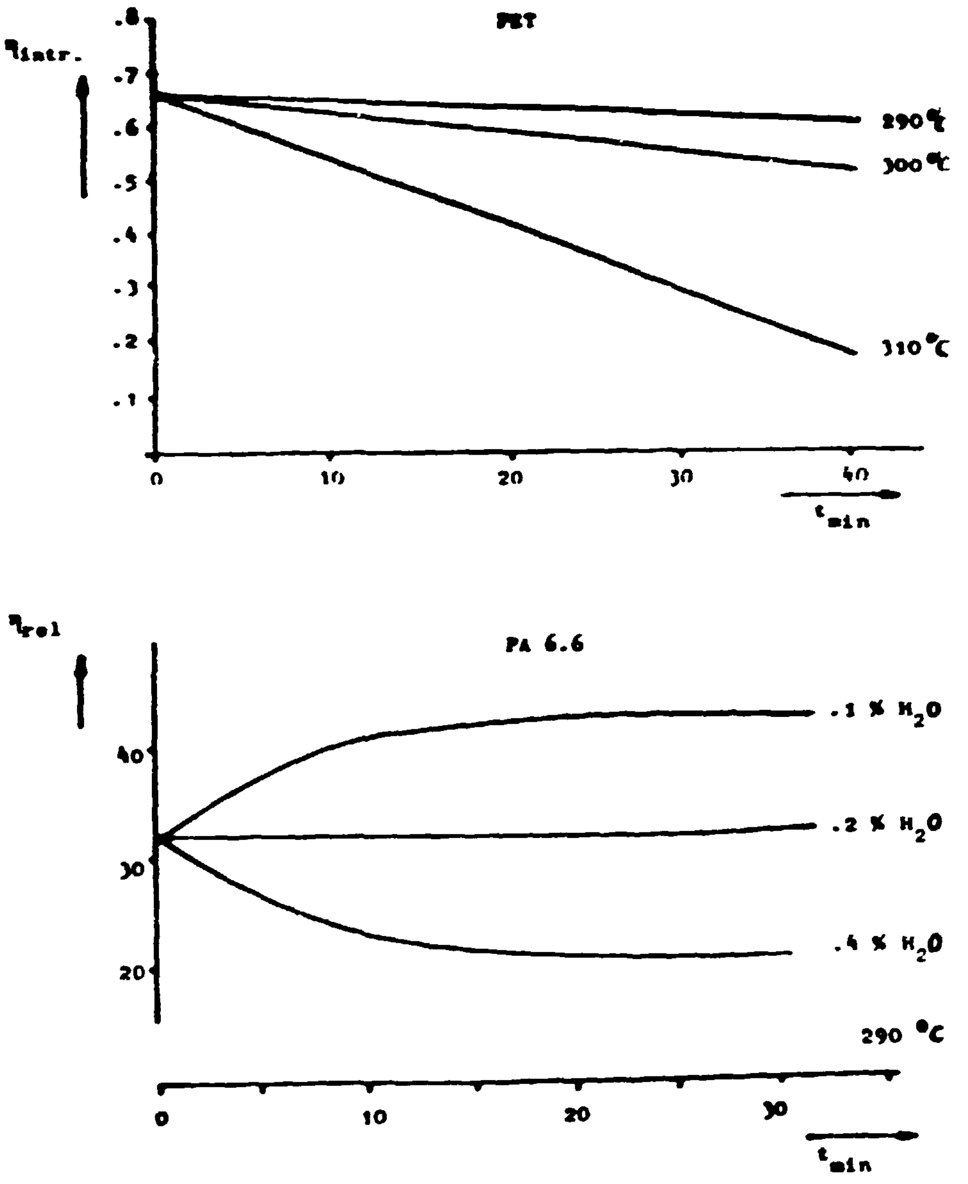


Fig. 8: Influence of residence time on polymer melt

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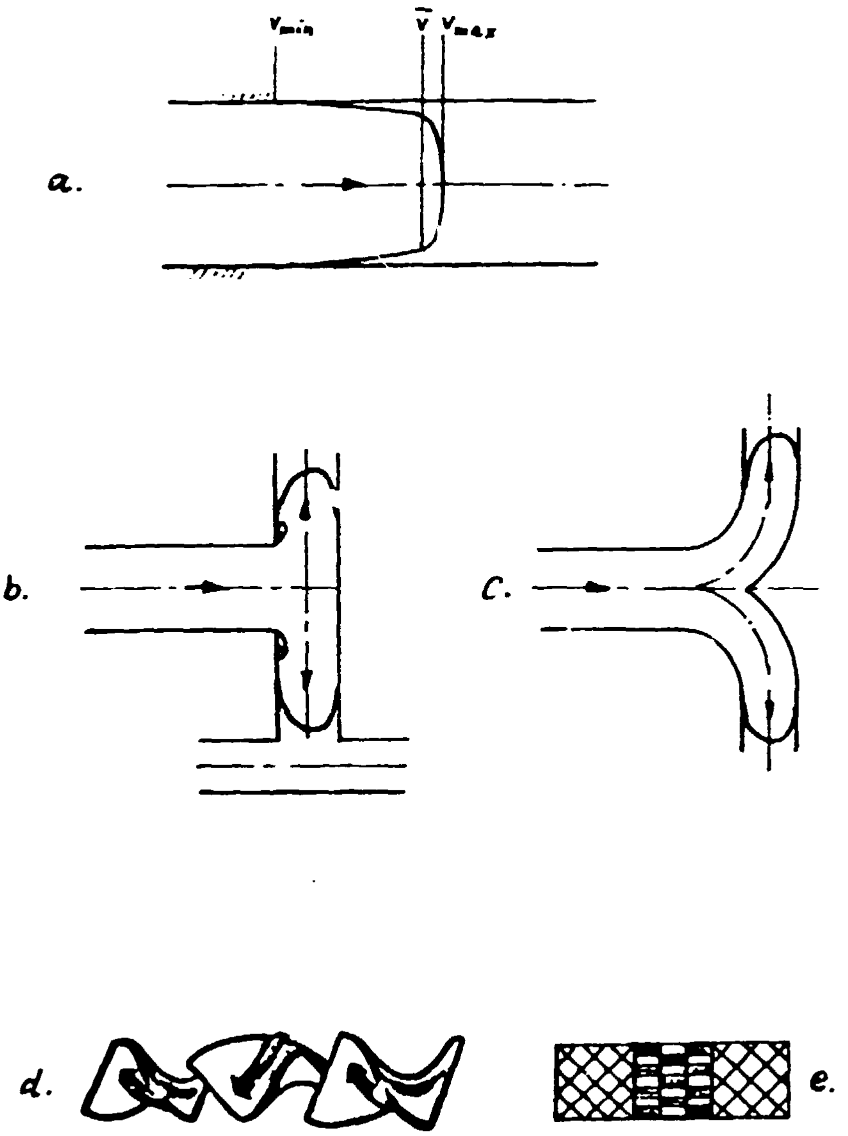

Fig. 9: Polymer flow in tube (a)
Stream branching (b, c)
Mixing (d, e)

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ZIMMER

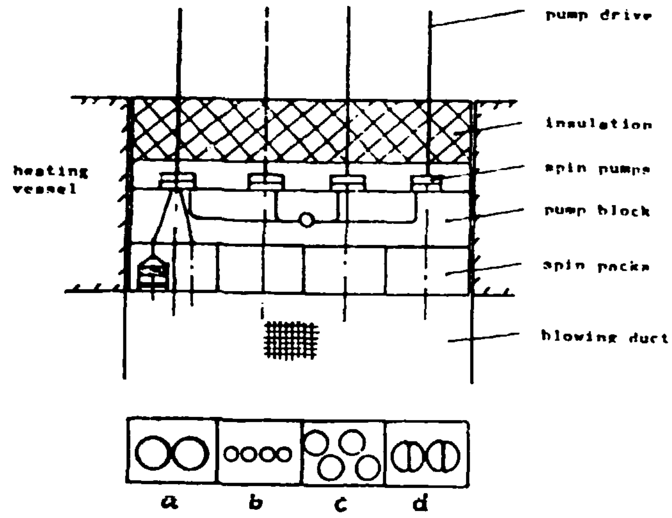


Fig. 10: Section of a spinning position (Type BN 44/45)

Example: PA 44/13 dtex
5200 m/min; 16 end/position

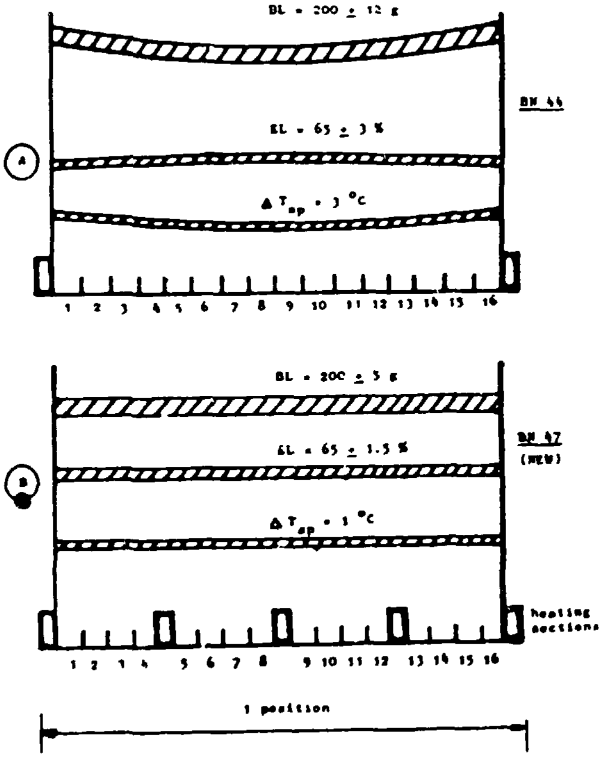


Fig. 11 Textile physical data and temperatures of different spinning systems

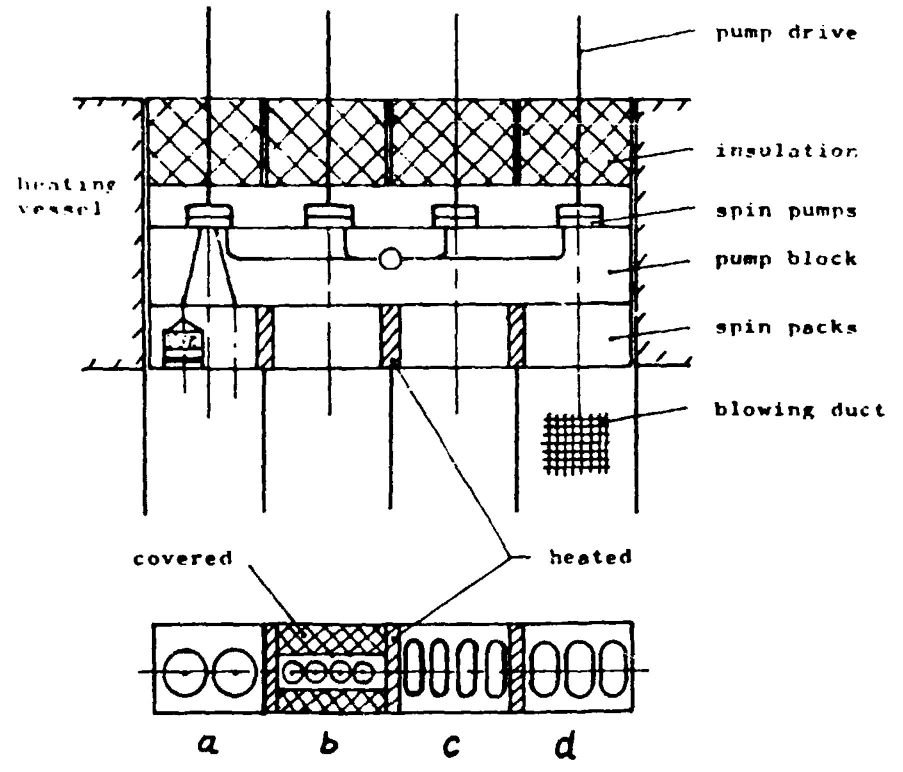


Fig. 12: Section of a spinning position (Type BN 47)

Davy

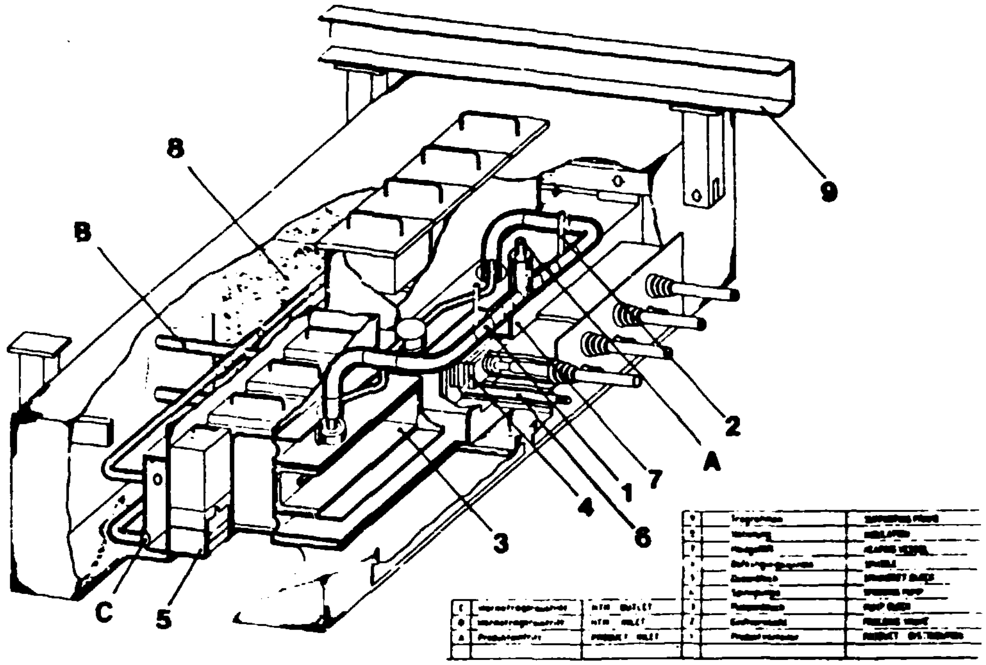


Fig 13 : Spinning unit, Type BN 47

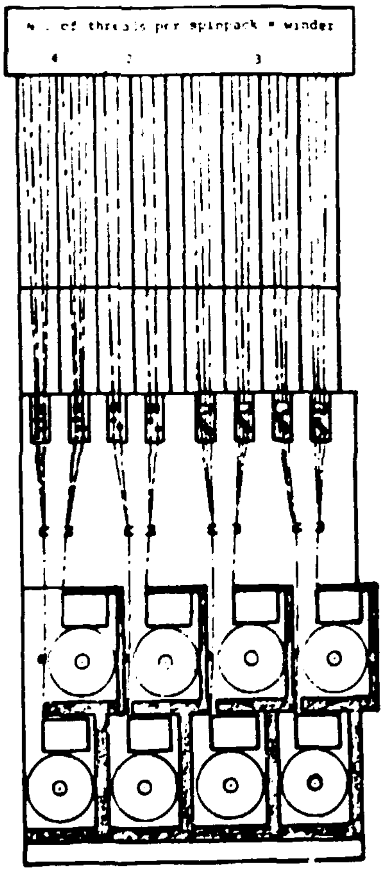
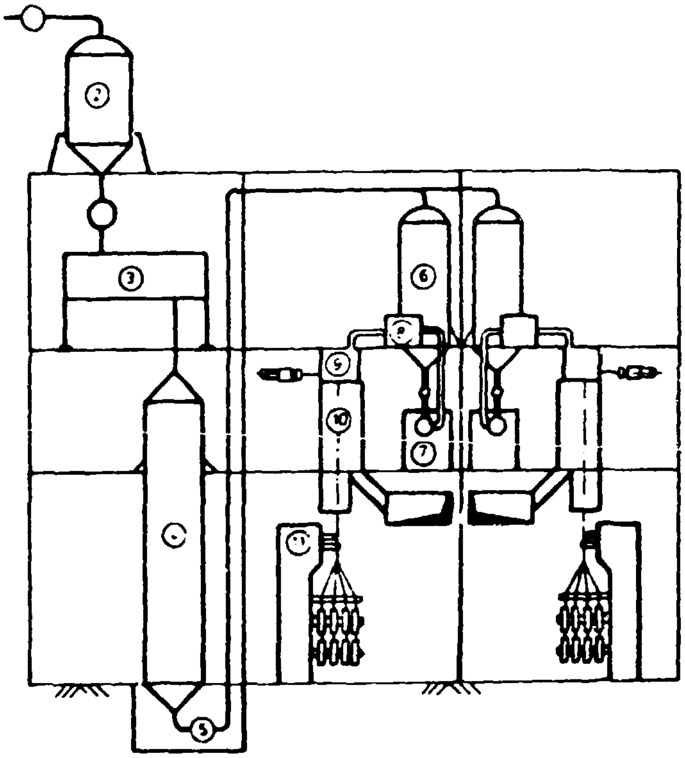


Fig : 14 Thread-path from spinneret to winder



1 - chip feeding
2 - chip silo
3 - crystallizer (PETP)
4 - dryer
5 - pneumatic conveying
6 - chip silo
7 - extruder
8 - polymer filter
9 - spinning manifold
10 - quench cabinet
11 - take-up unit

Fig. 15 Schematic diagram of melt spinning (Example : PETP-POY)

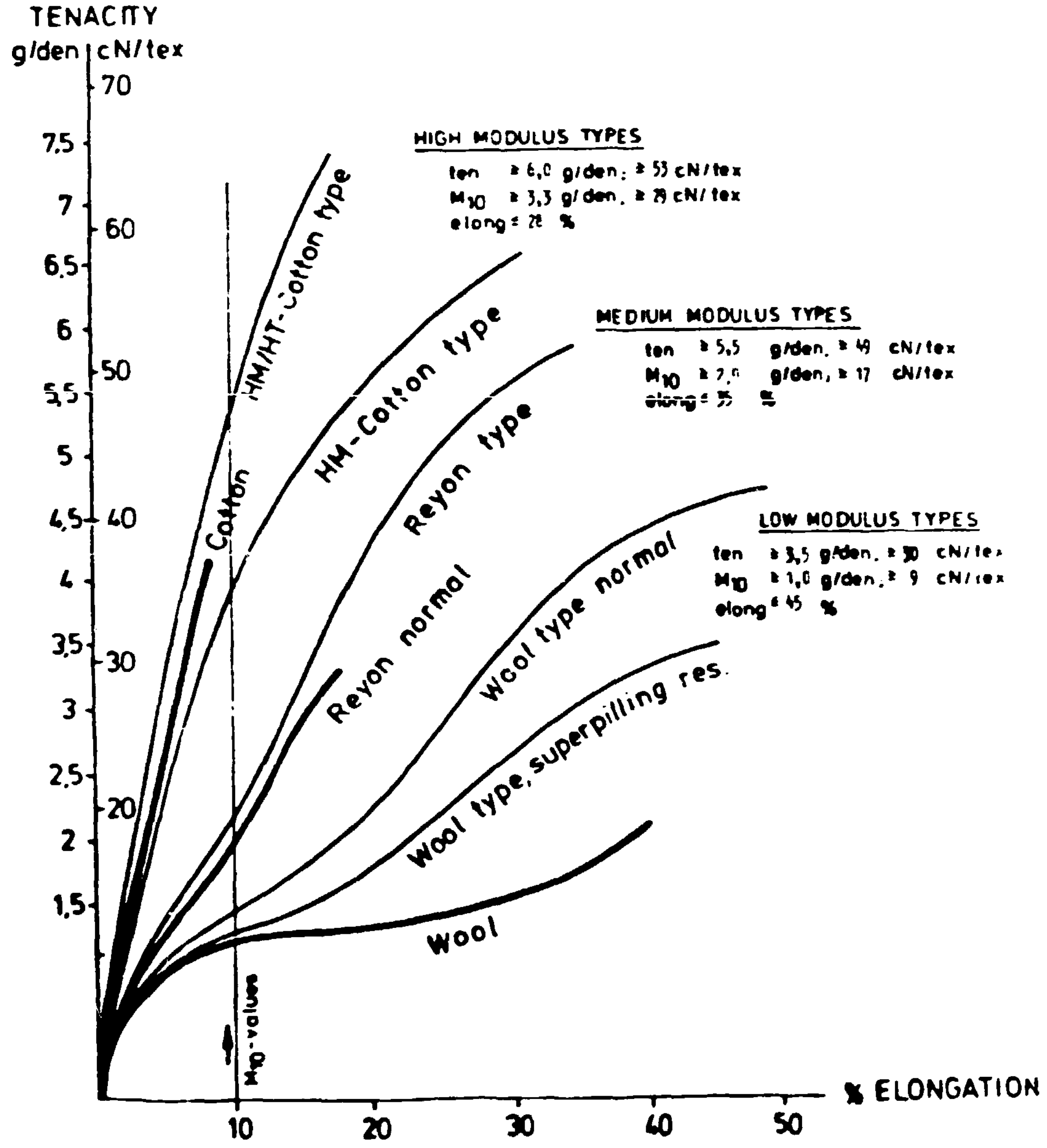
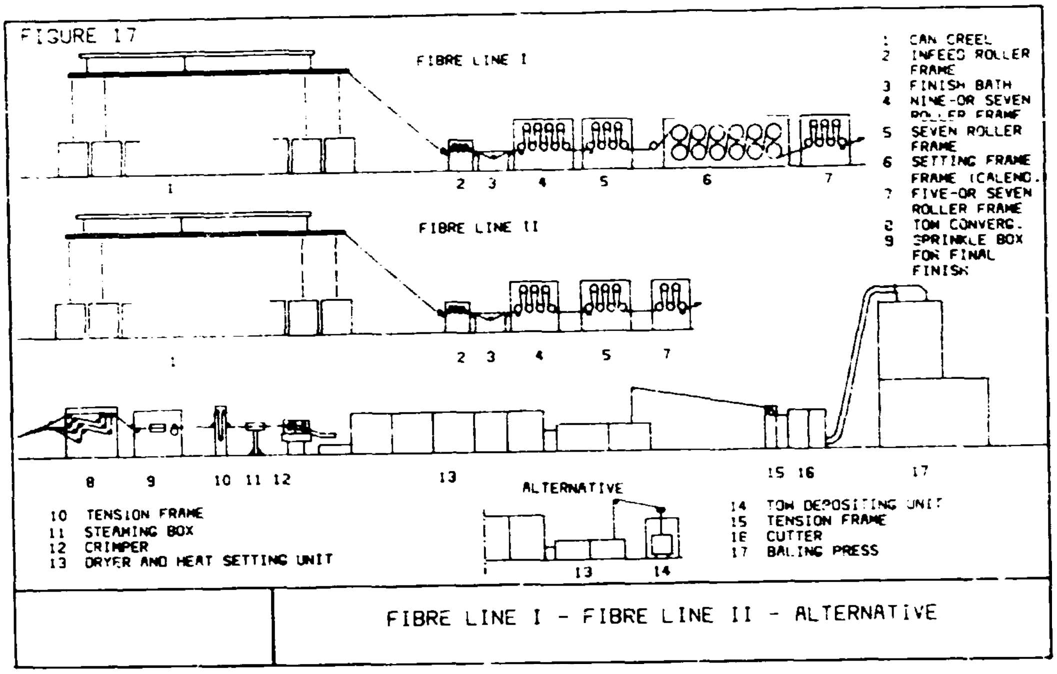


Fig 16:

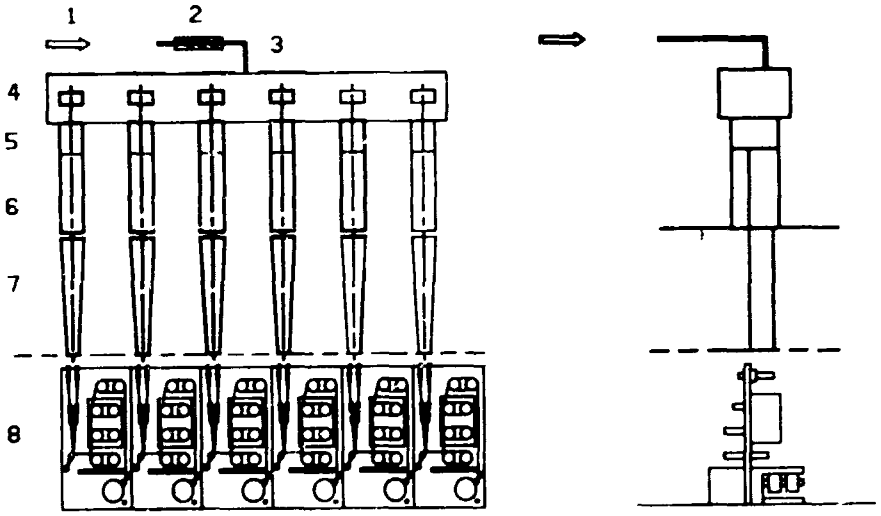
THE DIFFERENT POLYESTER BLENDING PARTNERS IN COMPARISON TO THE CORRESPONDING NATURAL FIBRES

FIGURE 17



FIBRE LINE I - FIBRE LINE II - ALTERNATIVE

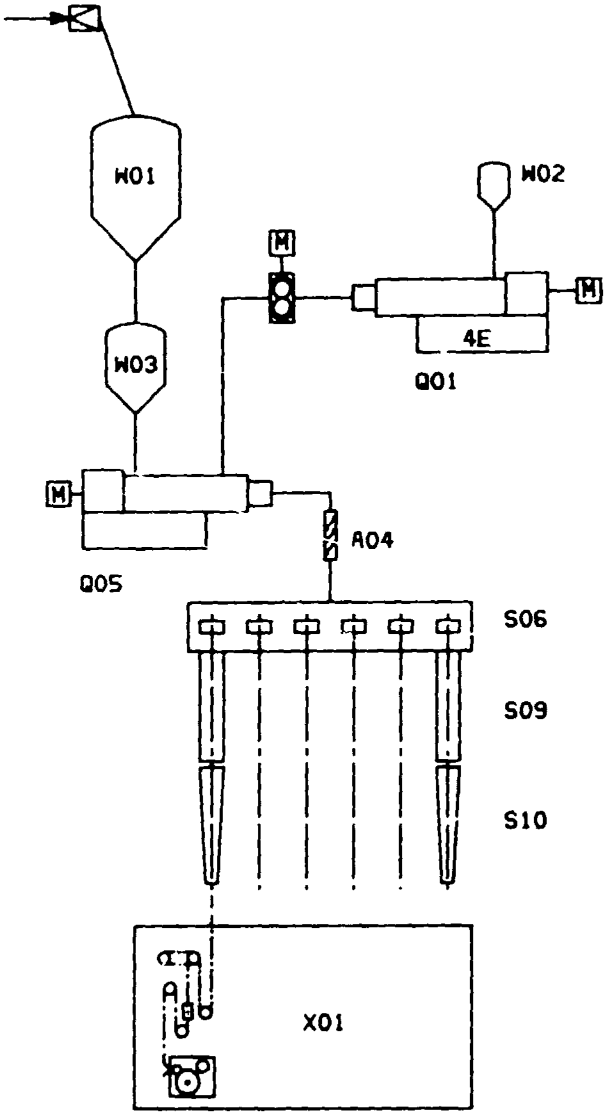
FIGURE 18



1. POLYMER FEED
2. STATIC MIXER
3. PRODUCT LINE
4. SPINNING MANIFOLD
5. AFTER HEATER
6. QUENCH DUCT
7. SPINING TUBE
8. DRAW-WINDER

SCHEMATIC DIAGRAM OF THE
SPIN-DRAWING PROCESS

FIGURE 19



W01	SILO
W03	INTERMEDIATE SILO
Q05	MAIN EXTRUDER
A04	STATIC MIXER
S06	SPINNING MANIFOLD
S09	QUENCH DUCT
S10	SPIN DUCT
X01	SPIN-DRAW-TEXTURING-WINDING MACHINE

ADDITIVE SYSTEM:

W02	SILO
Q01	ADDITIVE EXTRUDER
S02	METERING PUMP

SCHEMATIC DIAGRAM OF THE SPIN-DRAW-TEXTURING PROCESS

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International Conference on
Man-Made Fibres for Developing Countries

March 29 - April 2 1982 SASMIRA, Bombay

STRUCTURE AND PROPERTIES OF FIBRES

PROF. DR. KARL HEINZ HERLINGER
Institutes of Textile and Fibre Research Stuttgart and University of Stuttgart

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PROF. DR. KARL HEINZ HERLINGER was born in 1931 in Ludwigsburg, Federal Republic of Germany. He studied chemistry at the University of Stuttgart and worked for his Ph. D. Thesis under Prof. Dr. H. Bredereck in heterocyclic organic chemistry in 1958. From 1958 he was a member of the central scienfitic research laboratory of the Bayer AG. Leverkusen and assistant to Prof. Dr. Otto Bayer. In 1963/1964 he worked as a co-ordinator for the planning commission for the new centre of natural sciences of the University of Stuttgart. From 1964-1967 he was a research group leader of the Central scientific research laboratory at the Bayer AG. In 1968 he became director of the new founded institute of chemical fibres and in 1972 he became a full professor at the University of Stuttgart for textile and fibre chemistry. At the same time he became a director of the Institutes of chemical fibres and textile chemistry of the Institute of Textile and Fibre Research Stuttgart. He worked also as a scientific consultant for UNIDO.

He has worked on synthesis of heterocycles, pharmaceuticals, organic intermediates, reaction kinetics, polymerisation, synthesis of high temperature resistant polymers, elastomers, spinning technology, photo reaction of polymers, textile finishing processes, dyeing-mechanisms, physical chemistry of textile finishing processes.

About 350 publications and patents in the journals Textile Praxis International, Chemiefasern, Melliand, Textilberichte, Makromolekulare Chemie etc. describe his and the work of the Institute since 1968.

Synopsis

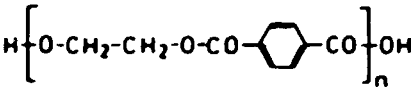
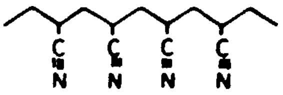
Steps leading to the development of various synthetic fibres have been outlined. Relation between structure of the fibres and properties has been elaborated. Out of the interdependence of chemical, physical and morphological structure results a profile of properties. The utilisation of a fibre polymer for textiles depends on different fibre properties considered together.

STRUCTURE AND PROPERTIES OF FIBRES

PROF. DR. KARL HEINZ HERLINGER
Institutes of Textile and Fibre Research Stuttgart and University of Stuttgart

For the development of fibres to their present level of properties it is important to find out the correlation between structure and properties of fibre polymers.

The paper shows to you how it was possible to create a large number of synthetic fibres with broad spectra of properties. The big four classical synthetic fibres are products which are produced in a quantity of millions of tons.

$H{\left[HN-(CH_2)_6-NH-CO-(CH_2)_4-CO\right]}_n OH$	PA66	W.H. Carothers DuPont 1934
$H{\left[HN-(CH_2)_5-CO\right]}_n OH$	PA 6	P. Schlack AGFA 1939
	PES	J.R.Winfield Calico Printers 1940
	PAC	H.Rein Cassela 1934/1943

Following the order as they were invented these products are

Polyamide 66: as a result of one decade of research work by William Hume Carothers at Du Pont

Polyamide 6: was invented by Paul Schlack who found the acid catalysed ring opening polymerisation of caprolactum.

Polyethyleneterephthalate: was invented by I. R. Winfield at the small Company Calico Printers in 1940 and it was further on developed by ICI.

Polyacrylonitrile: as a polymer was known since forty years till in 1934 H. Rein from Cassella found a solvent for PAC, the dimethyl-formamide. But it lasted till 1941 that PAC-fibres from DMF have been succesfully spun by Du Pont.

For all the raw chemicals processes have been developed in a technical scale for fibres this means millions of tons per year.

We can state here the first specific demand for fibre polymers.

1. Fibre polymers and their raw materials are mass products
2. as we learned from PAC the best fibre polymer with the best properties is useless if we cannot spin fibres from it in one of the known spinning processes.

From todays point of view we can see four important steps in fibre development.

Step 1 The empirical chemical synthesis of linear polymers, which probably can be used for fibre spinning. From this period the classical fibre polymers PA 66, PA 6, PES and PAC result.

Parallel to the development of technical processes of the polymers much development work on the different spinning methods has been done,

for meltspinning, dry spinning and wetspinning.

The last two spinning processes had already been introduced in principle for the production of viscose fibres and cellulose acetate fibres.

Step 2 In the development laboratories of the fibre producers and in research institutions intensive studies started to find correlations between molecular structure, polymer morphology and physical properties. This work is not completed even today.

From this studies we have our knowledge on form of polymermolecules in solution and solidstate. In this period the different models on fibre structure have been developed.

At the same time these new fibres were offered to the textile industry — and in this industry the specific processing methods of textile technology have been developed further.

We understand that this offer of new textile raw materials gave a strong impulse for the development of new machines for the production of textiles, of new dyestuffs, textile finishing products and dyeing procedures.

We can state at this point a further demand on a synthetic fibre material. "The best fibre material is useless in textiles if it cannot be dyed in all colours."

In this period of development it was necessary to answer many questions, for instance

"How can these new fibres be processed?"
"Which new processing technologies are necessary and possible"—here we think only on texturising processes.

"What are optimated dyeing conditions?"
"How can we vary dyeing behaviour?"

Questions and questions, which for a long time have been asked by textile industry.

To say it in one sentence—the textile and fibre industry needed some decades only to show the quality and advantages of the classical synthetic fibres in its full extent. People learned the whole spectrum of properties of synthetic fibres.

Step 3 With growing understanding of the properties of synthetic fibres new demands arose which as a sum of wishes have been demanded by industry in form of profiles of demand.

For every specialist it is no question that we cannot combine all properties.

Nevertheless many of the profiles of demands could be realised—for instance polyamides for differential dyeing processes.

With this level of knowledge on the correlation on structure and properties many profiles of demands could be realised. This lead to a broad variety of fibres, for instance polyester-cotton-types, polyester-wool-types, carrierfree dyeing polyester, polyester-tyre-cord and many others.

We can state, "the chemical and physical modification of fibres was the work of decades of fibre development."

Step 4 By chemical and physical modification of fibres almost every profile of demands could be realised. The next step was, where are the limitations. Here we discuss only two mechanical properties—

(a) extremely high modulus or
(b) high rubber elasticity.

Our knowledge on correlation of polymer structure and fibre properties showed to us the way for research work.

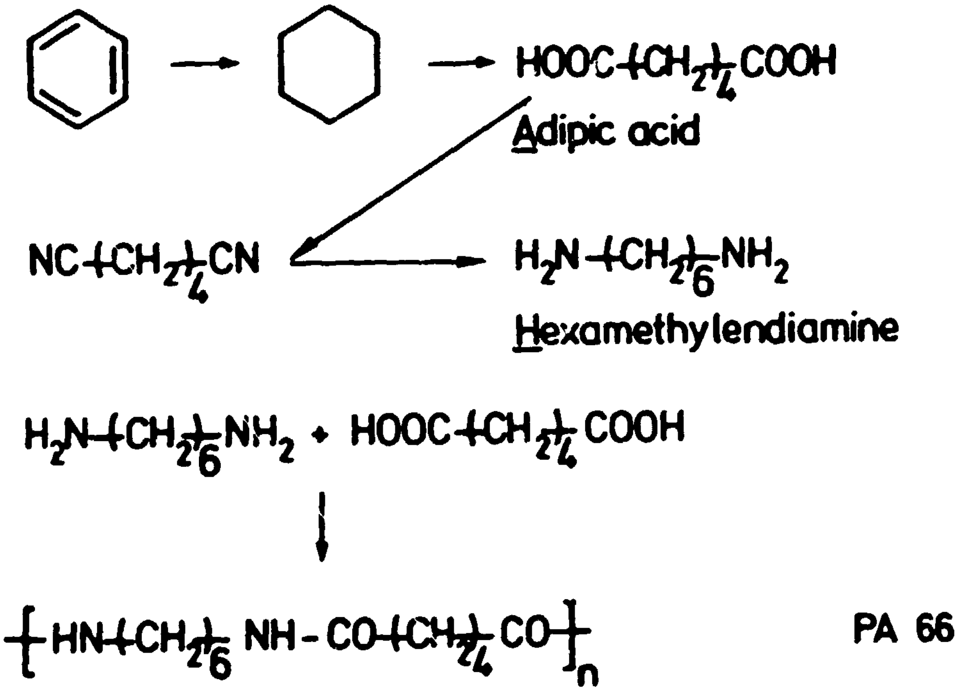
Of course we had to find solutions for many problems of preparative macromolecular chemistry realisation of specific structures spinning technology optimated end use and so on.

The result is Aramides and Elasthanes.

We shall come back to this point at the end of my paper. I want to show you now *why* a certain development took place and at which state of development we are nowadays.

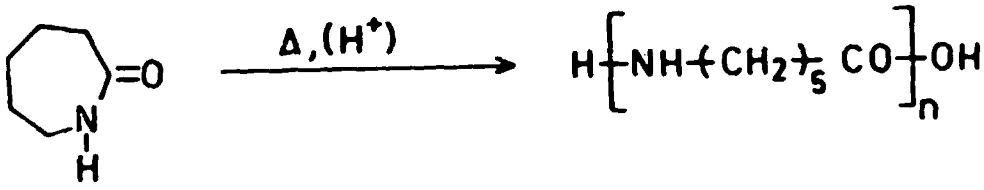
Let us start with some questions on polyamide 66—

"Why was this the first synthetic fibre polyamide?"



Both chemical raw materials adipic acid and hexamethylendiamine could be synthesised in a laboratory and later on in a technical scale. The polycondensation process is without serious problems. The melting point of the polymer is low enough for fibre spinning and high enougn for practical use in textiles and the glastransition point is low enough for simple dyeing procedures.

When DuPont worldwide applied its patents on polyamide 66, of course many other competitors wanted equivalent fibres.



PA 6, Paul Schlack 1939

So Paul Schlack succeeded in polymerisation of caprolactum.

With these two polyamides we can discuss the importance of symmetry of molecules for the macroscopic properties.

One important property for practical usé is the melting point.

$$\Delta G = \Delta H - T_s \Delta S$$

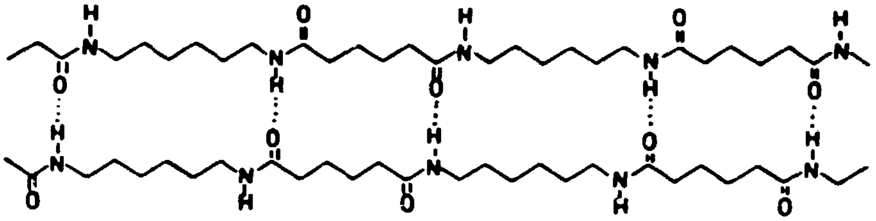
$$\Delta G = 0$$

$$T_s = \frac{\Delta H}{\Delta S}$$

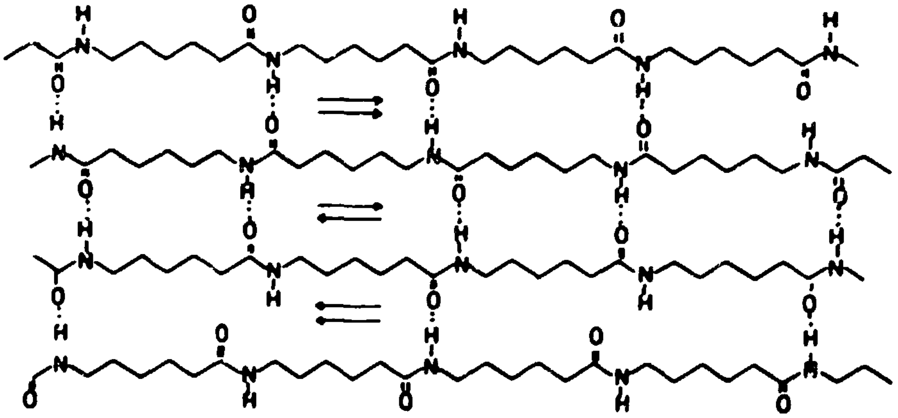
$$\frac{\text{Enthalpy}}{\text{Entropy}}$$

At the melting temperature we have an equillibrium between solid state and melted state.

This means that changes in Gibb's Energy is zero and from this we see that the melting point T_s is the ratio between enthalpy and entropy. Entropy is a measure of order for a system, — order on the other side is a question of symmetry, this means, systems with higher symmetry are able to have a higher order and therefore change of entropy ΔS under comparable conditions is small.



PA66 . $T_S = 257°C$ no molecule direction



PA6 . T = 225°C molecule direction

As a consequence for PA6 and PA66 means:

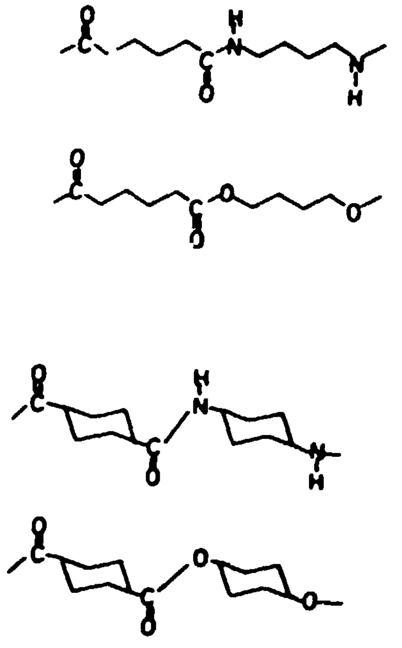
If we take two parallel polymerchains in such a way that we can get a maximum of interaction, this is realised by dipole-dipole interactions of hydrogenbonds, we can see, that for PA6 molecules we need a certain direction for a maximum of hydrogenbonds.

In PA66 we need no high order of molecule directions, this molecule has a higher symmetry as PA6 and so a lower change in entropy at melting equillibrium and therefore a higher melting point.

Till now we have seen two factors which determine the properties of a polymer.

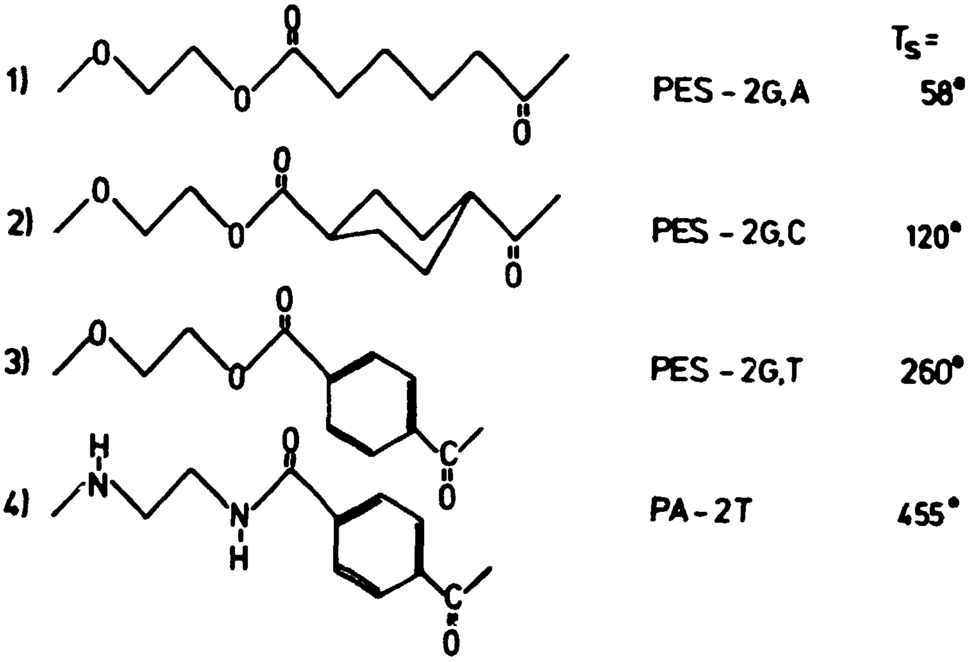
1. molecule interaction
2. molecule symmetry.

With the example of Polyamide and Polyester we shall now discuss the influence of mobility of conformations of polymer chains on melting behaviour.

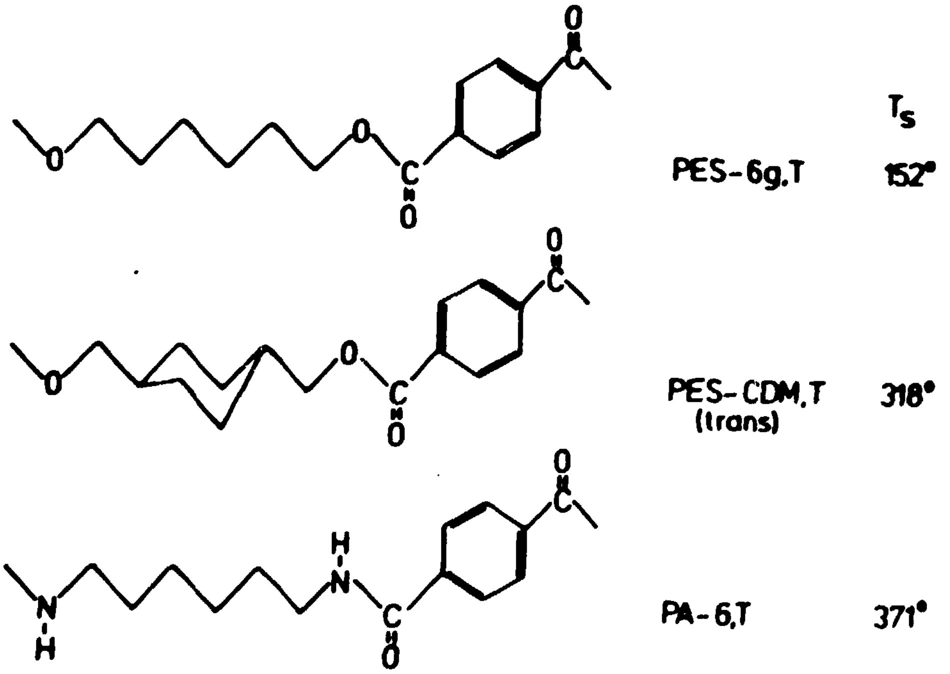


	Smp.
PA 4,6	295°
PE 4,6	58°
PA c 6,6	>500°
PE c 6,6	>300°

If we compare polyesters and polyamides of similar conformational mobility we find that polyesters have a lower melting point. The reason is, that a dipole-dipole-interaction of a polyester is lower than the interaction of carbonamide groups which form hydrogen bonds. This is the reason why Carothers besides all his efforts in synthesis of aliphatic polyesters could not get a high melting fibre forming product.



In the following figure we can see to which extent the melting point is influenced by conformation and molecule interaction. We also can see that under this aspect Polyethyleneterephthalate is the polyester of choice. This is the case not at least by the availability of the chemical raw materials.



An other diole for polyester is the hydrogenation product from DMT, the Cyclohexyl-dimethanole. Condensation of this product with terephthalic acid forms the cycloaliphatic polyester. To study the influence of the conformational stability on thermal properties we have to compare with the polyester from TPA and hexanediole. We see here that conformational more rigid molecules have higher melting points.

The melting point of a polymer which can be used for fibres is *only one* of the important properties.

We can summarise a number of properties which are important for fibre polymers and fibres

1. Demands on the Polymer

Availability of raw materials in big scale
Simple polycondensation processes
Low meltviscosity near melting point
High productivity in spinning processes

2. Demands on fibres

Processing possbility on conventional textile machines
Possibility for modification of fibre configuration (texturising processes)
Dyeability
Mechanical—, thermal—and lightstability
Good mechanical properties as modulus, mechanical fastness, abrasionstability

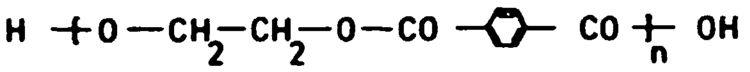
Properties for use: Comfort of clothing
Comfort of cleaning, washing

These are only a few of the demands we can ask for.

We cannot realise all possible demands in one fibre type. For this reason we shall produce for a long time onwards the classical synthetic fibres, but we shall optimate specific fibre properties by polymer—and fibre modification.

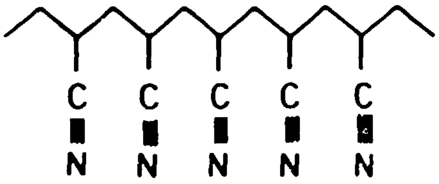
$H - [HN - (CH_2)_6 - NH - CO - (CH_2)_4 - CO]_n - OH$ PA 66

$H - [HN - (CH_2)_5 - CO]_n - OH$ PA 6



PES

Till now we discussed systems of the polycondensation type. We now come to, which fibre forming polymers and which monomers are available in technical scale.

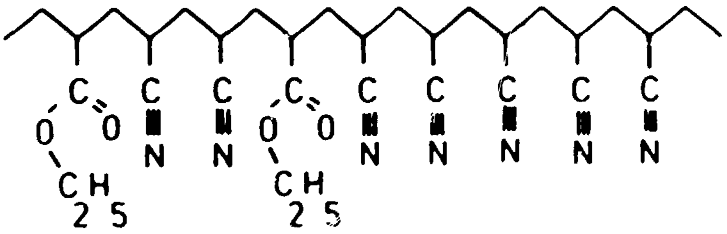


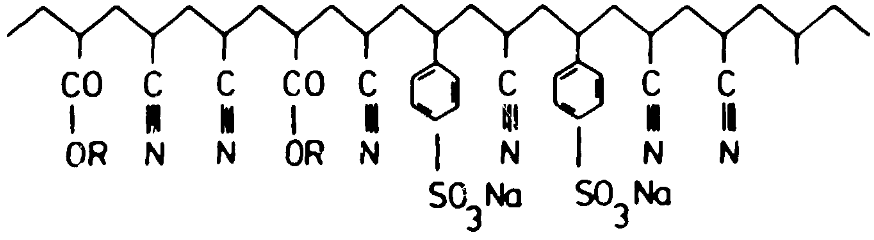
SOLV DMF

DMA

DMSO

HNO_3



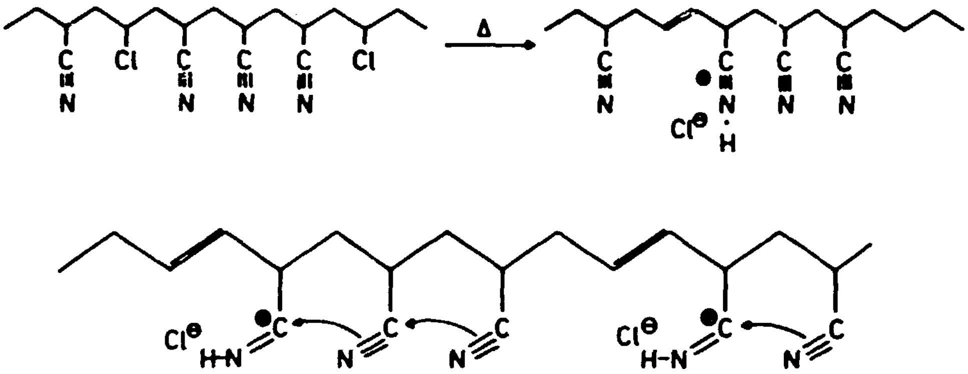


From the vinyl-polymers the PVC and PAC have been long known polymers before they have been used for fibres. PAC is long known, but only new solvents as DMF or DMA allowed spinning of PAC-fibres.

For this purpose some modifications of the polymers were necessary to improve plasticity and dyeability. This can be done by introduction of plasticising monomers as acrylates and acidic groups by copolymerisation with styrene sulfonate.

Further studies on correlation of structure and properties showed principles by which specific properties can be achieved.

Flame retardant PAC-fibres for instance can be produced from a copolymer of acrylonitrile and vinylchloride.



To understand what are the best compositions it is necessary to study the chemical reactions during pyrolysis and burning. The fast cyclisation of the nitrile groups to the first step of carbon fibres reduces the formation of volatile burning compounds.

At this and many other examples we can demonstrate by which way demanded properties can be realised.

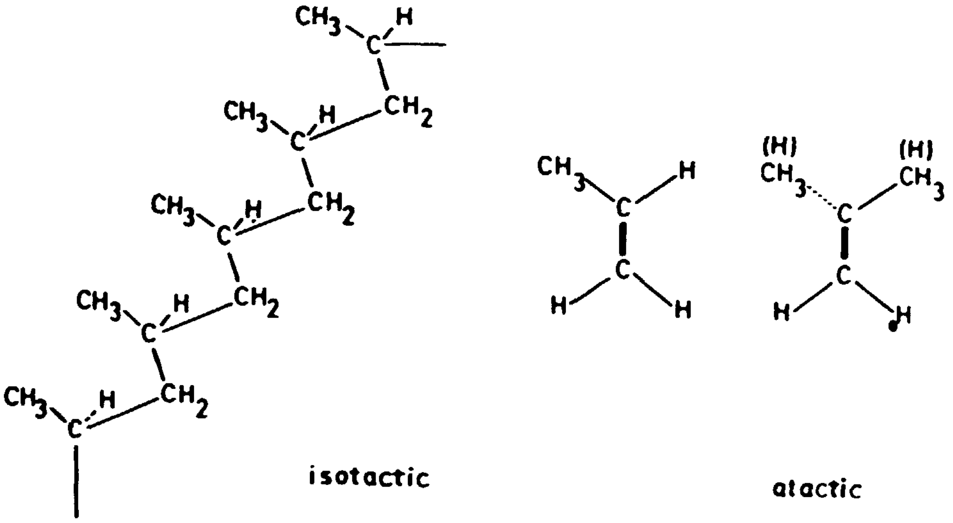
In every case it is necessary to understand all physical and chemical reactions which occur under certain conditions before we are able to optimate specific properties.

For the classical synthetic fibres such properties are:

- force-elongation behaviour
- dyeability
- lightfastness
- washability
- flame retardancy

and many other properties.

Raw material for acrylonitrile to day is propylene. Of course polypropylene has been developed to a fibre forming polymer. But this only was possible when Ziegler and Natta had discovered the sterospecific polymerisation.

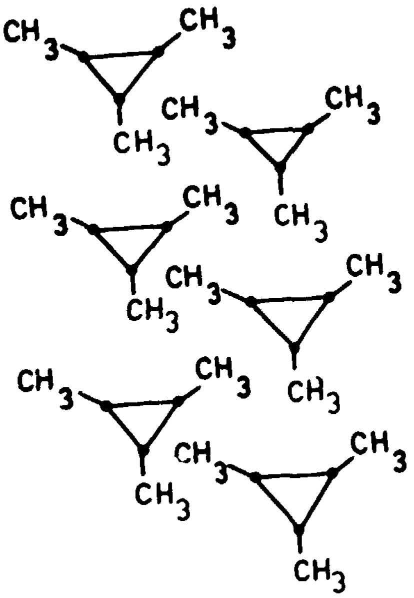


isotactic

atactic

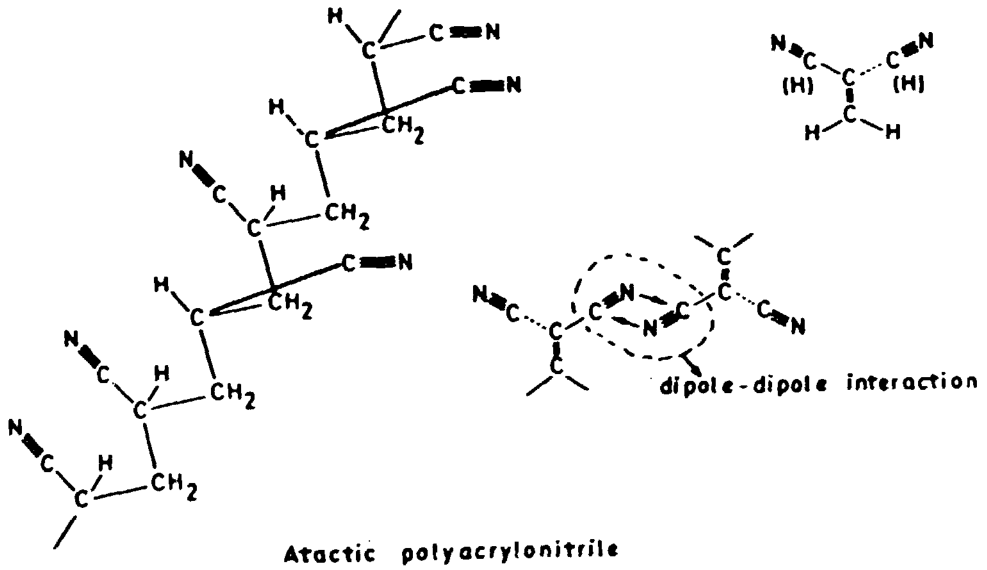
To achieve a sufficient interaction of molecule groups and to achieve a certain conformative stiffness an isotactic arrangement of methylgroups along the polymethylene backbone is necessary.

Because of stereochemical and energetic reasons a polypropylene chain is arranged in a helix. The arrangement of the substituents in 1, 3—position by steric reasons hinders an all-trans conformation. The system prefers a helix conformation. The polymer backbone forms a spiral, the substituents are arranged at the outer side of the spiral. In a simple picture we can see this in a projection on the molecule axis.



These helical structures under each other develop interactions in form of dispersion forces.

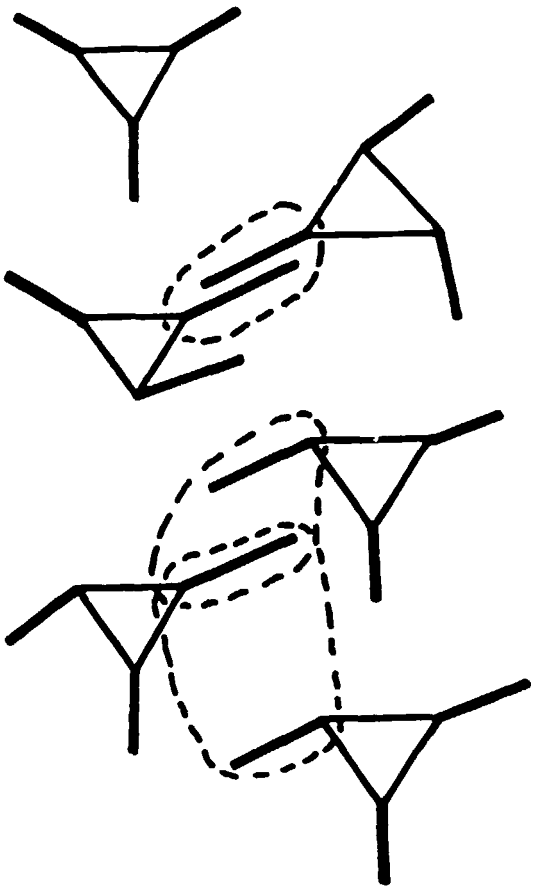
In isotactic polypropylene we have a structure of high order. The stiff helix is a consequence of a uniform configuration of the molecule. This reflects in the force elongation behaviour. In polypropylene we have no groups with affinity to dyestuffs. For the mechanical and thermal properties the high symmetry is important. All trails to cooperate comonomers with groups of high affinity to dyestuffs had to fail. Every change in polarity of the monomers reduces the stereo-specificaly of the polymerisation reaction.



Atactic polyacrylonitrile

In the radical induced polymerisation of acrylonitrile only atactic polymers are formed. In a perspective projection with an all trans conformation of the backbone we have an irregular arrangement of the nitrile groups.

The dipole-dipole interaction of the nitrile groups is extremely strong. This is one of the reasons for low solubility of PAC. The dipole-dipole interaction can only be lowered by strong polar solvents (DMF, DMA etc.), protonating agents as nitric acid or complexation with zinchloride.



PAC - helix interaction

Of course also from this atactic arrangement of substituents there arises a strong dipole interaction of the nitrile groups, but this does not reach its possible maximum value.

From what I have discussed till now we can conclude:

> "Symmetry and configuration of a polymer group deteramine the polymer conformation. The molecule conformation determines the arrangement of the chain molecules in the crystalline and non crystalline part of the polymer.
>
> In the noncrystralline part we have a chain segment mobility under changes of conformation."

Chemical constitution ———→ configuration

configuration
molecular interaction ———→ conformation

conformation ———→ microstructure

microstructure ———→ crystallites

———→ secondary structure

———→ tertiery structure

MACROSCOPIC PROPERTIES

The most probable conformation of a molecule is determined by the configuration which results from chemical structure.

Conformation but also determines structure units which determine secondary structure.

Microscopic properties as mechanical fastness and modulus we can only measure at solids of microscopic dimensions.

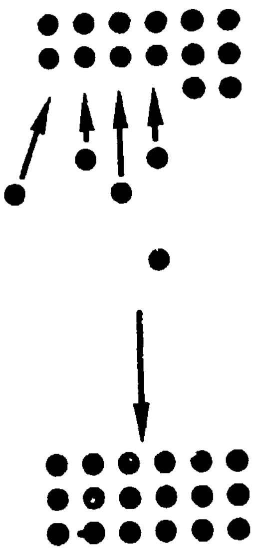
This means we have to observe the arrangement of ensembles molecules if we want to discuss, modules elasticity and so on.

At this point we come to the question :

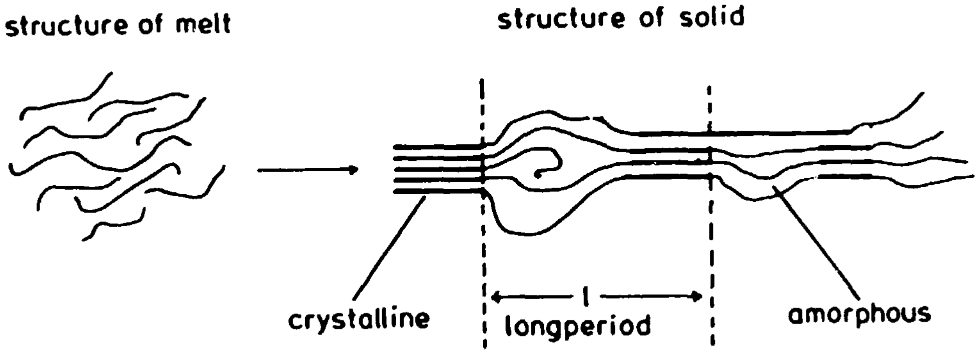
What is our picture of the arrangement of the molecules in the polymer? This means, we have to construct structural models and proof this models by physical measuring methods, x-ray-structure etc. or we have to deviate this structural models from physical measurements.

From x-ray analysis we know that the polymers are only partly crystalline.

If we realise what is difference in the way of crystallisation of a chain molecule to the way of crystallisation of a low molecular substance, then we can understand our present structural model.



In low molecular compounds the free places of a lattice are filled one after the other and indepent from each other.



An other situation we have with high molecular compounds. Here the segments of a macromolecule is built in different crystallites at the same time.

In the crystalline parts we find a strong interaction of the polymer chains.

model of the fringed micelle concept.

A very instructive model of a fibre structure has been given by W. Statton.

In the noncrystalline areas the molecules above the glass transition point move against each others, this means we have a certain chain segment mobility.

The chain segment mobility becomes higher in the presence of water, carriers, softeners etc. With this mobility we get a dynamic movement of the free volume which allows a dyestuffmolecule to diffuse into the polymer.

From this structure model we can draw conclusions for further developments in the fibre field.

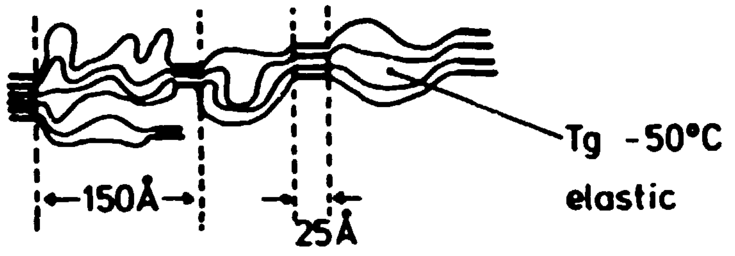
In polyethyleneterephthalate the glass transitin point is above 100°C— this means in an open dyebath the chain segment mobility of polyester is to low for a sufficient diffusion volecity of substances which have chain segment mobilities as for instance carriers.

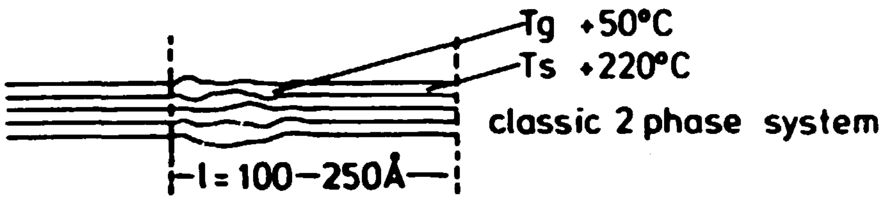
A higher chain segment mobility results from comonomers with low conformational stiffness. For this reason we can form fibres from a copolycondensate of ethyleneglycol, polyethylenglycol and terephthalic acid which can be dyed in an open dyebath.

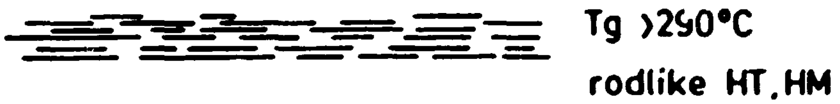
With the realisation of a carrierfree deyable polyester we have seen, how a straight foreward modification of properties is possible.

We come now to discuss the last and latest aspect of fibre development — the definite construction of fibre properties.

To understand this development we look again on three possible structure models of polymers and ask which macroscopic properties result from such structures.







In a structure model of a classical two phase system we have long periodes of 100-200 A^0 length. The amorphous and crystalline part have the same chemical constitution. The glass transition point is about 30-100^{0}C, dependent upon the conditions. This means for dyeing we need temperatures from 40-130^{0}C.

If we want a fibre with high rubber elasticity we need segmented polymers. In this systems we have a sequence of segments with low and high molecule interaction.

For realisation of such structures we can use a principle which was discovered in 1935 by 0. Bayer, the di-isocyanate-poly-addition-principle. Segments with high hydrogenbond-density form the socalled hard blocks and form points of physical crosslinking.

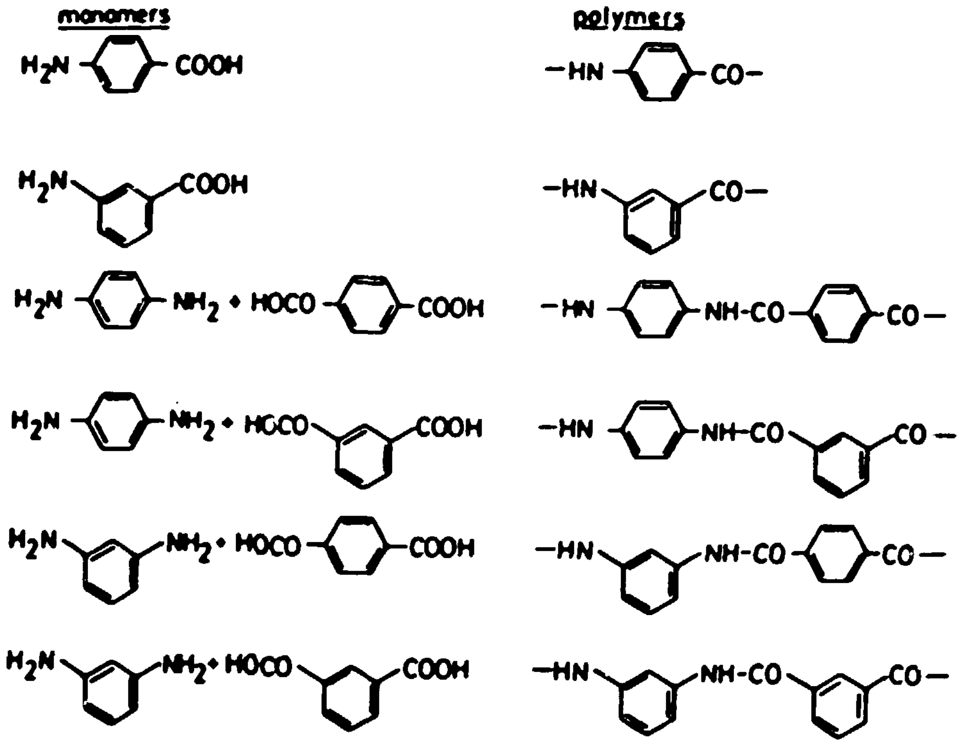
Polyether-parts in the polymer have a high conformative mobility and a very low glass transition point.

This segments at room temperature are in a quasi-liquid state.

An other type of polymers which can be used for production of fibres consists of conformative extremely stiff polymerchains with a high interaction of the polymer chains.

We have already seen to which extent thermal and thermo-mechanical properties are determined by molecule conformation.

If we apply this principle on polyamides we can expect that aromatic polyamides will have specific thermomechanical properties.

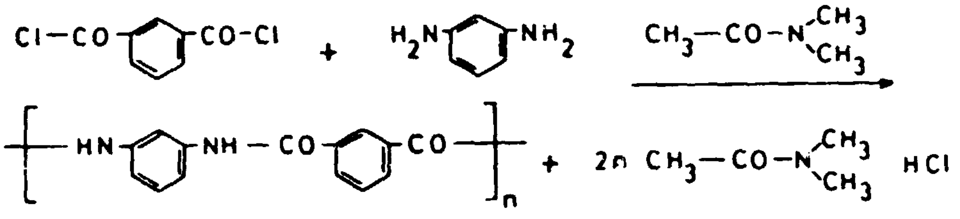


As monomers we have here p-amino-bencoic acid, terepthalic acid, isophthalic acid, p- or m-phenylendiamine.

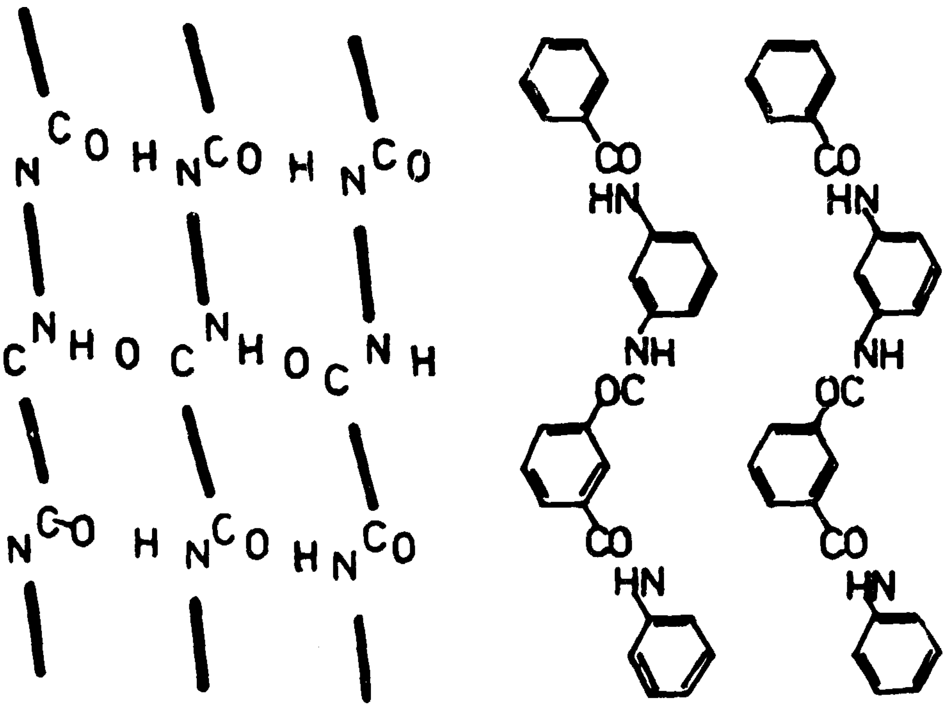
For the production of fibre forming polycondensates we have as a general rule.

Monomer and polymer should be over the whole polycondensation process in an homogeneous state.

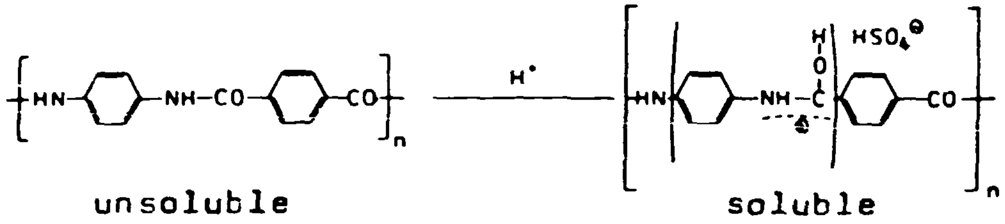
Polymers from the meantioned monomers however melt above 400-600°C. For this reason we cannot use a melt polycondensation process. It is necessary to condensate a solution-polycondensation process. In addition the amino-groups of the aromatic compounds have a low reactivity so that we have to activate the carbonic acid inform of their acid chlorides.

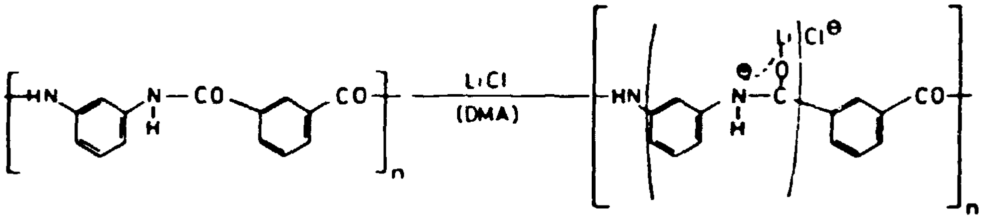


For this reason we add dicarbonic acid chlorides to a solution of aromatic diamines in an aprotic polar solvent, which in its anhydrous form is a strong base to add the developed hydrogen chloride.



Polymers of this typ form physically crosslinks which leads to a low segment mobility. The result is a very high melting point.



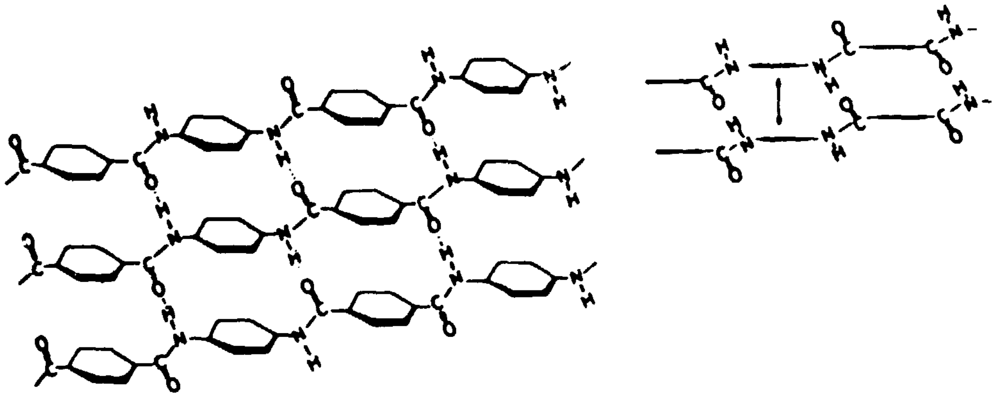


If we succeded in synthesis of a polymer of sufficient high molecular weight, and as we cannot use a meltspinning process-, we need a solvent to spin the polymers to fibres.

Poly-m-phenylene-isophthalamide is soluble in dimethyl-acetamide lithiumchloride. By addition of the lithiumchloride to the carbonamide bond a polyelectrolyte is formed which is soluble in the solvent DMA.

From such a solution we can spin fibres. The fibre properties are those of a relative stiff fibre. But as we have only a low concentration of carbon-hydrogen-bonds in the polymer we have a low of flammability.

For this reason textile materials from this fibres are used for professional clothing where a danger of fire is possible.

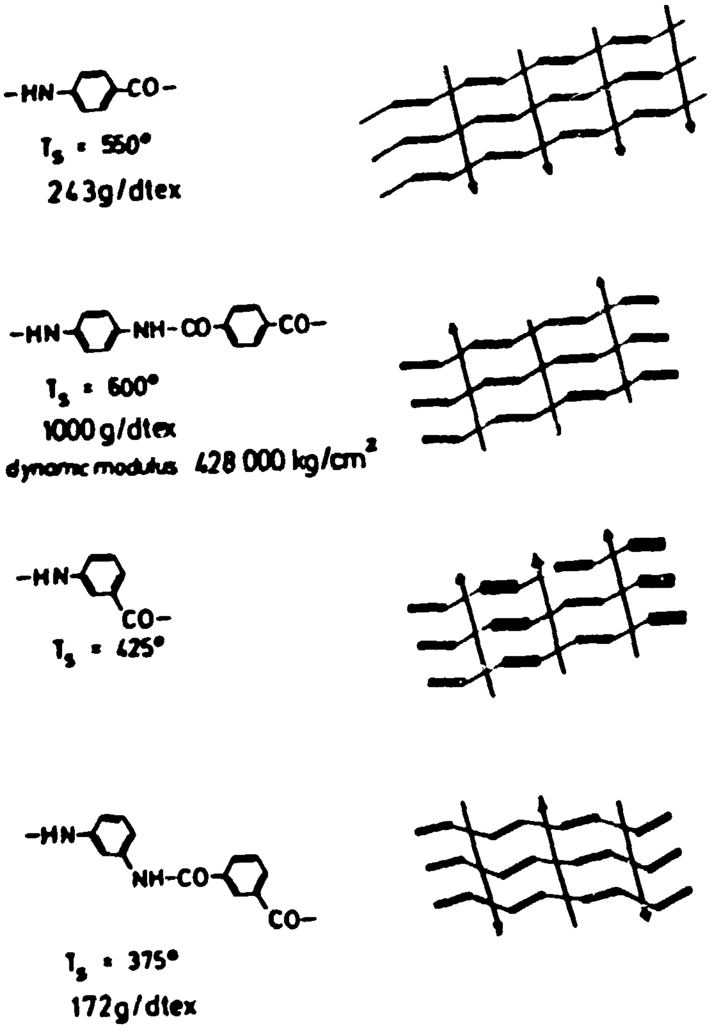


Poly-p-phenylene-terephthalamide Ts = 500° C

orientation of hydrogen-bonds in poly-p-phenylene-terephathlamide

By polycondensation of p-phenylendiamine and terephthalatic acid chloride we get the p-linked polyamide. Here also we have a crosslinked hydrogenbond system. In this system the symmetry is still higher than in the meta-linked system.

Such polymersystems dissolve in sulfuric acid. The carbonamide groups are protonated and the resulting polyelectrolyte forms anisotropic solutions of liquid crystalls. This leads to a high preorientation of the molecules before spinning.



orientation of hydrogen-bond-dipoles

The thermal behaviour, modulus and strength of fibres is determined by symmetry of the polymergroups and by order and orientation.

In which way the fibre modulus is influenced by symmetry and hydrogen-bond-direction we see in a comparison of some aramide structures.

The higher the symmetry of the system and the lower the inner energy by dipole compensation the higher we find the modulus and melting point.

Which consequences can we draw from this facts on the use of aramides.

	aliphatic PA	Poly-m-phenylene isophthalamide	glass	Poly-p-phenylene terephthalamide	steel	carbon
fastness $[kg/mm^2]$	186	95	350	427	420	350
modulus $[kg/mm^2]$	9019	2503	10019	19055	21000	45000
density $[g/cm^3]$	1.43	1.40	2.58	1.45	7.9	1.7
specific fastness [km]	130	67.8	135.6	$\boxed{294.5}$	53.2	$\boxed{205}$
specific modulus [km]	6306	1781	3883	$\boxed{13141}$	2658	$\boxed{26500}$

Fibres with a high modulus are important components for composites.

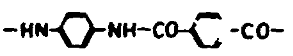
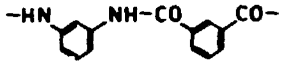
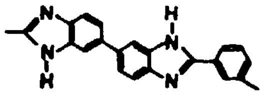
If we compare the moduli of glass-, steel-, carbon- and aramide fibres, we see that this data are on the same level.

For many uses however not only fastness and modulus are important but reenforcing strength, this means fastness and modulus per weight of the fibre.

For this reason we have to take into our calculation the density of the material, this means, we have to express the reenforcing power of the fibre in from of a specific fastness or specific modulus.

Because of the low density we find for poly-p-phenylenterephthalamide extremely high specific fastness and modulus. If we take also into consideration the price we get with this fibre the highest value per money unit. Besides this no other fibre has such a high dynamic modulus. So we can use this for tire cord or antiballistic clothing.

Of course such a differentiation is only very coarse, so every specific fibre owns further specific properties which determine their application.

polymertype	T_g dyeability	Ts thermomechanical properties	application
$-HN(CH_2)_6NH-CO(CH_2)_4CO-$	45°	257°	textiles
	> 300°	600°	tyre cord composites
	286°	375°	textiles, filters fr-products
 PBI	—	600°	technical textiles fr-products

We know from the spectrum of PA66 that this fibre is especially useful for textiles.

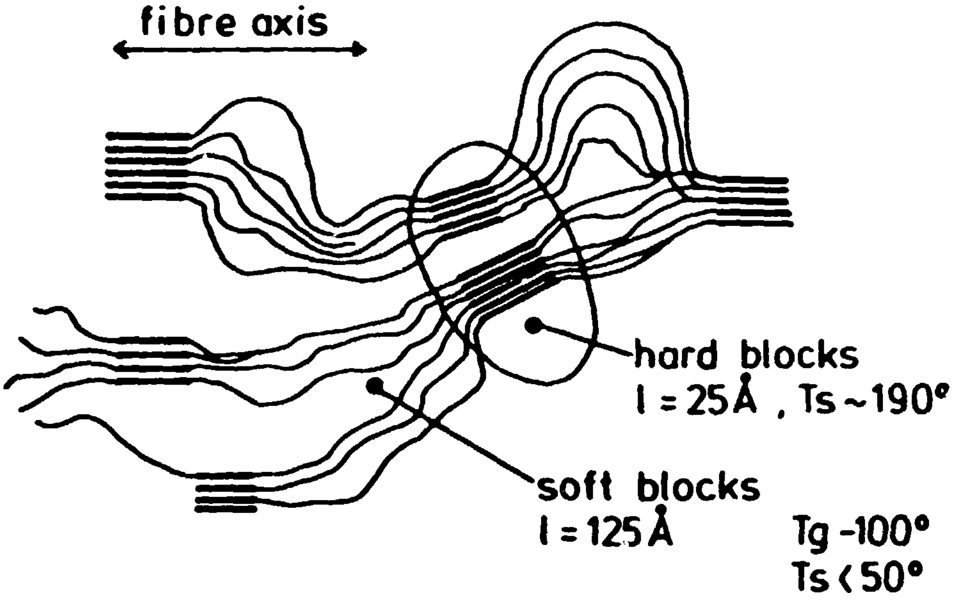
For thermal resistance however a sufficient thermal restiance of shape is necessary which is connected with the melting point and glass-transition point. In PA66 we have a sufficient low thermoplasticity so that we are able to texturise. Dyeability is favoured by the low glass transition point in the presence of water in a dyeing bath.

From the high symmetric, p-connected aramides we use the high static-and dynamic modulus. Such a high modulus prevents the use in textiles for clothing. Systems with lower symmetry as poly-m-phenylene-isophthalate have a low flammability. The reason is the low percentage of C-H-bonds. So this system can be used for special clothing.

A still higher thermal stability is achieved if we lower the percentage of C-H-bonds further by using poly-heterocycles.

This we find in the poly-benz-imidazole.

In Polyheterocycles and condensed aromatic systems temperature fastness is on a still higher level. But also here we have to make compromises between bending-behaviour, compressibility, fastness vertical to the fibre axis on the one side and modulus and temperature resultance on the other side.



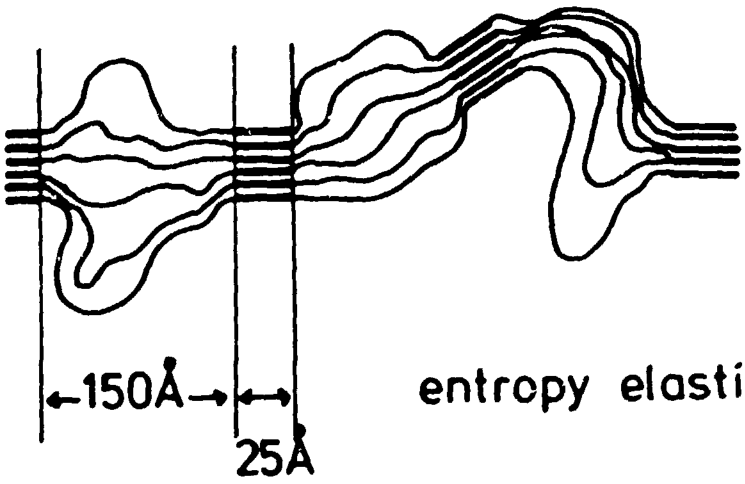
Elasthane fibre polymers

We have seen in the last chapter how the density of energy of cohesion of a linear polymere is influencing the macroscopie fibre properties.

An other building-principle of polymers consists in the arrangement of a polymer in segments of different energy of molecule interaction.

A rather defined arrangement of building blocks is only possible in stepwise synthesis of the polymer.

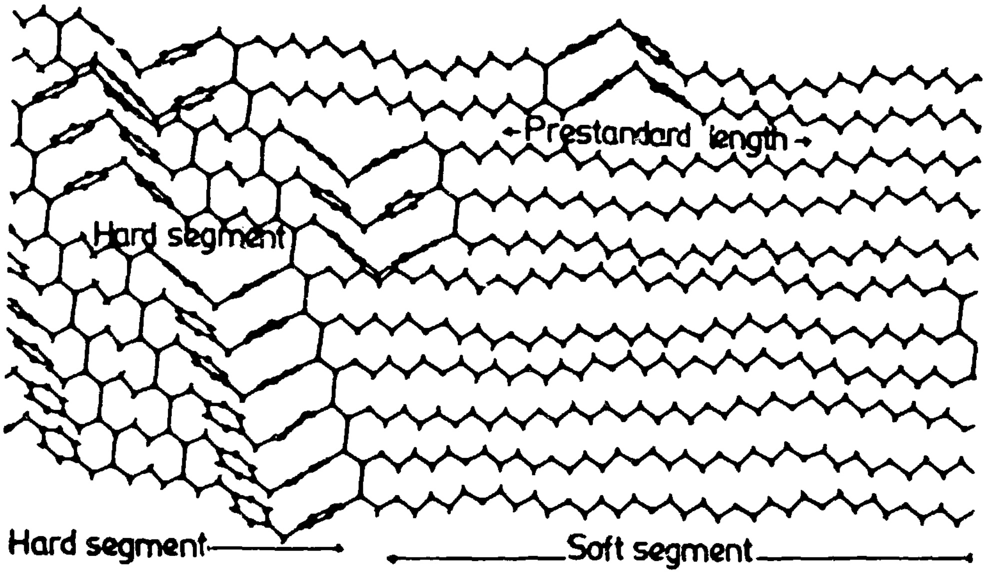
classical crystalline-amorphous system



entropy elastic system

For this purpose we can connect segments of low molecule interactions and high conformational mobility — for instance polyethers — with segments of high potential hydrogenbond density.

If we arrange two building blocks of this type in an alternating segquence we can realise a entropy-elastic fibre forming polymer. The soft segments at room temperature are in a liquid state.



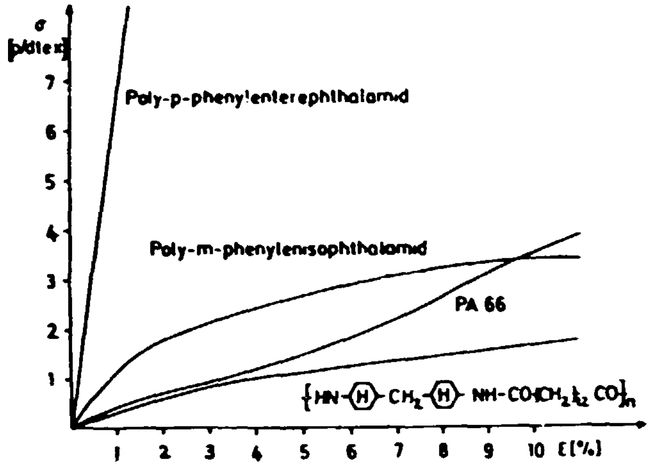
If we give a load on a fibre system of this type under the most favourable conditions all polyethersegments come to an all-trans-conformation. The hard blocks stay crosslinked because of their high hydrogen-bridge density. If we lower the load for on such a fibre, the polyethers will come to a state of higher entropy. This behaviour reflects the properties of a rubber elastic material. By the discussed principle of syntheses we can realise systems with a reversible elongation of 700 %.

But what is the difference compared with normal classical rubber material?

Rubber elasticity of natural and synthetic rubber results only from a valcanisation process. The formed covalent crosslinks lead to a polymer which is not soluble in any solvent. So we cannot produce fibres of the necessary low titer

In the polyurethanes however we have no covalent bonds between the chain molucules, but only hydrogen bonds. For this reason this polymers dissolve in polar solvents and from such polymer solutions we can spin elastomer fibres.

If we spin around such elastomer yarns PA6 or PA66 we can get highly elastic core yarns for elastic textiles.



We have now discussed the most important principles of fibre polymer construction.

For most applications modulus and maximum elongation is important. With the present knowledge on correlation of structure and properties we can realise different fibres types with elongations of 1-700% and with moduli from 0,2 — 1000 g/dtex.

We have also discussed the question — how interaction of polymer building groups determine fibre properties.

The used momers determine the chemical constitution of the polymer — its chemical properties.

The basic chemical units determine the configuration of the polymer, the interaction of the building determine stereochmistry, conformation, crystallisation and all cooperative properties.

The thermal behaviour, meltviscosity, solubility etc. determine the possibility to spin fibres.

Spin - and stretching processes at last determine morphology and possibility to optimate enherent properties.

Out of this interdependence of chemical, physical and morphological structure at last there results a profile of properties.

mechanical	properties	fastness, modulus, relaxation abrosion resistance
textile	properties	hand, bendingmodulus, stiffness surface structure, light reflection appearance drape
comfort	properties	water uptake, water transport thermal insulution, wearing comfort comfort of washing, drycleaning non ironing

textile chemical	properties	blending, opt. brightening dyeing **textile chemical modification** antistatic, soil realease flammer tardant, crease resistance

If we can use of fibre polymere in textile technology or not, is a question of the level of the sum of fibre properties.

This properties are:

mechanical properties	as	fastness, modulus relaxation behaviour abrasion restistance etc.
textile properties	as	hand, bending modulus stiffness, surface structure light reflection appearance, esthetics etc.
comfort properties		comfort of chlothing thermal insulation water transport physiological properties cleaning comfort as washing dry cleaning etc.

To realise all this properties we need a number of chemical and technological processes.

It is one of the most important conditions, that the fibres can be processesd in pure form or in blends with natural fibres on conventional textile machinery.

But also an other group of demands to produce textiles from fibres have to be fulfilled.

For instance a number of textile chemical processes have to be applicable, such as dyeing, bleaching, textile chemical modifications for soil release, antistatics, shrink proofing, flame retardancy and many others.

We cannot realise these properties on a textile material without understanding the behaviour of fibres in the textile manufacturing processes.

We now also understand that it is not possible to have one universal fibre.

The raw materials we use nowadays in fibre and textile-production allow to realise a broad variety of properties.

How we can realise and modify the basic properties of the classical synthetic fibres will be the subject of the coming papers on this meeting.

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POLYESTER USAGE IN THE KHADI, HANDLOOM AND POWERLOOM SECTORS OF THE TEXTILE INDUSTRY

R KUNJUR
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Chemicals and Fibres of India Limited

Introduction

The use of man-made fibres has been growing very rapidly all over the world and has been providing supplementary source of raw material for clothing because pressure on available arable lands for food production is increasing. Among the various man-made fibres, polyester staple fibre had phenomenal growth because of its versatility and its ability to produce attractive, easy care and durable fabrics in blend with natural fibres. It has become a cheap clothing material in developed countries and it should be possible even in India to make this available to rural masses at reasonable prices by producing the fibre in economically large size plants and by rationalising the duty structure on this product.

This paper highlights the need for increasing usage of synthetic fibres, polyester staple fibre in particular in the decentralised sectors of the textile industry for fulfilling the various targets set for the clothing production and to provide a durable and attractive clothing to masses at reasonable prices.

India has a large textile production capacity in the decentralised sector of the textile industry, namely Powerloom, Handloom and Khadi Sectors. In the Sixth Plan, these sectors have been given a dominant role for cloth production because they generate large employment in the rural and semi-urban areas of the country. The VIth 5-year Plan outlines cloth production in various sectors of the textile industry is as follows:

(In Million metres)

	Annual production 1979-80	Targeted production 1984-85	
Mill Sector	4,285	4,900	+ 14%
Powerloom Sector	3,450	4,300	+ 25%
Handloom Sector	2,900	4,100	+ 41%
Total:	10,635	13,300	+ 25%
Wool/Khadi		300	
		13,600	

Raw Material Requirement

The total raw material requirements for this enormous production of clothing will be the order of 1.7 million to 2 million tonnes (105 to 115 lac bales) per annum of various types of fibres. Cotton would still be the predominant fibre that will be used for clothing in this country and could cater upto 80 to 85 lac bales per annum in a normal year with current acreage of cotton growing arable lands. The balance 30 to 35 lac bales (i.e. 500,000 to 600,000) of fibre requirements has to be met by man-made fibres such as polyester viscose, acrylic fibres, if the country's requirements of clothing should be fully met as per the above targets. Like elsewhere in the world, fabrics made from polyester fibre in blend with viscose and cotton has shown wide acceptability by fabric manufacturers as well as consumers both in urban and rural areas. Several social-cost studies made in the past have shown that polyester staple fibre have a lower input cost compared to cotton and other fibres, mainly because polyester blended fabrics are 3-4 times more durable than cotton and input costs of polyester are lower than other synthetic fibres. In developing countries, where per capita consumption of clothing is low providing such durable clothing becomes very relevant in respect of funds to be invested for production of fibre and clothing to cater to the ever increasing population. In India, about 1,00,000 tes of polyester fibre can be produced using only 1.3% of the country's crude oil production. The current production of polyester fibre by indigenous manufacturers is 36,000 tonnes and will increase to 80,000 to 90,000 tonnes over the next two to three years. Considering the social cost and other benefits offered by this fibre and the need to cater to the ever increasing population, it is but logical for the country to encourage large scale production of durable clothing from blends of polyester staple fibre. In fact, the World Bank Mission, in its study on the future of man-made fibres in India has recommended a capacity of 300,000 tonnes of polyester staple fibre by the end of the decade.

Decentralised sectors — Current Status

The usage of polyester fibre hitherto was largely confined to the Mill Sector and the benefit of high durability of polyester blended fabrics has been enjoyed by the more affluent section of our population — mainly in the urban area. This was due to high cost of fabrics, high excise duties levied by the Government at various stages of its manufacture and also due to small size polyester manufacturing plants allowed by the Government.

During the last 4-5 years, polyester fibre manufacturers promoted usage of this versatile fibre in the Handloom, Khadi and Powerloom sectors and have carried out extensive development work.

Khadi Sector

Technically, polyester blends can be spun, woven satisfactorily by hand spinning, handloom weaving with certain modification on the equipment currently used. Hand spinners using Ambar Charkha have spun polyester/cotton, polyester/wool, polyester/viscose blends and handloom weavers have produced attractive fabrics. Because of the good tensile properties, production in spinning and weaving have been 50% to 60% more than cotton thus enabling spinners and weavers to earn better wages, as can be seen from the following table :

(Average earning per day)

Units	KHADI Mandir, Rashtriya Shala, Rajkot		Udyog Bharati Gondal, Saurashtra		KVI Public Charitable Trust, Gandhigram	
	Cotton	'Polyvastra'	Cotton	'Polyvastra'	Cotton	'Polyvastra'
Spinner	Rs. 6.40	Rs. 8.38	Rs. 7.07	Rs. 10.71	Rs. 6.00	Rs. 8.10
Weaver	Rs. 17.83	Rs. 22.91	Rs. 11.95	Rs. 20.69	Rs. 17.00	Rs. 21.00

To process the grey fabrics, mini process house comprising of seven simple hand operated processing machinery has been developed and it is now possible to dye and finish polyester blended fabrics in small batches at fairly low cost of Rs. 2.00 per metre.

Khadi and Village Industries Commission have been able to introduce Ambar Charkha spinning and handloom weaving of polyester blends at over 150 rural centres run mostly by Khadi institutions and social organisations. A 50/50 polyester/cotton blend spun on the Ambar Charkha and woven on handlooms are sold as 'Polyvastra', a name registered by the Khadi and Village Industries Commission. The Planning Commission has approved Khadi Commission's proposal tc establish 2500 such rural units exclusively for 'Polyvastra' production and Rs. 60 crores have been earmarked for this project during the VIth 5-year Plan.

A spinning unit with 25 Ambar Charkhas, 4 roving machines and other accessories costs Rs. 25,000 to 30,000 and this unit will employ 30 unskilled people, thus providing employment at a very low cost of investment (Rs. 1000/- per person). Although, opening, carding and blending of polyester fibre with cotton are currently carried out on mill machinery, simple opening and carding units have been developed to make the rural institutions self-reliant in this respect. The yarn spun by these rural units are woven on all types of handlooms without any difficulties. Two mini process houses have already been installed in leading Khadi Institutions for dyeing, heatsetting and singeing these fabrics.

'Polyvastra' currently produced by the rural units have adequate fabric performance and has evoked considerable interest even among the urban consumers due to their unique appearance and soft handle.

Since 100% cotton Khadi is expensive to maintain and has poor durability, the production of cotton Khadi is declining. Moreover, wages earned by cotton Khadi spinners and weavers are appallingly low and it cannot attract rural people any more. 'Polyvastra' has the capacity to rejuvenate the Khadi Sector because of its better wage earning capacity and excellent fabric performance compared to cotton.

It should be possible to make 'Polyvastra' a poor man's clothing if the Government consider full exemption of excise duties. A 50/50 'Polyvastra' shirting currently costs Rs. 21/- per metre with the excise levies at various stages but can be brought down to Rs. 13 to Rs. 14 per metre (only 30% costly and 300% more durable than cotton shirting if full exemption of excise duties is given. Moreover, this will be a product produced by rural people for the rural people thus saving considerable costs due to transport, octroi, traders' commission, etc.

Handloom Sector

There are over 3.5 million handlooms in the country and almost 50% of them are partially idle due to various extraneous factors not connected with the weaving skill or capacity of handloom weavers. Some of the reasons are irregular supply of suitable yarns, fluctuating prices for cotton yarn, poor market knowledge of handloom societies. Extensive development work as carried out in collaboration with the Development Commissioner, Handlooms to promote polyester usage in this sector. Apex Handloom, Societies in five States were selected for production of polyester/cotton saris and shirtings in a big way and progress so far made has been very satisfactory. Two apex societies are also producing on their own fairly large quantities of polyester blended saris and shirtings and marketing them without any difficulties.

Polyester usage in the Handloom Sector would substantially increase during the VIth Plan because of the new textile policy which envisages over

750 m.mtrs blended fabric production in this Sector. The Govt. has also given some concessions in excise duties in this year's budget. Several cooperative spinning mills have been purchased to spin suitable polyester/cotton yarns for the handloom cooperative societies in various States. With the availability of steady supplies of yarn and better marketing techniques adopted by apex societies, it should not be difficult to step up production of polyester blended fabrics in this Sector substantially over the next few years. Since polyester/cotton yarns give higher productivity than cotton on handlooms, there is enough motivation for the handloom weavers to take up its production. Combination of traditional skills of handloom weavers and the excellent properties of polyester blended yarns could provide durable fabrics of high fashion to consumers both in the domestic and export markets.

Powerloom Sector

Powerloom Sector has over 350,000 powerlooms which is more than what the Millsector has. They produce polyester blended fabrics in substantial quantities — but on conversion basis to mills and traders. There has been no organisation like Apex Handloom Cooperative Societies in this Sector to service the powerloom weavers which are run as small family units all over the country. Last year, powerloom operators from all States have formed a Federation of All India Powerloom Weavers' Association who have plans to set up their own spinning units, processing centres and research organisation to service powerloom weavers. The Government has also set up recently an All India Powerloom Board to look after the interest of these weavers. Hereagain, the Textile Policy envisages a production of 500 m. metres of blended fabrics in this sector and major share of the production will be polyester blends due to their enormous popularity in the apparel field. The Federation has planned a phased programme of production of good quality polyester blended fabrics in the leading powerloom centres.

Conclusion

Whilst the organised mill-sector in the country has benefitted by the introduction of polyester blends in their product range, the decentralised sectors can be revitalised by its usage. It is advantageous for the country to utilise enormous human resources available for yarn production in the rural areas and idle capacities of handloom sector for fabric production than making fresh investments on Capital Machinery and other infra structures in the organised mill-sector. This is possible if these decentralised sectors of the textile industry change their present production pattern and manufacture polyester blended fabrics to make their fabrics attractive, durable and easily marketable.

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Inauguration of the Demonstration Plant For Synthetic Fibres

Welcome Address by
Mr. D. N. Shroff
President, Sasmira.

The Silk & Art Silk Mills' Research Association
Sasmira Marg, Worli, Bombay-400 025. Tel: 422 5351 Grams: 'SASMIRA' Bombay-400 025.

Welcome address by Mr. D. N. Shroff, President, Sasmira at the inauguration of the Demonstration Plant for Synthetic Fibres held on 4th April, 1982.

Hon'ble Minister, Mr. Pranab Mukherjee, distinguished Guests, Ladies & Gentlemen:

It is my proud privilege to extend on behalf of Sasmira and my own behalf a very warm welcome to you, Mr. Minister, to our distinguished friends from UNIDO, from the Industrial nations, from the developed countries, to members of the Consular Corps and to other distinguished guests, who have joined us on this auspicious occasion of the inauguration of Sasmira's Demonstration Plant.

I am particularly grateful to you, Mr. Minister, for taking the trouble to come to Bombay and give us an hour of your precious time. We are all familiar with the crucial role you are playing in the affairs of the Nation. We are conscious also of the manifoid problems which have been entrusted to your care and of the numerous calls that are made on your time. The fact that you have chosen to be with us this morning is proof of the importance you attach to the development of man-made fibres and fabrics in our country and to Sasmira's role in futhering it. Your kindness to us place us under a debt of gratitude to you personally and encourage us to strive to extend and develop our work further.

The Demonstration Plant, as also the Fibre Research Laboratory attached with it, is the outcome of triangular co-operation between the United Nations Development Programme (UNDP), Government of the Federal Republic of Germany and Government of India. I take this opportunity to offer my thanks to the aiding agencies for having selected

Sasmira for this project and the assistance extended by them for putting up the plant.

The project which is about to be inaugurated has a number of unique features. The plant which has been installed is versatile. It can be used for imparting training in fibre production technology, providing technical services to the industry and conducting research on synthetic staple fibre and filament for apparel and industrial uses. I am told by my distinguished friends from abroad that such a Demonstration Plant, open to industry, research scholars and students, does not exist anywhere else in the world. It shall be our duty to do our best to optimise its usefulness to meet national requirements and to serve our friends abroad.

A special word of thanks is due to J. K. Synthetics Ltd. We owe it to Mr. Sitaram Singhania who came forward and took over the responsibility for completing and commissioning the plant. The expertise and know-how from his organisation was placed at the disposal of Sasmira and it has been possible to commission the plant in time to be inaugurated today.

For the commissioning of the staple fibre line we had taken the assistance of Chemicals & Fibres of India Ltd., and Mr. D. N. Tripathi, Managing Director of CAFI has extended his co-operation along with his technical personnel to carry out this work. I thank Mr. Tripathi, his organisation and his team of engineers for coming forward and carrying out the required work in time. In the early stages of plant erection Messrs. Nirlon Synthetics & Fibres Ltd. extended their assistance. I am indebted to them.

This renews my confidence in the competence and capacity of our technicians and engineers to contribute to the accelerated expansion of this industry in our country.

Thanks to UNIDO's initiative and generous support from the Ministry of Commerce, Sasmira has had the privilege to host an International Conference on Man-made Fibres for Developing Countries. Twelve Developing Countries were represented at this Conference. It gave to the representatives an opportunity to study the working of Sasmira, inform themselves of the enormous strides taken by industrial nations in technological innovation, exchange ideas amongst themselves on the situation in their respective areas, and put their heads together to find solutions for the problems that confront the developing world.

The Conference in all held eight sessions. My thanks are due to the Chairmen of these sessions for their wise counsel and guidance.

It gives me particular pleasure to report that at its concluding session over which Ambassador K. B. Lall, Chairman of the Indian Council for Research on International Relations presided, came to the following unanimous conclusions:

> First, man-made fibres and fabrics have an important role to play in enabling the 3rd world to meet its basic needs.
>
> Second, the developing countries have ample potential to meet the growing needs of their rising population for man-made fibres and fabrics.
>
> Third, this potential can be realised through effective triangular co-operation between the industrial nations on the one hand and developing countries rich in its raw material and technological resources on the other.

It is a source of pride for me to share with this distinguished audience the impressions of the participants, in the Conference in regard to Sasmira's work. They have been generous in applauding our success in adapting modern technology to local environment, imparting technical education and providing research and other facilities to the industry. The Conference accordingly recommended that Sasmira should consider expanding their present facilities to provide its technical and education services to other developing countries and proceed as soon as possible to elaborate the present facilities into an International Institute of Textile Technology so that developing countries become more self-reliant in meeting their basic needs.

Prof. Dr. Herman F. Mark, the world renowned polymer scientist, has been generous enough to express the view that polymer, spinning and finishing units now available at Sasmira could be used for the promotion of man-made fibres and fabrics throughout the developing world. He is also of the opinion that the value of Sasmira's services will be enhanced if a Polymer Science and Engineering unit could be added to serve the emerging technical and industrial needs of the developing countries. This would help to expand basic understanding in the 3rd world of the chemistry and physics of polymeric materials.

We in Sasmira have been greatly encouraged by the conclusions of this Conference. We would like to do our bit to collaborate with UNIDO in its effort to secure for the developing world a reasonable share in the global production of man-made fibres and fabrics. As always, we will be depending on you Mr. Minister and on the Government of India to assist Sasmira in giving practical shape to the recommendations of the Conference.

With these words, may I request you Mr. Mukherjee to inaugurate the Demonstration Plant and give us your blessings to reach the new goals set for us by the Conference.

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Inauguration of the Demonstration Plant For Synthetic Fibres

Vote of Thanks by

Mr. B. N. Kothary,

Vice-President, Sasmira.

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Vote of thanks by Mr. B. N. Kothary, Vice-President, Sasmira at the Inauguration of the Demonstration Plant for Synthetic Fibres held on 4th April, 1982.

It is a proud day for all of us in Sasmira to have Mr. Pranab Mukherjee to inaugurate the Demonstration Plant for synthetic fibres, the project which will open new vistas for the man-made fibre and textile industry in India and other developing countries.

As you are aware, we have just concluded the International Conference on Man-made Fibres for Developing Countries of which one of the objectives was to bring this project into focus with a view to encourage co-operation in the field of textiles amongst the developing countries. Whilst achieving this objective this national project has achieved international status.

We are deeply indebted to Shri Pranab Mukherjee for inaugurating the Demonstration Plant. In spite of his busy schedule and the budget session of the Parliament he has spared some time for us. I convey my grateful thanks to him on behalf of Sasmira and myself.

The project is the result of co-ordinated assistance of United Nations Development Programme and Government of the Federal Republic of Germany, Government of India and the man-made textile industry. We would like to thank the aiding agencies for their generous aid in setting up this project. In implementing this project, we have received assistance, guidance and expertise from numerous experts and organisations. I would like to convey my thanks to them and specially to Mr. R. Polgar and Mr. M. J. Priestley of UNDP, Dr. D. G. A. Butaev, Dr. H. May, Mr. M. A. Youssef, Mr. M. C. Verghese and Mr. A. Krasia. ov of UNIDO; Dr. (Mrs.) Eva Lindmann, Consul General and Mr. H. Hamm, Dy. Consul General of the Federal Republic of Germany: Mr. E. R. Biermann and Mr. Y. S. Toma of GTZ and Prof. H. Herlinger, Scientific Consultant to the Project.

In completing this project, Sasmira has been receiving unstinted support, encouragement and co-operation from Government of India, particularly Ministry of Commerce, Ministry of Industry, Department of Economic Affairs, Ministry of Finance, Planning Commission, Department of Science & Technology, the Council of Scientific & Industrial Research, and the Textile Commissioner to the Government of India. I would like to thank them all.

I take this opportunity to express my thanks to the Government of Maharashtra, Municipal Corporation of Greater Bombay, the B. E. S. & T. Undertaking, Collectorates of Customs & Central Excise for their assistance and concessions extended to Sasmira. For the implementation of the project various consultants, professionals and contractors were involved in carrying out specialised work. I thank them all.

I extend my grateful thanks to the organisations of weaving industry viz., Rayex (India) Ltd., Silk & Art Silk Mills Association Ltd., and Rayon Mills Commercial Corporation Ltd. for their generous contributions for the project.

I also convey my thanks to Messrs. J. K. Synthetics Ltd., who have rendered considerable assistance during erection and commissioning of the plant. J. K. Synthetics Ltd. worked as our National Consultant to this project. Our thanks are also due to Nirlon Synthetic Fibres & Chemicals Ltd. and Chemicals & Fibres of India Ltd., for the assistance rendered by them during erection and commissioning of the plant

Our President, Mr. D. N. Shroff has been the guiding force in bringing this project to a successful completion. He has sacrificed his time and energy in finding solutions for the numerous problems faced from time to time. In this task he has been ably assisted by the Demonstration Plant Project Committee and I convey my sincere thanks to Mr. Shroff and the members of the Demonstration Plant Project Committee.

I thank you all ladies and gentlemen for gracing this function.

My thanks to you, Sir, once again for accepting our invitation to inaugurate the Demonstration Plant for synthetic fibres.

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