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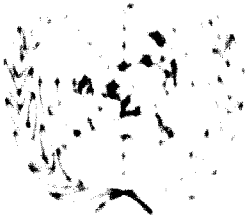
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Interim Report on the Progress of the
Development of the Petrochemical Industries in
Developing Countries

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Geneva, 1969, 2 - 11 October 1969

2

PETROCHEMISTRY AND THE MAN-MADE FIBRE INDUSTRY

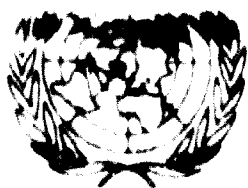
IN THE DEVELOPING COUNTRIES^{1/}

by

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SUMMARY

SYNTHETIC FIBRES IN DEVELOPING COUNTRIES 1/

by

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The whole synthetic fibre field covers nowadays a wide range of different types. Science and experience of the recent decades showed us the most preferable use of many man-made fibre in both textile and industrial applications. In the beginning best knowledgeable experts in the field of synthetic fibres worked in United States and Western Europe. Today, important work in science and technology of man-made fibres is carried out all over the world.

Due to their chemical and mechanical properties, there are four groups of synthetic fibres, which have turned out to be of outstanding importance: polyamides, polyesters, polyacrylonitriles and polyolefins. For the time being, the use of man-made fibres in the textile field

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is in fact the only important use which will concern developing countries. Textiles are second in necessity only to food as a item of consumption and their use depends directly on local standards of living. Any improvement of income is immediately reflected in the demand for textiles. On the long run, the local market offers a better potential than the export market. Meanwhile, long-term efforts are made to finance the development of local textile industries. However, since the main problem of developing countries' textile industry continues to be an acute shortage of capital in both local currency and foreign exchange.

The economic situation in a developing country makes it all the more desirable to ensure the right type of fibre for production. As there are not only varieties in the properties of the different fibres, many of them are produced both in filament and in staple fibre form.

There are two types of man-made fibres, which do enter the market in developing countries:

- Nylon-6 as bulked filament used for garments, and
- Polyester staple fibre used in blends with cotton and wool.

In both cases, usually the monomers have to be bought, while polymerization, fibre processing and finishing etc. are carried out in the country itself.

Nylon-6 shows the greatest expansion due to its relatively straight forward production at every step; processing, dyeing, finishing. The nylon-6 fibre is, because of its increasing standard of quality, the main export item in some developing countries.

Polyesters being a more difficult production process, come secondary. Used as a staple fibre in blends, the dyeing and finishing operation require much more know-how as well as different textile machinery. This is not only due to the specific properties of polyester which have to be taken into account, but also to the varying properties of the components of the chosen blend.

All the other kinds of fibres, whatever they are, stay far behind in their importance for developing countries. But seen in any other long-term view, depending upon the individual performance of economies in the various countries, acrylics in particular in form of staple fibre may soon be on the production programme.

With increasing standard of living more and more different kinds of man-made fibres will enter the production line. But, as the situation in developing lands shows, the biggest item of consumption will still be polyamides and polyesters.

This report points out:

- a) How necessary it is for developing countries to provide sound and healthy clothing conditions for their population by installing adequate man-made fiber producing units and
- b) How much petrochemistry is today the indispensable background for all synthetic textiles.

Introduction

Shelter, food and clothing have always been the basic essentials for human life at any level and, as a consequence, the industries which serve these needs have been the most important at all times and in all countries. The textile industry specifically has developed for many centuries on the basis of relatively few natural fibers but has been greatly enriched and modernized recently by the advent of a variety of man-made fibers. This report will first discuss the raw material basis of the most important man-made fibers, describe the present state of their production in developing countries and wind up with a forecast for the immediate future. Finally, a short survey on fiber characteristics will be given.

2) Raw materials for man-made fibers

All essential raw materials for the important man-made fibers come almost directly from petrochemistry. This is shown in the following list:

- 1) Polyolefin fibers are made from polyethylene and polypropylene; both polymers come directly from ethylene and propylene.
- 2) Polyacrylic fibers are produced from acrylonitrile and a few other acrylic and vinyl monomers. Acrylonitrile is today made by the oxidative ammoniation of propylene and the other monomers which are only used in 10 - 15 proportions are all based on ethylene or acetylene.
- 3) Polyester fibers are based on terephthalic acid, a direct oxydation product of para-xylene and an ethylene glycol a direct oxydation product of ethylene.
- 4) Polyamides are made from several dicarboxylic acids, all of which are obtained from propylene, butadiene or benzene, from

diamines which are also derived from the same petrochemicals and from cyclic lactams which come from benzene or cyclohexane. In fact not only the basic fiber substances but also such important adjuncts as solvents - dimethyl-formamide - and spinning fluids - diphenyl oxide - are direct products of petrochemistry.

Thus, the four largest families of man-made fibers are closely allied to oil producing and oil refining operations, a fact of great importance for integrated activities in these developing countries, which either possess oil or have ready access to it through neighbors or allies.

3) Present man-made fiber production in developing countries

It is generally agreed that developing countries should not, at this stage of development, attempt to invent new processes and products but should take over such operations and materials which are already safely established in Europe, USSR, U.S. and Japan. This concept has been realized in some 15 countries where such fibers as rayon, polyamides, polyesters, polyacrylics and polypropylenes are already in production.

The whole synthetic fiber field nowadays covers a wide range of different types. Knowledge gained during recent decades has shown the most desirable use of man-made fiber in both textile and industrial applications. In the beginning most knowledgeable experts in the field of synthetic fibers worked in United States, Western Europe, Japan and the USSR. Today, important work in science and technology of man-made fibers is carried out all over the world.

There are four groups of synthetic fibres which turned out to be of outstanding importance due to their chemical and mechanical properties.

Polyamides, polyesters, polyacrylics and polyolefines. For the time being the use of man-made fibers in the textile field is in fact, the only important one relevant to the situation in developing countries. Textiles are second in necessity only to food as an item of consumption and their use depends closely on local standards of living. An improvement of income is immediately reflected in the demand for textiles. In the long run the home market offers a better potential than the export market.

Meanwhile large-scale export earnings to finance the development of local textile industries are necessary, since the main problem of developing countries textile industries, even though to be a source shortage of capital in both local and foreign currencies.

The general situation in a developing country asked at all the more desirable to choose the right fiber type for production. There are not only variations in the properties of the different fibers but also in the form in which they may be produced whether as filament or as staple fiber.

There are two types of man made fibers, which dominate the market in developing countries:

1. nylon 6 as bulked filament used for garments,
2. polyester staple fiber, used in blends with cotton and wool.

In both cases usually the monomer is bought, while polymerization, fiber processing, finishing and the following textile processes are carried out in the country itself.

Nylon 6 shows the greatest expansion due to its relatively simple production at each step; processing, dyeing, finishing. The Nylon 6 fiber is, because of its increasing standard of quality, the main export item in some developing countries.

Polyesters, being more difficult in production process, are secondary. Used as a staple fiber in blends, the dyeing and finishing operation calls for much more know-how and for different textile machinery. This is not only due to the specific properties of polyesters which have to be considered but also to the varying properties of the chosen blend.

All other kinds of fibers, whatever they are, lag far behind in their importance for developing countries. But, seen in any long term view and depending upon the individual economic performance in the various countries, acrylics especially, the form of staple fiber will come into the production programme also.

With increasing standard of living more and more different kinds of man made fibers will enter the production line. But, as the situation in developing countries shows, the biggest item of consumption is still polyamide and polyester.

4) Trends for future developments

Whereas the present production facilities in the developing countries are based essentially on well known and firmly established techniques it is obvious and desirable that these countries are - for their future planning - well aware of existing trends to improve and modify existing processes and products. In the remainder of the report I intend to review briefly the basic principles of fiber formation and the trends which are supposed to bring us better and cheaper products in the near future.

Let us discuss the existing important fiber forming polymer families one after the other and start with the most important of them, the polyamides.

a) Polyamides

It is well known that there are several ways to influence the mechanical, thermal and applicational properties of polyamides in a definite quantitatively controllable manner.

a1) First of all there is the distance between the amide groups along the macromolecular chain in linear aliphatic polyamides such as nylon 3, 4, 5, 6, 6.6, or 11. This group produces intermolecular forces in the form of hydrogen-bonds between neighboring chains; short distances between them along the backbone chain leads to rigid, high melting and relatively insoluble products whereas longer distances produce softer, lower melting and more easily soluble polymers. For instance nylon 1 and nylon 2 do not melt at all because their decomposition temperatures are below their melting points; 4 and 5 nylon have melting points in the range of 240°C while nylon 6 and 11 melt around 180°C . There is a similar regularity with symmetric polyamides: 22 and 33 nylon have high melting points, 66 nylon is intermediate (200°C) whereas 88 and 100 nylon melt already below 200°C . The distance between the polar amidegroups in linear polyamides also effects the moisture absorption because the paraffinic polymethylene segments between the amidegroups are hydrophobic. Thus the equilibrium moisture regain of 3,4-, or 22-nylon is about 5.5% whereas the corresponding values for 6- and 66 nylon are around 3.5%. Here hydrophobic

systems like 11- and 10-nylon show less than 1,5% moisture absorption under standard conditions. It is also important that short distances between successive $-C-N-$ groups produce fibers which have high Young's moduli and good recovery from small elongations (2-3%) because of the enhanced intermolecular forces and high values of β . This all shows that particular combinations of melting point, solubility, rigidity and moisture absorption can be obtained by the selection of a suitable type of polyamide.

(2) There is next the chemical character of the chain between the amidegroups. Normal paraffinic systems $-(CH_2)_n-$ are easiest to introduce; they lead to crystalline regions with the chains in a planar zig-zag conformation which have a relative high entropy of melting because the rotations around the single $-C-C-$ bonds are only slightly hindered. When normal polyethylene segments are replaced by aliphatic or aromatic rings the molecular stiffness of the chain increases, the entropy of melting decreases and the melting point and modulus of elasticity assumes higher values. The rate of moisture absorption and of dyeability however are correspondingly reduced. Equally interesting is the introduction of methyl-substituted dicarboxylic acids like $HOC-C(CH_3)_n-CH_2-C(CH_3)_n-COOH$ or $HOC-C(CH_3)_2-CH_2-CH_2-C(CH_3)_2-COOH$ or methyl-substituted diamines. It is known from polypropylene, polyisobutylene and poly(methyl methacrylate) that methyl groups give rise to helical conformations as a result of their steric requirements. This leads to valuable mechanical properties like elastic relaxations and high resilience but also high sensitivity against solvents and reduced crystallizability. Thus it is obvious that even small chemical changes in the character of the chain segments have important consequences on mechanical and thermal properties and therefore must be carefully considered in order to obtain desired textile properties. A new family of polyamides - the Crant fibers - have just been introduced with great success on the basis of a cyclic aliphatic diamine combined with acids having between 8 and 12 C atoms.

a3) Besides the details of chain architecture which refer to every segment, there is also the influence of the chain ends, even though for a degree of polymerization of about 2×10^4 , they are not present to an extent of more than 0.2 and 0.5%. Both end groups, i.e. polyamide, $-COOH$ and $-NH_2$, are polar and hydrophilic; they enhance the moisture absorption and uptake of dyes, but are also sensitive spots for the attack of light, heat, oxygen, acids, alkali, for the occurrence of discoloration and brittleness. In order to prevent the undesired phenomena the end groups are reacted with a monofunctional acid or base, respectively, when a neutral, unreactive chain end is produced.

a4) The hydrogen atoms of the amide groups $-CO-NH-$ are relatively labile and therefore can be used for various chemical reactions of the material. Thus for instance treatment with formaldehyde gives a methylol group $-CO-N(OH_2^+)-$ for every reacting amide group. Because of the primary hydroxyl groups each of these substitutions leads to hydrophilic behaviour so that a sufficient amount of substitution finally gives water-soluble polyamides. The resulting polymers have little importance as fiber-formers but find application in other areas - films, protective coatings, etc. If the free hydroxyl groups are methylated or acetylated the hydrophobic character of the polymer is essentially re-established but now there are no longer hydrogen bonds between the macromolecules and the intermolecular cohesion is decreased. As a result the modified products are easier soluble, have lower melting points and can be spun into fibers having a low modulus of elasticity, high elongation at break and marked elastic recovery. They have been the forerunners of the pendex fibers.

a5) Besides the normal chemical grafting, polymeric chains can be grafted on linear polyamide to give branched systems. Closest to the ethylation is the grafting of polyethylene glyde-chains on the surface of the fiber through the amino end groups. The moisture and dye absorption of the material is increased without decreasing its rigidity and without much degeneration of other valuable textile properties. Much work has been done on the radiation-grafting of

acrylic - and vinyl monomers on polyamides, directed towards improvements of hand, moisture and dye absorption, and prevention of static charges. It is indeed possible to graft considerable amounts (10% and more) of acrylic acid, acrylamide, vinylpyrrolidone, and other hydrophilic monomers by means of grafting reactions to influence the above mentioned properties in a favourable sense.

a6) Another possibility to modify the properties of a given polyamide in a desired direction is to produce some cross-linking between the chain molecules, which results in a higher Young's modulus and a better recovery from moderate elongations. It can be accomplished with formaldehyde, ethyleneoxide, and other bifunctional compounds which react with the -NH-group of the polyamide chains. Variation of the degree of cross-linking and of the length of the cross-linking chains produces different properties which are of practical interest for some special applications.

a7) Many interesting results have been obtained recently by mechanical admixture of various polymers to polyamides (poly-blending). The purpose of this technique is to improve moisture and dyestuff absorption of the fibers and to diminish the accumulation of static charges. Accordingly one usually blends hydrophilic systems like polyethyleneoxide, poly(vinyl alcohol), polyacrylamide or polyacrylic acid with the polyamide melt under assistance of surface active agents.

a8) An important development in the technology of polyamides is systematic use of certain additives for the prevention of:

1. Discoloration of the material during polymerization, extruding and spinning.
2. Decrease of viscosity during extrusion.
3. Discoloration of the finished fiber by heat, light, and repeated washing processes.
4. Decrease of tenacity during use especially in the presence of acid, alkali, heat, light and oxygen.

There are many types of effective stabilizers, e.g.

1. Arylated and alkylated phosphines.
2. Arylated and alkylated derivatives of phosphorous and hypophosphorous acid, especially salts of certain heavy metals like Cu, Sn, Pb, etc.
3. Iodides of potassium and of quaternary ammonium bases in the presence of reducing organic salts of elements like Cu, Sn, Pb, and Fe.
4. Alkylated phenoxides of the elements Sn, Pb, Zn, Cd, and Fe.
5. Epoxy compounds which contain metal salts of carboxylic or sulfonic acid groups but which are soluble in the polyamide matrix.

The use of these stabilizers enables practical realization of certain important processing steps like heat-setting, cross-linking or radiation-grafting without any undesired deterioration of the material.

b) Polyesters

The possibilities for a systematic improvement of polyester fibers are in general similar to those for polyamides. However, an important difference must be taken into account: instead of $-CO-NH-$ (amide-) groups we have $-CO-O-$ (ester-) groups which contain no H-atom, and can therefore not produce inter-molecular hydrogen bonds or be replaced by organic substituents. Again a systematic change of melting point and solubility is effected by the distance between the ester groups in the macromolecules. The 1-polyester, i.e. polymeric anhydride of carbonic acid, $-CO-O-CO-O-$ has not yet been prepared, but W.H. Carother's fundamental work has shown that the 2-polyester, $-CH_2-CO-O-CH_2-CO-O-CH_2-CO-O-$ is poorly soluble and melts above $200^{\circ}C$; carbonates and oxalates of the low glycols are also difficultly soluble and melt between $150-200^{\circ}C$. But adipates and sebacates of most glycols are easily dissolved and soften below $100^{\circ}C$. The generally higher melting points of polyamides are understandable as a consequence of the lateral hydrogen bonds, each of which has a dissociation energy of about 5 kilocalories per mole while the dissociation energy of the dipolar ester bonds amounts only about 2.5 kilocalories per mole. As with polyamides the introduction of cyclic elements leads to higher

melting and more difficultly soluble products an effect which was first discovered by Carothers with polyesters of para-xylyleneglycol and oxalic acid. Later it was utilized technically with great success by T. Whinfield through the systematic use of terephthalic acid in polyester fibers.

Nowadays a series of polyester fibers with alicyclic and different aromatic components are under development or already on the market. In general, they represent a technical progress over the homopolymeric fiber and cover wider fields of application in a desirable manner. It was also found that the introduction of longer flexible chains between the stiff cyclic units results in higher solubility and lower softening points. Thus polyesters of terephthalic acid and octa- or decamethylene-glycol melt below 15 °C. Most fiber-forming polyesters have only hydroxylic end groups which have neither acidic nor basic character and are accessible with difficulty because of the highly crystalline character of the material; this leads to a moisture absorption of only about 2.5% in drawn polyester fibers which is much less than that of the corresponding polyamides like nylon-6 and 66.

Chemical substitutions in the monomers of polyesters have interesting and far-reaching consequences. Methyl groups in aliphatic polyesters reduce the free rotation of the links of the chain and lead to lower solubility and higher softening ranges. In the special case of poly (hydroxy pivalic) acid they also bring about the preference of helical conformation, i.e., an enhanced resilience in the range of low elongations (3-5%).

Many other modifications and changes which have been discovered for polyamides cannot be easily applied in the polyester field because of the intrinsically greater hydrolytic sensitivity of the ester bond as compared with the amide bond. As a consequence systematic research has been initiated to find effective stabilizers for polyesters against hydrophilic degradation. Many compounds have been tested and it seems that the linear dimers and oligomers of isocyanates of the form R-N=C=N-R have a noticeable stabilizing effect and might present new modifications and uses of polyester fibers.

c) Vinyl-and Acrylic Polymers

The third large group of prominent synthetic fiber-forming materials consists of addition polymers of vinyl - and acrylic compounds with acrylonitrile as most important compounds. These polymers and copolymers are made from monomers, the costs of which are considerably below those of the monomers for polyamides and polyesters. The polymers are produced by very simple and inexpensive processes in suspension or emulsion and can be varied over a very wide range of properties without additional costs or complications. At present all fibers of this type are spun from solutions of 25-30% either in a dry cell or in a bath. After that they are stretched at elevated temperatures, washed and dried.

Many chemical and physical procedures are at the disposal of the chemist who is confronted with the problem to modify polyacrylonitrile fibers in a desired manner. These procedures differ from those available for polyamides and polyesters because of the different mechanism of addition polymerization. In general there are more choices for modification than with the condensation polymers. There is, first, the molecular weight distribution, which can easily be modified by the use of appropriate initiators, accelerators, chain transfer-agents, and by the temperature. Thus it is possible to produce broader and narrower distribution curves as the occasion demands. It is even possible to obtain polymers for which the molecular weight distribution function shows two or more maxima, which represents an interesting new degree of freedom in the preparation and application of such polymers compared with condensation polymers. Another advantage of addition polymers lies in the freer choice of end groups, which, for condensation polymers, are essentially limited to Cl , NH_2 , and COOH . In addition polymers they can be varied over a wide range of chemical character by the use of suitable telomers.

The fact that with addition polymers cross-linking can be produced and even controlled to a large extent, makes it possible to use macromolecules with more than two end groups, a technique which permits to enhance the influence of certain end groups chosen for particular reasons. In general, acid end groups are preferred because they favorably affect the absorption of dyes and improve the stability of the

fiber against discoloration by heat and chemical reagents.

The greatest and most valuable property of addition polymers is the almost limitless possibility for modifying their behaviour by copolymerization. Whereas only moderate improvements can be obtained with polyamides and polyesters by this method, the entire technology of vinyl - and acrylic fibers is based on the systematic use of copolymerization. The main component is usually acrylonitrile but the homopolymer itself is so sparingly soluble and its solutions are so unstable that spinning is very inconvenient. Therefore comonomers are introduced in the polyacrylonitrile chain which improve the solubility without disadvantageous effects on other properties such as softening temperature, rigidity and resistance to swelling in water and organic solvents even at elevated temperatures. Monomers of this kind include vinylacetate, methylacrylate and cyclohexylacrylate. The next problem is to control the properties of the fiber and to attain favorable dyeability. This is accomplished by introduction of acidic or basic monomers like vinylsulfonic acid, vinylpyridine and many others which can be varied widely in composition and concentration. If there is need for a softer hand of the fiber after satisfactory attainment of mechanical and tinctorial properties this can be largely fulfilled by copolymerization with small quantities of vinyl stearate or stearyl acrylate. Finally it is possible to introduce active centers for cross-linking reactions by the introduction of suitable monomers like glycidyl acrylate or divinyl ether which after cross-linking increase the softening range of the fiber and influence its elastic behaviour in a favorable way primarily with respect to enhanced resilience, improved recovery power and crease resistance. Thus it is likely that the near future will see fibers of the acrylic type containing three or more monomers with resulting favorable influence on the properties of the products.

Just as one can introduce by copolymerization monomers with the capacity for cross-linking, one can also introduce suitable centers for graft polymerization and obtain favorable properties with addition polymers in an especially effective way.

5) Fiber characteristics

A subject of outstanding practical importance lies in the successful use of synthetic fibers for textile purposes. It is essential that certain fiber characteristics should be understood in order to design fabrics with specific reference to the final wear or usage purposes. These data are given in the following paragraphs with special emphasis on those fiber groups which are for the time being of importance for developing countries.

a) Polyamides

Nylon 6 and nylon 66 are mainly distinguished by their melting point. All other properties show no important differences. The melting point of nylon 6 is 216°C while nylon 66 melts at 256°C .

The tenacity of 4-5.8g/den for nylon 6 and 7.5 - 6.3g/den for high tenacity yarn is very high. The tenacity of staple fiber is somewhat lower, 3.5 - 5.5g/den. This very high breaking tenacity combined with an outstanding abrasion resistance makes the nylon fiber useful in both the textile and industrial field.

The elongation of polyamides varies between 16 - 50%, depending on the fiber type. As is the case with all synthetic fibers, staple fibers have the lowest grade of tenacity and the biggest elongation, while filaments, and here again high tenacity filaments due to their processing are of the highest tenacity value and lowest elongation percentage.

The elastic properties of polyamides are excellent and in most types a stretch of up to 8% will be fully recovered within one minute.

The Heat resistance is very similar in both the dry and wet stage and shows, when observed over a long time, average degradation. The fiber turns slightly yellow to brown when heated in dry air.

The degradation by action of light is similar to that of other textile fibers. The bright nylon fiber is of better resistance than the semidull one.

The chemical resistance of nylon is extremely good. Dry cleaning solvents normally used do not affect it. Nylon dissolves in formic acid, phenol and cresol.

The moisture absorption is 4 - 5% at 21°C and 65% relative humidity.

Due to its outstanding physical and chemical properties, the use of nylon covers a wide field in both the industrial and textile areas. Nylon is used as a cord in car tires and in aircraft tires. It is often the basic fabric in polymer-coated tarpaulins. It is also extensively used in the fabrication of industrial filter cloths and nets. In the field of high tenacity textiles nylon 66 has some advantage due to its higher softening point and its greater resistance to deformation under heavy loads.

In textile applications it is especially used in ladies stockings and hosiery. The heat setting properties of nylon make it possible to set the stockings in the desired shape which is then retained indefinitely in use.

The development of texturized yarns opened a new mode of application in apparel. The bulked yarn is used in the weaving and especially in the knitting fields. The use of texturized nylon filaments in carpets is steadily growing.

Blending the staple fiber with wool gives yarn with improved abrasion resistance and tenacity. As both fibers are of polyamide character and have similar elasticity properties, the spinning and dyeing process of such a blended yarn shows no difficulties.

a2) Polyester

The melting point is 256°C, the temperature range over which the fiber softens and melts is very narrow.

The tenacity of regular filament is between 4.4 - 5.0g/den, while high tenacity filament yarn ranges between 6.3 - 7.8g/den. It is therefore of less strength than polyamide fibers, but nevertheless of very high tenacity.

The elongation of polyesters ranges from 19 - 36%. Regular filament usually has an elongation at break of 19 - 25%; high tenacity filament has elongation from 10 - 12%, while staple fibers show 25 - 36%.

The work recovery properties of polyesters are very similar to wool, both fibers producing fabrics with excellent resilience.

The heat resistance of polyester fibers measured after days of exposure to high temperatures shows a very different behaviour due to

the chemical composition of the material under wet and dry conditions. Polyesterfibers exposed for 120 days to dry heat of 120°C show no decrease of strength. The same material, kept under saturated steam of the same temperature, is disintegrated completely after 5 days, the ester being hydrolyzed. Heating in dry air causes very little discoloration of the fiber.

The chemical resistance is different compared with polyamides. Polyesters have an outstanding acid resistance, but are relatively easily attacked by stronger alkalis at room temperature, being disintegrated in boiling alkaline solutions.

The resistance against dry cleaning solvents is generally good. Polyester has an excellent resistance to bleaches and other oxidizing agents.

The moisture absorption depends on type and varies between 0.4 - 0.8%. This very low water content makes the dry and wet state of behaviour of polyesters in its stress - strain relations remarkably similar.

The end-uses of polyester fibers are in the textile apparel and industrial field. In the making of garments it is used 100% pure and in blends with other fibers. Blended with cotton it improves the performance of cotton without destroying its character and comfort. Blended with wool, it compensates for the inadequacies of wool without detracting from wool's natural advantages.

It works equally well with other man made fibers as rayon, nylon and the acrylics.

The acceptance of polyester fibers is due to improved resistance to wrinkling and to crease or pleat retention during wet weather conditions. Wash and wear fabrics of polyester in blend or 100% synthetic opened up a vast market. Knitted fabrics, made of texturized polyester filament have become of outstanding importance.

Because of their resistance to stretch and rot, their strength and recovery properties, polyester fibers occupy an increasingly important position in the industrial market. Some principal uses are in tire cords, fire hose, safety belts, filter cloths, industrial felts, conveyor belts and as reinforcements in plastic sheets.

a3) Polycrylics

Polycrylics are not easily classified under a single conception. Their properties vary significantly depending on their chemical composition and spinning process. The differences in chemical composition are due to the varying content of modifier combined with acrylonitrile and its chemical constitution. The modifier can be nonionic, acidic or basic and the different manner of incorporating it produces a complex field of fibers.

Widely different fiber properties are also obtained by several kinds of spinning methods. Dry spinning from organic solvents produces a cross section in dogbone structure. Wet spinning from organic solvents produces fibers with different properties depending on whether water is used as coagulant; wet spinning from aqueous salt solutions produces the most different properties, this process producing the most varieties.

Polycrylics do not melt, their sticking range is between 190-240°C.

The tenacity of staple fibers is 2.2 - 3.2g/den.

The elongation is 2% - 3%.

The heat resistance is very good in the dry state and in saturated steam at elevated temperatures. Polycrylic fibers exposed for 120 days to dry heat at 120°C show no decrease in tensile strength, but are ultimately disintegrated after 60 days exposure to saturated steam of the same temperature. Polyacrylonitrile fibres exposed to higher temperatures discolour rapidly, turning brown to darkbrown, especially when heated for a long time.

Comparing the heat resistance of polyamid, polyester and polyacrylonitrile, polyacrylonitrile is the most resistant fiber under combined wet and dry temperature conditions up to 120°C. Polyester fibers retain their strength under dry conditions, but loose it rapidly in heat and moisture. Polyamide fibers show a relatively poor heat resistance under the above mentioned conditions both in wet and dry state when exposed through several weeks.

The chemical resistance of polyacrylonitrile is very good. The fiber is neither attacked by weak alkalis nor by mineral acids. Dry

cleaning solvents do not affect it and it is not harmed by oils and greases.

The action of light and weathering does not cause deterioration of initial fiber properties. Thus the polyacrylonitrile fiber is preferred for use in outdoor applications, where polyamides and polyesters are less suitable due to their lower weathering resistance.

The moisture absorption is 1 - 1.5% at 21°C and 65% relative humidity.

Polyacrylonitrile fibers are outstanding in their ability to maintain their fatigue resistance. In spite of lower tenacity and abrasion resistance they will in many cases outlast fibers which originally are superior in these properties but are deteriorated by sunlight, bacteria or chemical attack.

Polyacrylonitrile fibers have a combination of desirable properties, making them important in the industrial field and for apparel as well. The low tendency to pill, good wrinkle recovery, resistance to hole melting, a low rate of creep, low tendency to retain soil and stains combined with low fiber swelling make the fiber of extensive use in garments. As polyacrylonitrile fibers provide warmth with minimum weight light-weight fabrics can be constructed. These fabrics have a warm dry hand and are pleasant next to the skin. The thermoplasticity makes possible differentially shrinkable staple which is adaptable to the "high bulk" process, thus intensifying the wear properties of garments.

The end-uses are in the textile and industrial field. High left acrylic yarns dominate the knitted outerwear field. Such yarns are made by combining yarns of different shrinkage characteristics following exposure to steam or immersing in boiling water. Differential shrinkage causes buckling of the non shrinking fibers and forms an exceptionally lofty yarn.

Blending the staple fiber with wool enhances the washability, crease retention and nonfelting properties of the natural fiber.

The use in home furnishing is steadily increasing.

The industrial applications of polyacrylonitrile fibers are based on its good average chemical and heat resistance. The fabric is used in filter cloth, protective clothing, dust bags and many other purposes, where its special properties give it advantages over other textile fibres.





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