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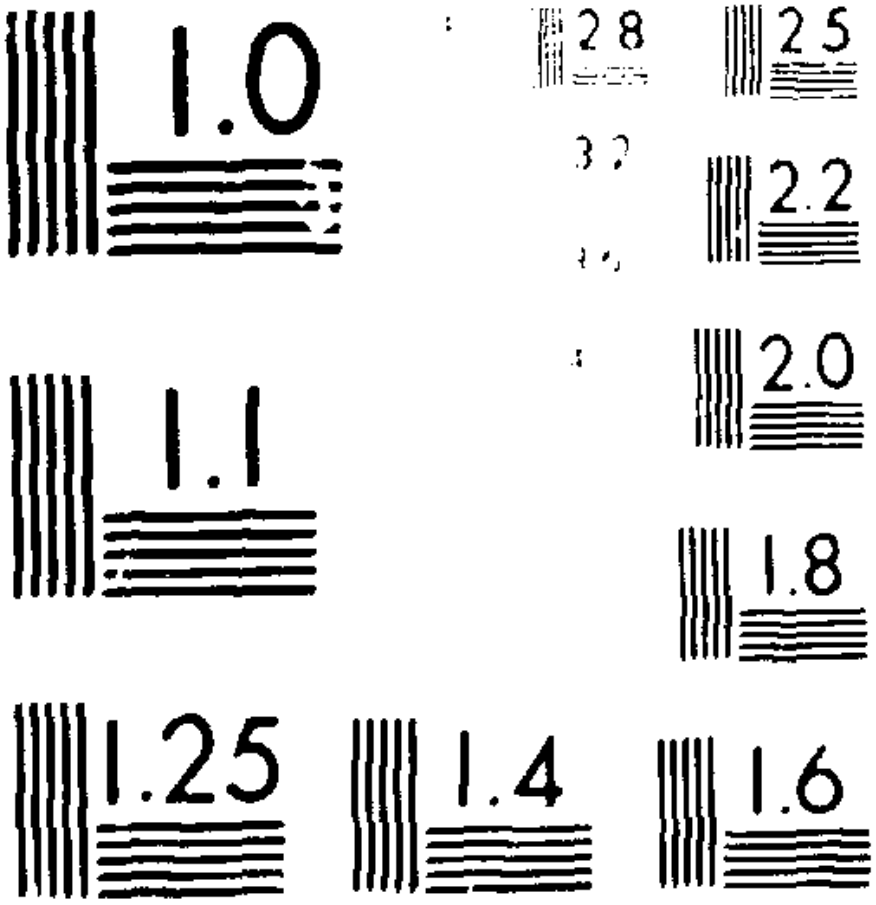
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POLYPROPYLENE FIBRES

VII

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09725

CONTENTS

1. The Polymer
   1.1. Raw materials
   1.2. Production process
   1.3. Properties of polypropylene
      1.3.1. Molecular properties
      1.3.2. Physical properties of PP in solid and molten state

2. The Fibres
   2.1. Types of PP fibres
   2.2. Fibre production processes
      2.2.1. Fibres from film
      2.2.2. Melt spinning
         2.2.2.1. Monofilaments
         2.2.2.2. Multifilaments
         2.2.2.3. Staple fibres
         2.2.2.4. Spunbonded fabrics
   2.3. Fibre additives and processing agents
      2.3.1. Stabilisers
      2.3.2. Pigments and dye-assistants
      2.3.3. Flame retardants
      2.3.4. Lubricants
   2.4. Fibre properties
      2.4.1. Parameters determining fibre properties
      2.4.2. Mechanical fibre properties
      2.4.3. Thermal properties
   2.5. Fields of application
      2.5.1. General application scheme
      2.5.2. Special fields of application
         2.5.2.1. Tufted carpets
         2.5.2.2. Needlefelt carpets
         2.5.2.3. Applications of low denier fibres
         2.5.2.4. Geotextiles and civil engineering

1. THE POLYMER

1.1. Raw materials

The raw materials for industrial production of polyolefins are petrochemically produced olefins. In most cases light naphtha is converted into several gaseous olefins by a steam cracking process at temperatures from 700 to 900°C. According to the conditions of the process, varying amounts of unsaturated products which are suitable for polymerization, are obtained (Table 1).

Table 1 - Olefin products of the steam cracking process

Number of C-atoms	Name	Chemical structure
2	ethylene	$CH_2 = CH_2$
3	propylene	$CH_2 = CH - CH_3$
4	butene-1	$CH_2 = CH - CH_2 - CH_3$
4	cis-butene-2	$CH_3 - CH = CH - CH_3$
4	trans-butene-2	$CH_3 - CH = CH - CH_3$
4	iso-butene	$(CH_3)_2C = CH_2$
4	butadiene-1,3	$CH_2 = CH - CH = CH_2$

For the production of fibres propylene polymers are most important. Polyethylene is also used for fibres to some extent. Polymers of higher olefins ($\geqslant C_4$) are basic materials for plastics and elastomers but not for fibre production.

The world-wide consumption of polypropylene is shown in Table 2. From these figures one can see that there is still an increase of production which perhaps will be somewhat slowed down by the recent situation of the petrochemical industry.

Table 2 - Consumption of polypropylene (1000 tons)

	1965	1970	1975	1977	1979*	1983*
World	310	1350	2400	3500	4000	
USA				1100	1400	
Japan				550	645	
Western Europe				900	1100	1700
Eastern Europe				160	243	419

* estimated

1.2. Production process

The polymerization process for polypropylene involves four major steps:

catalyst preparation
polymerization
polymer purification
polymer finishing

(see flow sheet Figure 1). First the coordination catalyst (Ziegler-Natta-catalyst) containing $TiCl_3$ and $Al(et)_2Cl$ is formed. Then catalyst slurry, purified propylene and hydrocarbon diluent (hexane or heptane) are fed into the reactor, where polymerization takes place at pressures of approx. 10 bars and temperatures between 50 and 75°C. A polymer slurry is obtained, containing 30 % insoluble isotactic polymer.

The diluent with soluble atactic PP is removed in a first centrifugation step; in the following second centrifugation PP is purified by washing with alcohol (removal of catalyst residues). After that the polymer is dried, mixed with additives, molten, extruded and pelletized.
The end-product is pelletized isotactic polypropylene, a linear polymer of high crystallinity, a melting range between 165° and 170°C and a density of 0,91. The molecular weight is controlled in the process by hydrogen which acts as chain transfer agent.
As a by-product 5 - 10 % of atactic polypropylene, a soft and sticky compound of amorphous PP is obtained. It is used for hotmelts, carpet backing, and in mixtures with asphalt (to reduce breaking of asphalt at low temperatures).

1.3. Properties of polypropylene

1.3.1. Molecular properties

As everybody knows from primary lessons of organic chemistry, polypropylene can occur in three different modifications (Picture 2):

Isotactic polypropylene is a linear polymer carrying all methyl substituents in identical positions on one side of the chain.

Syndiotactic polypropylene carries the methyl groups in alternating positions, but is only of theoretical interest.

Atactic polypropylene with substituents in irregular random positions.

Due to the regularity of its structure isotactic PP is able to form crystalline structures (in contrast to atactic PP). The molecular weight of PP is in the range between 150000 and 600000 for commercial products. A commonly used measure for the molecular weight ($\bar{M}_w$) is the melt flow index (MFI). It is the weight of polymer flowing through a standardized

capillary under standard pressure and standard temperature. The relation between molecular weight and MFI is shown in table 3.

Table 3 - Relation between $\bar{M}_w$ and MFI for isotactic PP

MFI	0,2	1,0	2,0	5,0	10	20
$\bar{M}_w \cdot 10^3$	650	450	400	300	250	200

For the production of fibres a comparatively low molecular weight range is used: 150 000 - 300 000 (MFI 5 - 30).

It must be said that PP, like all other polymers, does not have a well defined molecular weight but a rather broad molecular weight distribution. Therefore, instead of molecular weight and number of monomer units average figures are given, like weight average $\bar{M}_w$ and number average $\bar{M}_n$.

$$\bar{M}_w = \frac{\sum N_m M^2}{\sum N_m M} \qquad \bar{M}_n = \frac{\sum N_m M}{\sum N_m}$$

N_m ... number of molecules of molecular weight M

$\bar{M}_w$ is by definition larger as or equals $\bar{M}_n$; the ratio $\bar{M}_w/\bar{M}_n$ is commonly used as a measure for the width of the molecular weight distribution.

1.3.2. Physical properties of PP in solid and molten state

The geometrical regularity of isotactic PP-chains permits them to crystallize, i.e. to arrange themselves in regular helical conformations as shown in Figure 3. These helices aggregate to form crystallites with monoclinic unit cells. These crystallites in turn aggregate to produce spherulites (Figure 4).

The size of the spherulites depends on the conditions of crystallization and may range from a few microns (rapid cooling) to several millimeters (slow cooling). The structure of the crystallites is shown schematically in Figure 5. This figure shows the folded polymer chains (helical structure), the crystallites (lammellae) and non crystalline zones (tie molecules).

PP never consists of 100 % crystallites because there are always amorphous zones and tie molecules linking the crystallites. The actual degree of crystallinity can be measured by X-ray methods or by density measurements and may range between 30 and 80 %.

Spherulites and crystal lamellae in an unoriented film or filament are transformed into fibrillar crystallites in the course of cold deformation (drawing process) as shown schematically in Figure 6.

The most important thermal parameters of PP are shown in Table 4. Most properties depend on thermal history (degree of crystallinity), molecular weight, residual content of atactic polymer etc.

Table 4 - Thermal properties of polypropylene

Parameter	Unit	
Melting range	^{o}C	165 - 175
Density	(g/cm^3)	0,90 - 0,92
Heat of fusion	(cal/g) *)	39
Heat capacity	$cal/g/^{o}C$	0,45
Thermal conductivity	$cal/cm.sec.^{o}C$	$3 - 6 \cdot 10^{-4}$
Thermal expansion coeff.	^{o}C	$6 - 10 \cdot 10^{5}$

*) for hypothetical 100 % crystallinity

The flow behaviour of molten PP is of fundamental importance for the processing (spinning). PP-melts are non-Newtonian liquids, that means that they show so-called "pseudoplastic" flow (viscosity is not constant but a function of the shear rate). (Figure 7)

2. THE FIBRES

The development of the total world production of textile fibres is shown in Table 5.

Table 5 - World production of textile fibres (1000 t)

	1975	1977	1979*	1981*	1983*
Polyester	3370	4200	4770	5240	5770
Polyamide	2470	3000	3280	3500	3720
PACN	1400	1800	2030	2230	2360
Polypropylene	400	540	630	730	830
Other synthetic fibres	110	140	150	170	200
Cellulosic fibres	2960	3290	3700	3900	4150
Lain	1490	1260	1360	1470	1590
Cotton	11800	13400	14650	14940	15240

*) estimated

From these figures it is evident that polypropylene fibres, being a rather 'young' product, have a rather small part of the total synthetic fibre production. But as PP fibre production is a comparatively simple process, raw materials (although being based on crude oil) easily available importance of this fibre will still increase in the near future.

2.1. Types of PP-fibres

Basically we distinguish the following types of PP-fibres:

a) Monofilaments (30 - 1000 dtex+), corresponding to a diameter of approx. 7 to 40 microns)

+) dtex is a measure for fibre thickness and means weight of 10 000 m of filament in grams (also the unit 'denier' is used, meaning weight of 9000 m).

b) Multifilaments (continuous) with an individual titer between 3 and 17 dtex
c) Staple fibres (individual titer between 1,7 and 200 dtex)
d) Spunbonded fabrics

Types b and c can be made by two different processes:

1. from film (flat or profiled)
2. by melt spinning

Types a and d are produced by melt-spinning processes.

2.2. Fibre production processes

2.2.1. Fibres from film

Essentially two techniques have been developed in this area:

a) splitting of oriented film by mechanical fibrillation
b) splitting of oriented profiled film

The fibrillation processes have two advantages compared with conventional melt spinning: Costs for the production plant are low, giving attractive economics even at low production levels (minimum capacity approx. 500 t/year) and the requirements concerning polymer quality are not as restrictive as in conventional melt spinning processes.
In mechanical fibrillation the first step is the film formation (usually blowing), followed by drawing (ratio 1:8), annealing and fibrillation by passing over rotating pin rolls.
The cross section of split film fibres is essentially rectangular in contrast to most melt spun fibres, which have round, triangle or multilobal cross section (Figure 8).
In the "Barfilex" process the melt is extruded through a profiled die, giving a film consisting of parallel longitudinal ribbons; by stretching this film splits at the thin interconnections between the ribbons and thus gives continuous multifilaments. (Figure 9)

In the roll embossing process the profiling of the film is made by a set of two rolls. One of them is embossed with a pattern of fine grooves, the other one serves as a pressure roll.

2.2.2. Melt spinning

By melt spinning all four types of PP-fibres mentioned in section 2.1. can be obtained. The production techniques (spinning and processing) are essentially similar to those already developed for melt-spinning other synthetic polymers, like polyamide and polyester. They always include the following stages:

1. Melting of polymer (extruder or melting box)
2. Fibre-forming by spinnerets or die-plates
3. Cooling of filaments
4. Drawing
5. Heat setting
6. Texturation (in case of bulked fibres).

2.2.2.1. Monofilaments

A typical extrusion assemblage for monofilaments is shown in Figure 10. The temperature of the quench bath influences the degree of crystallinity; drawing ratio is usually between 1:4 and 1:10 to obtain appropriate strength. After leaving the final set of pull rolls the filament is annealed by raising the temperature and permitting a limited retraction (heat setting) thus stabilizing the filaments against shrinkage at higher temperatures.
Addition of foaming agent (e.g. azodicarbonamide $H_2OCN = NCONH_2$) which decomposes at certain temperatures (splitting off nitrogen), produces bulky filaments with densities down to 0,5 g/cm^3.

2.2.2.2. Multifilaments

The conventional process for spinning multifilaments differs in some respects from that used for monofils, and resembles that normally used for polyamide. A typical assemblage is shown in Figure 11. Polymer pellets are molten in a screw extruder, the melt passes through screen packs into the spinnerets by means of metering pumps (spin pumps). The spinning temperature for PP lies between 230 and 300°C. The spinnerets may have several hundred capillary holes (0,5 to 1,2 mm diameter). These holes have, as already mentioned, round, triangular, trilobal or other cross sections (Figure 8). The filaments are quenched by air under controlled conditions in a long cooling zone. Air quenching is sufficient because of the low filament diameter in contrast to thick monofilaments (where a water quench tank is necessary).
The filaments are taken up by godets at speeds up to 1500 m/min. At this stage they are still essentially unoriented in spite of the draw between spinneret and godets (approx. 1:10). Filament bundles of several spinnerets are wound up on one winding unit to give bobbins.
The drawing of filaments (orientation) is conventionally done in a separate step at lower speeds. For commercial multifilament yarn the bundles are drawn under heating (heated metal plates) at draw ratios between 1:4 and 1:6. In most cases the drawing is combined with a second process that can be twisting (in case of unbulked fibres) or texturizing.
Draw twisters combine the twisting with the drawing operation. A schematic diagram of such a machine is shown in Figure 12. The essential drawing section with heating plate can be seen in the centre.
Yarn for carpet manufacturing and other textiles need a bulky structure which they get by a texturizing process. Several of these processes are known:

Stuffer box: Filaments are transported by godets into a heated stuffer box at speeds up to 500 m/min. The stuffing

of the filament bundle in the box produces a wavy or zig-zag crimp. A schematical view of this process is shown in Figure 13. The bulk is stabilized by heat (heat set) in the box.

Air or steam jet process (Taslan), false twist process or self-curling process (bicomponent spinning) are also used for the production of BCF yarns (bulked continuous filaments). In recent developments drawing and texturizing is done in one step at speeds up to 1500 m/min.

High speed spinning: In order to reduce capital investment and to improve economic conditions, high speed spinning has been introduced for polypropylene, too. Production of pre-oriented yarns (POY) have already a longer tradition for PES and PA.
High speed spinning covers the range between 2000 and 8000 m/min. The upper limit is reached under experimental conditions, ordinary production speeds are between 3500 and 4500 m/min. There are two alternatives in high speed spinning:

a) direct take-up on a winding system
b) take-up by godets

with direct take up being more economic. The essential feature of high speed spinning is the orientation effect in the polymer melt before winding, that replaces subsequent drawing processes. The dependence of fibre properties on spinning speed is shown in Figure 14.

2.2.2.3. Staple fibres

Staple fibres are also produced by several different processes; the most important ones will be discussed.

Conventional processes: The melt spinning process for staple fibre is somewhat different from that used for multifilaments. A typical assamblage is shown in Figure 15.
There are also screw extruder and metering pumps. The spinnerets however contain up to 12 000 capillary holes

arranged in a rectangular fashion. In Figure 16 a plant with six spin positions is shown, each of them equipped with four spinnerets. The filaments are cooled by air, collected to a tow and in this form deposited in can feeders. Further processing is shown in Figure 17. The tows from 40 - 60 cans are combined on a creel and then drawn (hot air, steam or hot plates), crimped in a stuffer box, cut (40 - 150 mm according to end use) and pressed into bales.

Compact spinning plants: Recently compact spinning plants have been developed which allow very economic production even at small quantities. Spinning, drawing, texturizing, heatsetting and sometimes even cutting is done in one line at low speed (up to 25 m/min).
One process of this kind, already known for a longer time, is the Mackie process, shown in Figure 18. The polymer is fed into a melting box (there is no extruder), the melt is forced upwards by a pump through the die plate (6000 to 12 000 holes). In Figure 18 three spin positions, each of them with two die plates are shown. The filaments are combined to a tow which is drawn in a hot water tank, dried and heat set in a hot air oven, crimped in a stuffer box and deposited in can collectors from which the tow is lead to a cutter in a separate step.
These simplified procedures require less investment and operating costs than conventional spinning plants.

2.2.2.4. Spunbonded fabrics

The polymer raw material is molten in an extruder (see Figure 19), metered through the spinnerets by spin pumps; the filaments are cooled and subsequently drawn in a still molten state by high speed air jet streams (up to 4000 m/min); an electrostatic charge of the filament produces repulsion and spreading after leaving the ducts. The filaments are deposited as a random network on a perforated conveyor belt which moves at a speed of approx. 20 m/min and onto which the filaments are pressed by air suction.

The essential aspect of this process is that the filaments are drawn in the molten state and therefore, do not reach as high a degree of orientation as filaments drawn in solid state; but the tenacity is sufficient for the usual applications. The range of titers of individual filaments can be varied between 1,7 and 30 dtex; the weight of the spunbonded network can be varied between 50 and 1000 g/m^2. After deposition of the network on the conveyor belt bonding must be achieved by one of three possible techniques: needle-punching (200 - 400 punches/cm^2), heat sealing or chemical binders (synthetic latex).

2.3. Fibre additives and processing agents

2.3.1. Stabilizers

In practical use polypropylene fibres are subjected to degradation which leads to loss of tenacity and elongation. Two reasons can be found for that: Thermal oxidation and photooxidation.

Thermal oxidation occurs in the presence of oxygen at elevated temperatures. It leads to uptake of oxygen and to chain degradation by means of a radical chain reaction. To prevent this degradation stabilizer systems, in most cases combinations of antioxidants (e.g. hindered phenols) and peroxide decomposers are used. With combinations of this type good heat stability at processing temperatures up to 300°C can be achieved.

Photooxidation on the other hand occurs in the presence of oxygen and UV-light (300 - 400 nm) even at ambiant temperatures. It also involves oxygen take up, chain degradation and embrittlement.

Stabilization can be achieved by addition of small amounts of UV-absorbers, quenchers and radical scavengers (energy transfer agents), or combinations of both. By these stabilizers the light stability of polypropylene is so much increased that PP fibres can be used for out-door applications.

These stabilizers are applied as pre-mixtures (masterbatches) which are added to the polymer pellets before extrusion.

2.3.2. Pigments and dye-assistants

PP as a paraffinic hydrocarbon contains no reactive functional groups on which dyestuffs can be properly anchored to provide lightfastness, resistance to crocking, laundering and dry cleaning. Dyeability can be improved by various methods: Grafting (by chemical techniques or by irradiation) of vinyl pyridine onto the polymer chain or addition of dye receptors such as polyvinylpyridine or organic Ni-compounds. These measures are also used for improving printability.

Because of these difficulties in most cases melt-dying is used to produce coloured PP-fibres. Finely dispersed pigments offer a broad range of colour shades with good fastness properties. The most commonly employed technique uses pigment concentrates (masterbatches) which are compounded with the undyed polymer before final extrusion. In Table 6 some examples for commonly used pigments are given.

Table 6 - Pigments for PP-fibres

Colour	Pigment	Type
black	carbon black	o
blue, green	phthalocyanine	mc
red	cadmium	io
	quinacridone	mc
yellow	azo-compound	o
	cadmium	io
white	TiO_2	io

o . . . organic
io . . . inorganic
mc . . . metalchelate

2.3.3. Flame retardants

Flammability is an important property of fibres and plastics for safety reasons and becomes increasingly important in view of more and more severe international legislative measures, particularly in the area of home textiles.
PP burns in the absence of flame retardants but is not readily ignitable inasmuch it shrinks, melts and draws away from the flame. But once set on fire, it is not selfextinguishing. Therefore, the application of flame retardant systems have been developed which contain various components such as organic re-retardant (N-, Br- or Cl-compound), an inorganic synergistic component (Sb_2O_3) and a metalorganic acid scavenger. This formulation represents a complex system with high efficiency in respect to flame retardance without reducing desirable textile properties.
Flame retardant systems are also mixed with the polymer before fibre extrusion.

2.3.4. Lubricants

The processing of synthetic fibres requires the application of lubricants or lubricant systems. The purpose of these lubricants is as follows:

1. Reduction of friction
   a) between individual filaments
   b) between filaments and machine components
2. Avoiding static electricity in processing
3. Holding together individual filaments in untwisted yarns and tows
4. Improvement of textile properties (feel, soiling, etc.)

Lubricant systems usually contain three different components:

1. Slip agents (natural or synthetic oils; for PP mostly polyglycols, oxethyl fatty acids, alcohols, esters etc.)
2. Surface active substances (emulsifying agents) in order to disperse slip agents in water and to produce optimum wetting and distribution of lubricants on the fibre surface.

3. Antistatic agents (e.g. quarternary ammonium compounds or organic esters of phosphoric acid).

The various compounds must not cause any chemical changes in the fibre polymer (mineral oil can be used for PA and PES but not for PP); also exposure to elevated temperature (drawing) must be taken into account.
The lubricant system must be adapted to various spinning or non-woven systems (worsted, open end, needle felt etc.). In some cases high slippage between filaments is required, in other cases high adhesion.

The lubricants for PP-fibres are applied:

1. In the course of filament formation: 10 - 20 % aqueous lubricant system is applied by means of preparation rolls or spraying before winding, before drawing or before texturization.
2. In the course of processing: If the amount of lubricant applied in fibre production is insufficient for some kinds of processing (weaving, knitting etc.) additional lubricant can be sprayed on the fibres.

2.4. Fibre properties

2.4.1. Parameters determining fibre properties

Structural parameters involved are molecular weight, molecular weight distribution, crystallinity and orientation. These parameters affect all tensile properties such as tenacity, elongation, shrinkage etc.
Extrusion conditions affect all above listed structural parameters; subsequent quenching, drawing, and annealing affects only crystallinity and orientation. The influence of molecular weight (MFI) on tenacity and density of fibres produced under equal conditions is shown in Table 7 (spinning at 275°C, quenching with air, draw ratio 1:3).

Table 7 - Effect of MFI on PP-fibre properties

MFI Resin	MFI Fibre	Tenacity	Fibre density
		g/dtex	g/cm^3
43,5	47,5	2,1	0,9118
10,7	16,1	2,8	0,9105
4,4	6,1	3,2	0,9080
3,6	5,2	3,9	0,9065

Tenacity increases with falling MFI (better preorientation during spinning), density as a measure of crystallinity decreases (slower crystallization of higher-molecular-weight polymer).
The drawing operation orients the molecules and crystallites in the direction of the fibre axis; tenacity and modulus (stiffness) increase with increasing orientation, elongation decreases (Figure 20). Density effects, i.e. crystallinity, are more complex; increasing draw ratio reduces crystallinity which however can be compensated by increasing draw temperature (Figure 21). In general, desired crystallinity for a given polymer is obtained by a proper balance between quenching conditions, drawing conditions (ratio, speed, temperature) and annealing. Crystalline regions provide stiffness, abrasion resistance, strength, whereas amorphous regions determine flexibility and toughness. In most instances additional heat processing (annealing or heat setting) of the oriented fibre is desirable in order to improve the dimensional stability (reduced tendency to shrink at elevated temperature); annealing is performed commonly in a temperature range between 100 and 150°C.

2.4.2. Mechanical fibre properties

As mentioned above tenacity and elongation of PP fibres varies with production conditions. The relation between tenacity and elongation is chosen according to the end-use of the fibres. A tenacity of 1,5 - 7 g/dtex and an elongation between 15 and 150 % encompass the normal range for staple fibre and multifilaments. High-tenacity filaments used for ropes and cordage, have a tenacity of 8 - 8,5 g/dtex and elongation from 18 to 22 %. Typical data for PP and other fibres are given in Tables 8 and 9.

Table 8 - Range of properties for commercial PP-fibres

	Unit	Multi-filaments	Staple 7-17 dtex	Staple 30-110 dtex
Tenacity (dry and wet)	cN/dtex	4 - 7	3 - 4,5	2 - 3
Elongation at break	%	15 - 35	100-150	150-220
Elastic recovery on 5 % elongation	%	88 - 98	88-95	
Shrinkage in boiling water after 20 min	%	0 - 3	0 - 3	
Moisture regain	%	less than 0,03		

Table 9 - Some comparative mechanical properties of commercial fibres

Fibre	Specific gravity	Tenacity	Elongation dry	Elongation wet
Cotton, raw	1,50	3 - 6	3 - 7	-
Wool	1,32	1 - 2	25-35	25-50
Nylon 6, 66	1,14	4 - 9	20-40	20-40
Polyester	1,38	4 - 5	14-25	19-25
PP-Multifil	0,91	4 - 7	15-35	15-35
Steel	7,7	3,5	8	8

Cold flow (creep; deformation under constant load) of PP fibre is about 0,5 % at a load of 1,5 cN/dtex for 16 hrs. at room temperature, and is somewhat poorer than PA.

Elastic recovery of different synthetic fibres is shown in Table 10; inasmuch as it is time dependent, it is separated into immediate and delayed recovery and permanent set.

Table 10 - Recovery properties of polypropylene, PA and PACN fibres

	PA	PACN	PP
5 % Elongation			
Immediate elastic recovery	17	21	38
Delayed " "	83	74	62
Permanent set	0	5	0
10 % Elongation			
Immediate elastic recovery	15	12	29
Delayed " "	80	56	64
Permanent set	5	32	7
15 % Elongation			
Immediate elastic recovery	14	9	28
Delayed " "	71	49	62
Permanent set	15	42	11

Abrasion resistance is another important property, particularly for carpets. Abrasion is a result of deformation due to compression, tension, bending, shear and cutting. Maximum abrasion resistance is obtained using materials of high molecular weight, low tenacity and high elongation (fibres with low orientation). The mechanism of abrasion is believed to be surface fragmentation or peeling initiated at imperfections of the fibre crystallites.

2.4.3. Thermal properties

Thermal properties are summarized in Table 11 and also compared to other fibre material. PP fibres are very good thermal insulators because of their low thermal conductivity.

Table 11 - Thermal properties of different fibres

Fibre	Softening temperature °C	Melting temperature °C	Thermal conductivity (relative to air)
PP	145 - 150	165	6,0
PA	205	220	
Wool			7,3
Cotton			17,0

2.5. Fields of application

Polypropylene fibres are compared with other synthetic fibres very 'young' products and all possibilities of application are still not exhausted. According to the development of fibre production new fields for the use of PP fibres are found. Main end uses are shown in the following application scheme.

2.5.1. General application scheme

Monofilaments → bristles, belts, ropes, cordage

Multifilaments:

Split fibres → technical woven fabrics (filter cloth etc.)

Non texturized → garden furniture

BCF → upholstery, curtains

→ tufted carpets

→ woven carpets

Staple fibres → spun yarn → upholstery, home textiles,

→ underwear, working clothes, blankets

→ nonwovens → needle felt carpets

→ hygienic fleece (diapers)

→ geotextiles (civil engineering)

Spunbonded → base layer for needlefelt carpets

→ secondary backing for tufted carpets

→ backing for tufted carpets

Several important areas of application shall be discussed in the following giving also a short survey about the techniques and machines used.

2.5.2. Special fields of application

Tufted carpets

The tufting process is some sort of sewing technique: Into the backing material loops of yarn are punched by some sort of sewing machine; the loops are produced by the function of the looper (a functional schematic diagram is shown in Figures 22 and 23) and have to be anchored by means of synthetic latex (primary backing). To raise the comfort of use

normally a secondary backing (synthetic latex foam or nonwoven) is applied.
Tufted carpets are made either of BCF or of spun staple fibre yarns.

Needlefelt carpets

A needle felt sheet (randomized network) is produced from staple fibre on a carding machine as shown in Figure 24. This top sheet is combined with a similar needle felt base layer by needle punching (200 - 400 punches/cm^2) using a system of barbed needles (Figure 25). Instead of a base layer made of staple fibres also a preneedled spunbonded base sheet can be used. Afterwards the carpet is treated with SBR latex (impregnation).

Applications of low denier fibres

Low denier fibres (1,7 - 3,3 dtex) have recently been introduced in woven and knitted fabrics and also in non-wovens; knitted fabrics mainly for underwear (3 cylinder spinning), non-wovens in the hygiene range (baby diapers) and for technical filters (air filters, etc.), woven fabrics mainly as working clothes, filters and blankets (PP-yarn as well as combinations of PP with cotton or PA).
Processing of low denier fibres to yarns can be accomplished with all current technological systems (3 cylinder-, woolen-, worsted- and open end spinning systems).
The advantage of fabrics of this type is mainly due to low weight and hydrophobic properties (especially in the area of hygiene applications and underwear; no absorption of perspiration fluid but rapid evaporation). Other advantages are high abrasion resistance (home textiles) and high tear strength.

Geotextiles and civil engineering

A wide-spread field of application for nonwovens (made of staple fibre or spunbonded) has been found in the last years in civil engineering. A short survey is given in Table 12.

Table 12 - Applications of non-wovens made of PP fibres in civil engineering

Fields of application	Operating ranges						
	Separation layer	Filter layer	Base layer	Improved sub-base layer	Protective layer	Regulation layer	Drainage layer
Road construction	+	+	+	+			
Civil engineering hydraulics	+	+					
Railroad construction	+	+	+				
Tunnel construction					+	+	+
Foundation engineering	+	+	+	+			
Sports ground construction	+	+	+				
Drainage	+	+					
Building construction	+	+			+		

One special example is given in Figure 26, where the function of a spunbonded sheet in road construction is shown. The non-woven prevents penetration of granular material into the subsoil.
In civil engineering hydraulics the spunbonded fleece prevents erosion of constructions which are exposed to tidal forces of the water.
In other applications like drainage of wet grounds the filter properties of the non-wovens are of great importance.

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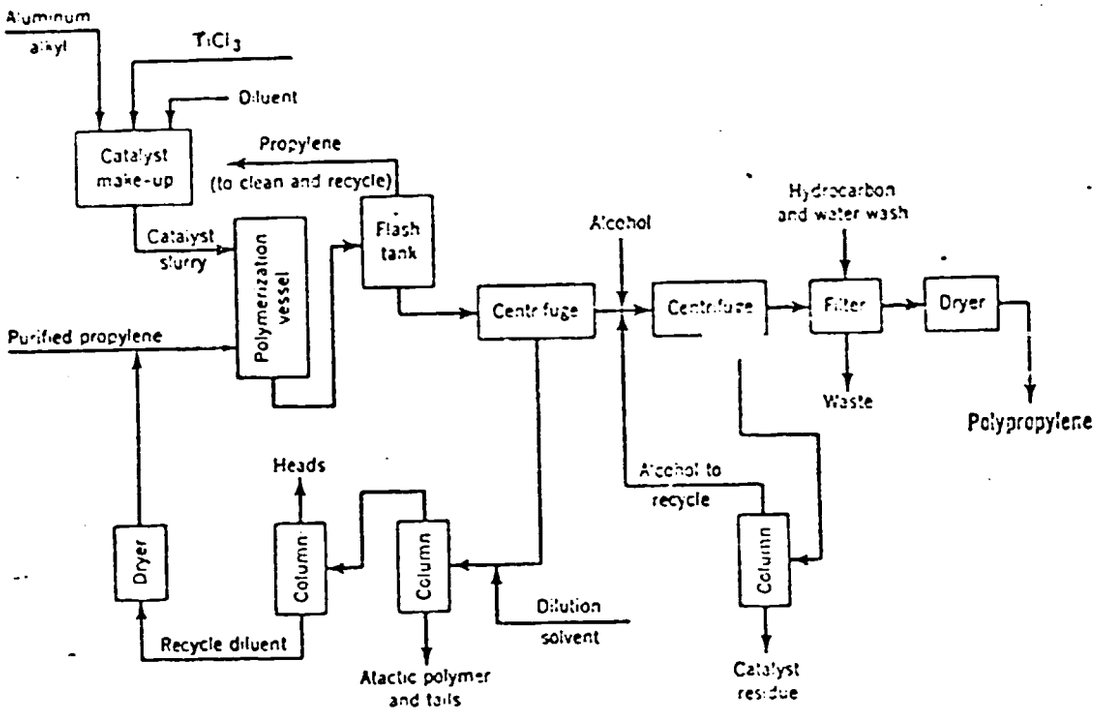


Figure 1 - Flow sheet of continuous propylene polymerization process

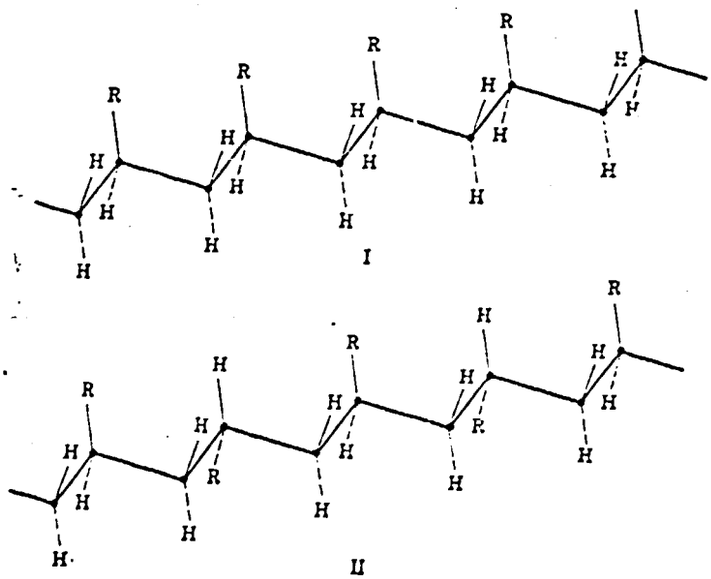


Figure 2 - Isotactic (I) and syndiotactic (II) modification of polypropylene

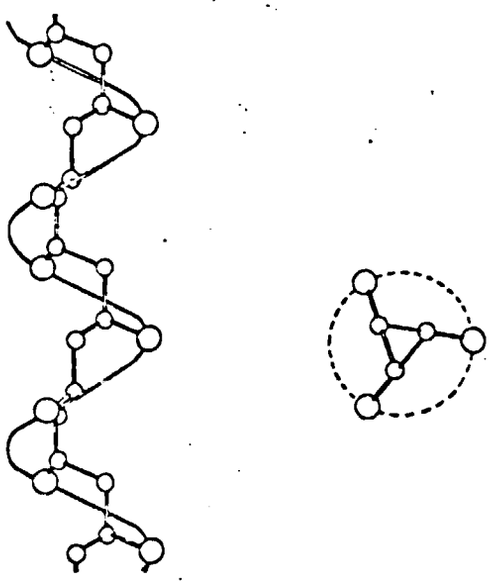


Figure 3 - Helical conformation of polypropylene

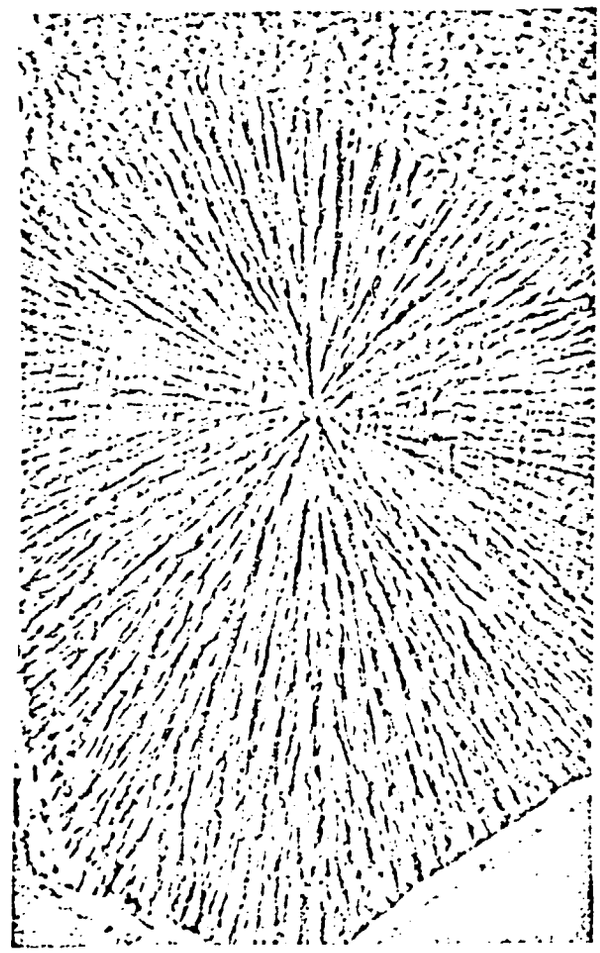


Figure 4 - Phase microscope photograph of an isotactic polypropylene spherulite

Figure 6: Schematic representation of the morphological structures in an undeformed film.

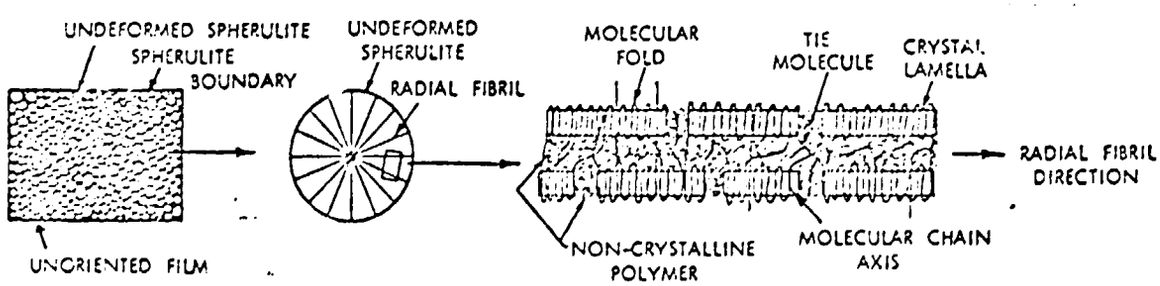


Figure 5 - Schematic representation of the morphological structures in an undeformed PP film

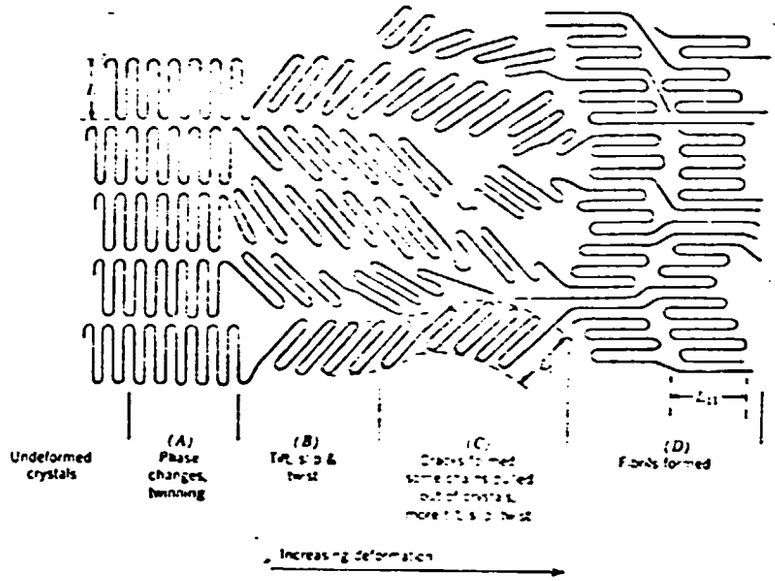


Figure 6 - Formation of fibrillar structure during drawing process

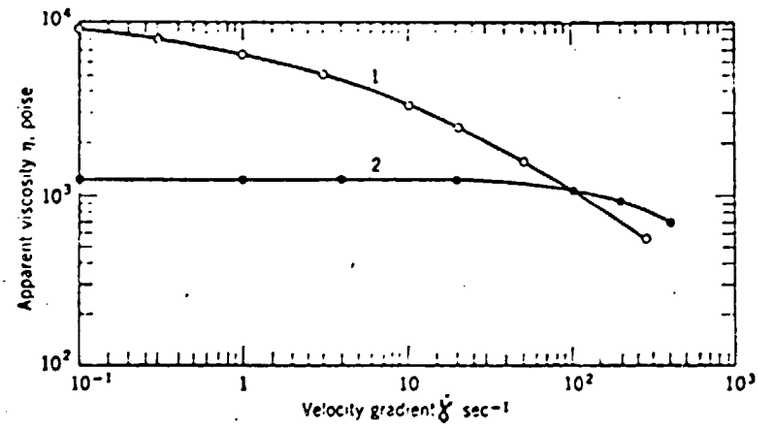


Figure 7 - Velocity-gardient-dependent viscosity of polypropylene (1) and polyethylene terephthalate (2)

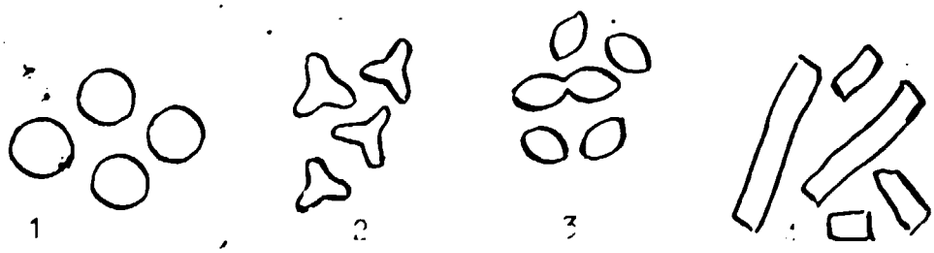


Figure 8 - Cross sections of round (1) and trilobal (2) multifilament, Barfilex fibres (3) and split film fibres (4)

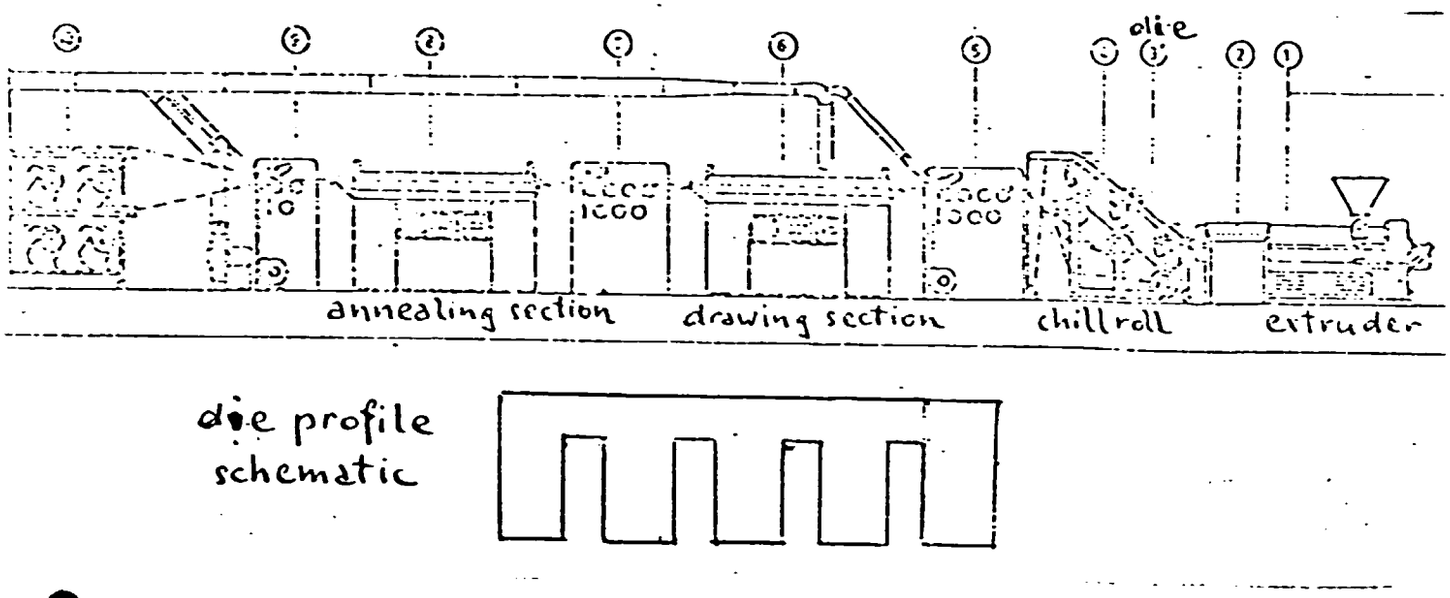
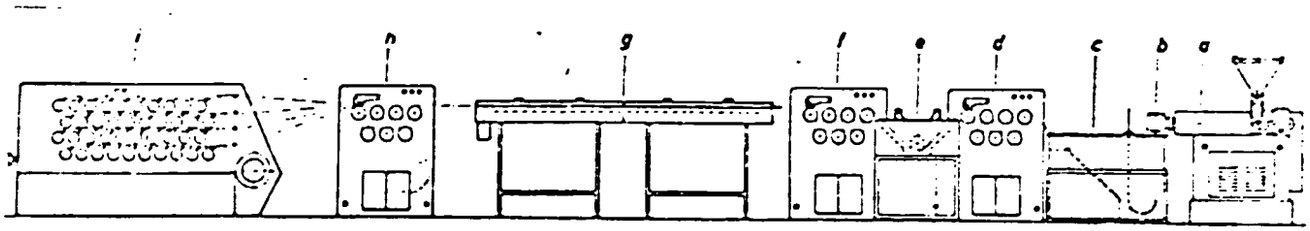
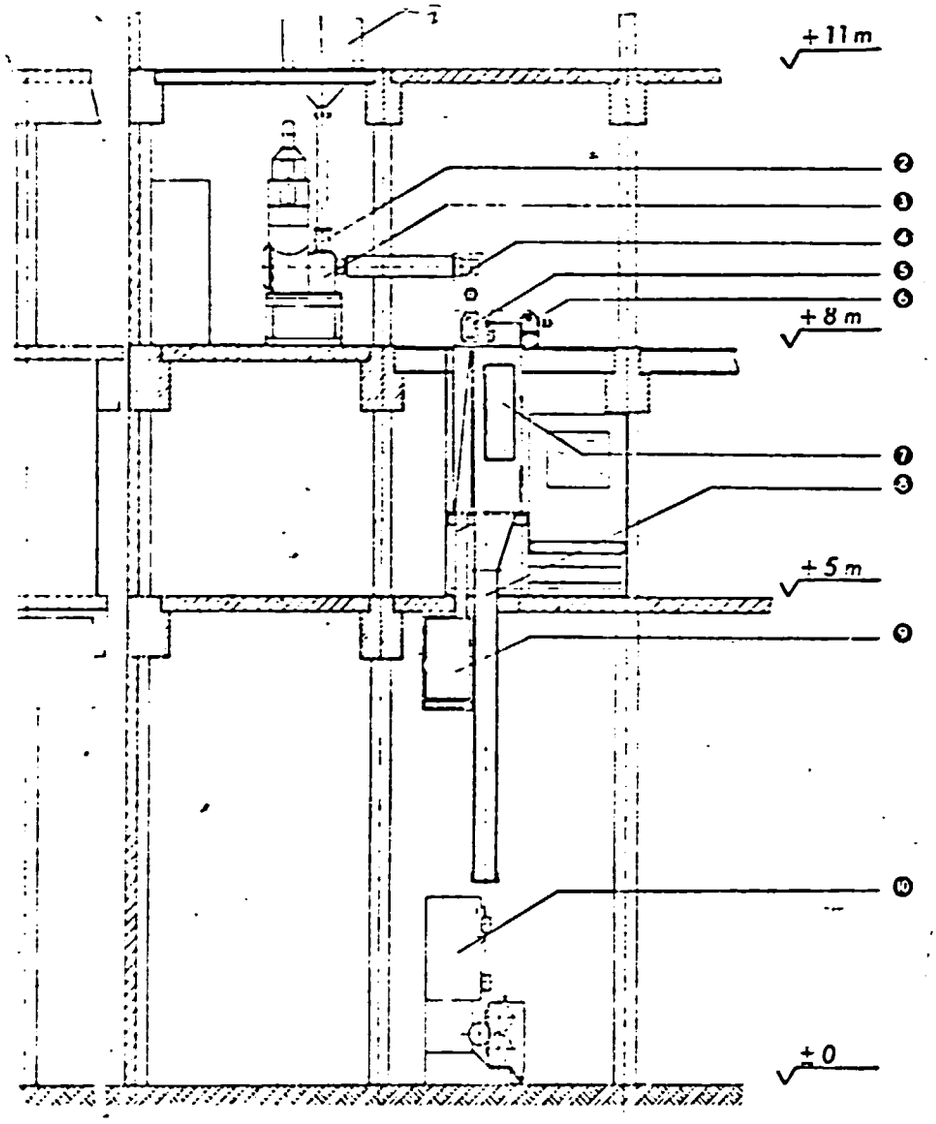


Figure 9 - Barflex process



Legend: Screw extruder (a), L/D 20, compression ratio $\geqslant 4$, equipped with a metering pump, extrusion die (b) with round, flat or special cross section (metal screen packs before the die), quench tank (c), godet roll system (d) (f) (h), orientation tank (e), orientation oven (g), wind up system (i).

Figure 10 - Diagram of monofilament production



Legend: (1) polymer pellet container, (2) shutter for pellets, (3) extruder, (4) temperature and pressure gauge and distribution system, (5) (6) spin beam with spin pumps, screen packs, and spinneret, (7) (8) air cooling chimneys, (9) air distribution channel, (10) take-up machine (including preparation in order to reduce friction and improve processing).

Figure 11 - Multifilament production plant

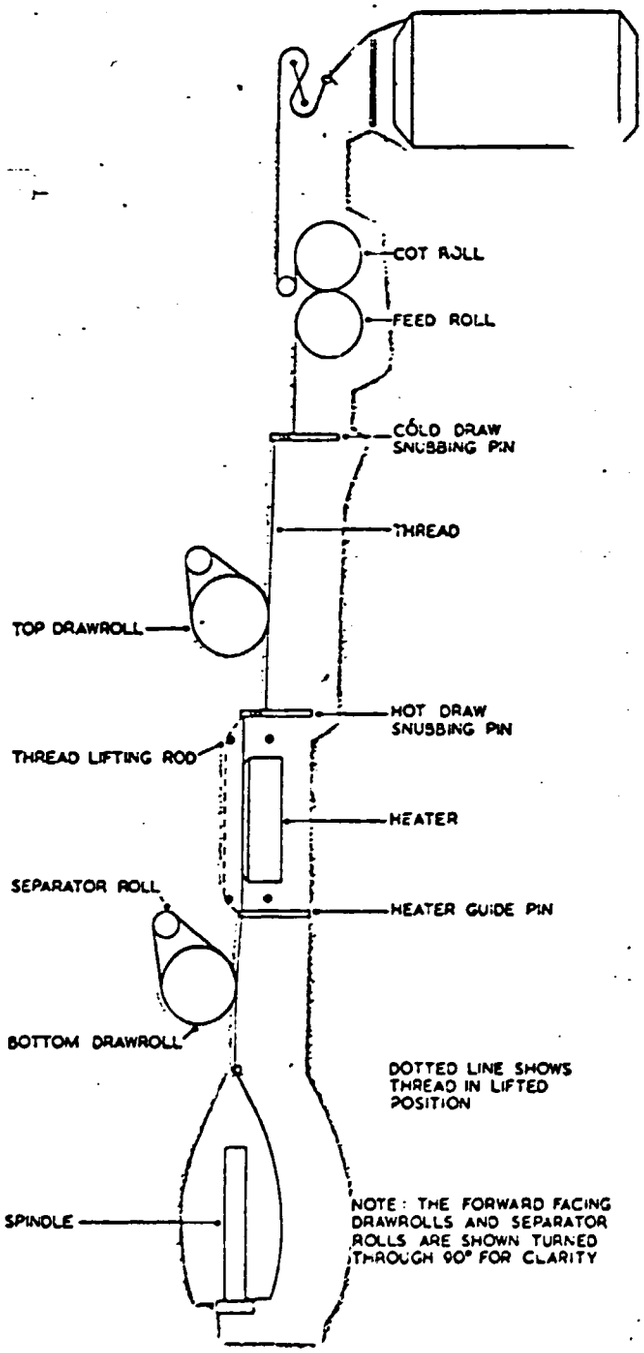


Figure 12 - Schematic diagram of a draw-twister

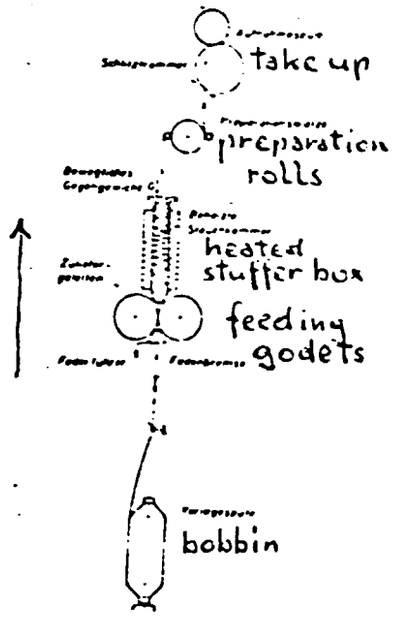
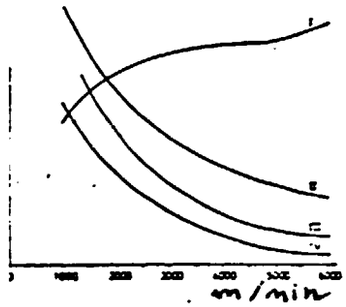


Figure 13 - Stufferbox texturization



I .. output
II .. titer
III .. elongation
IV .. diameter

Figure 14 - Influence of spinning speed of fibre properties

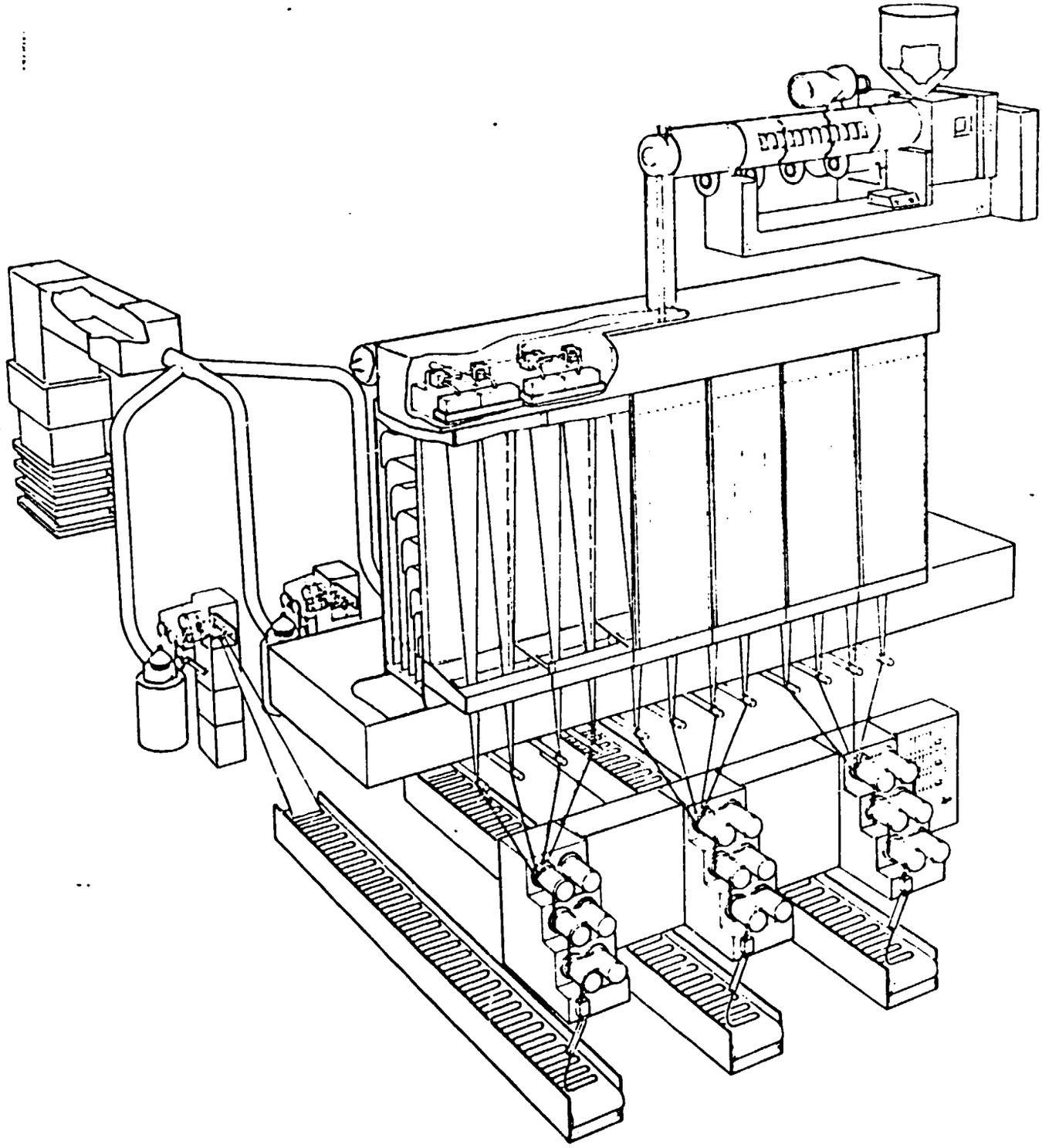
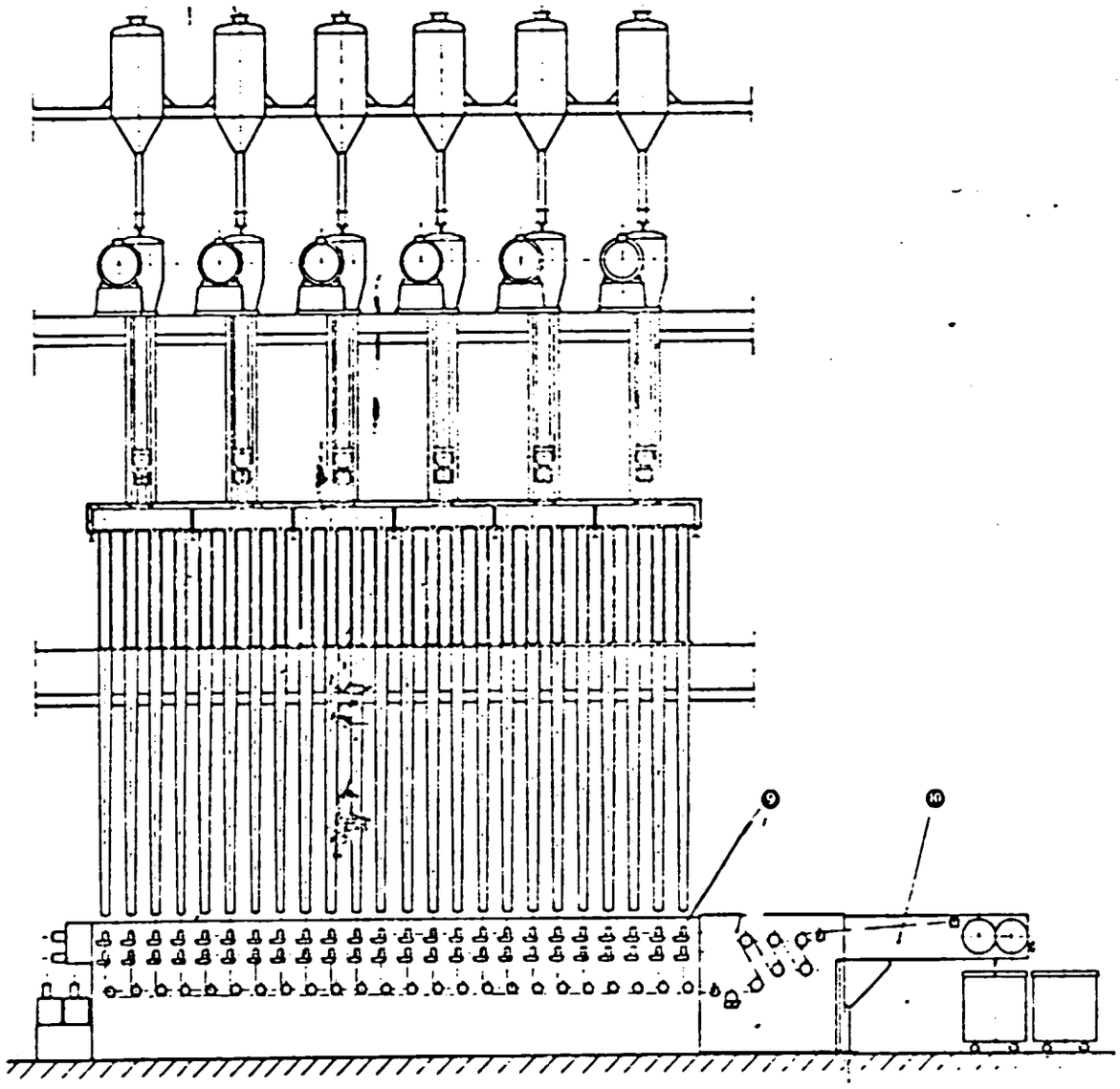


Figure 15 - Continuous staple fibre line



Legend: (9) preparation rolls, (10) can feeders

Figure 16 - Diagram of staple fibre production

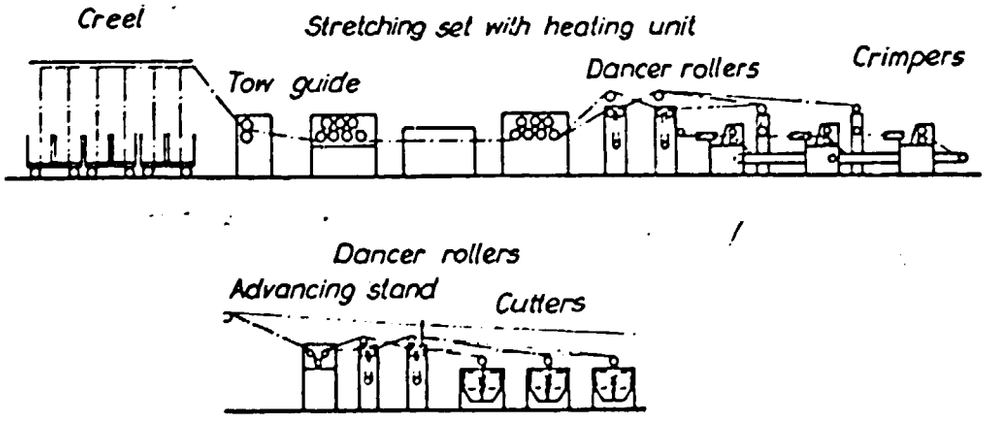


Figure 17 - Staple fibre processing

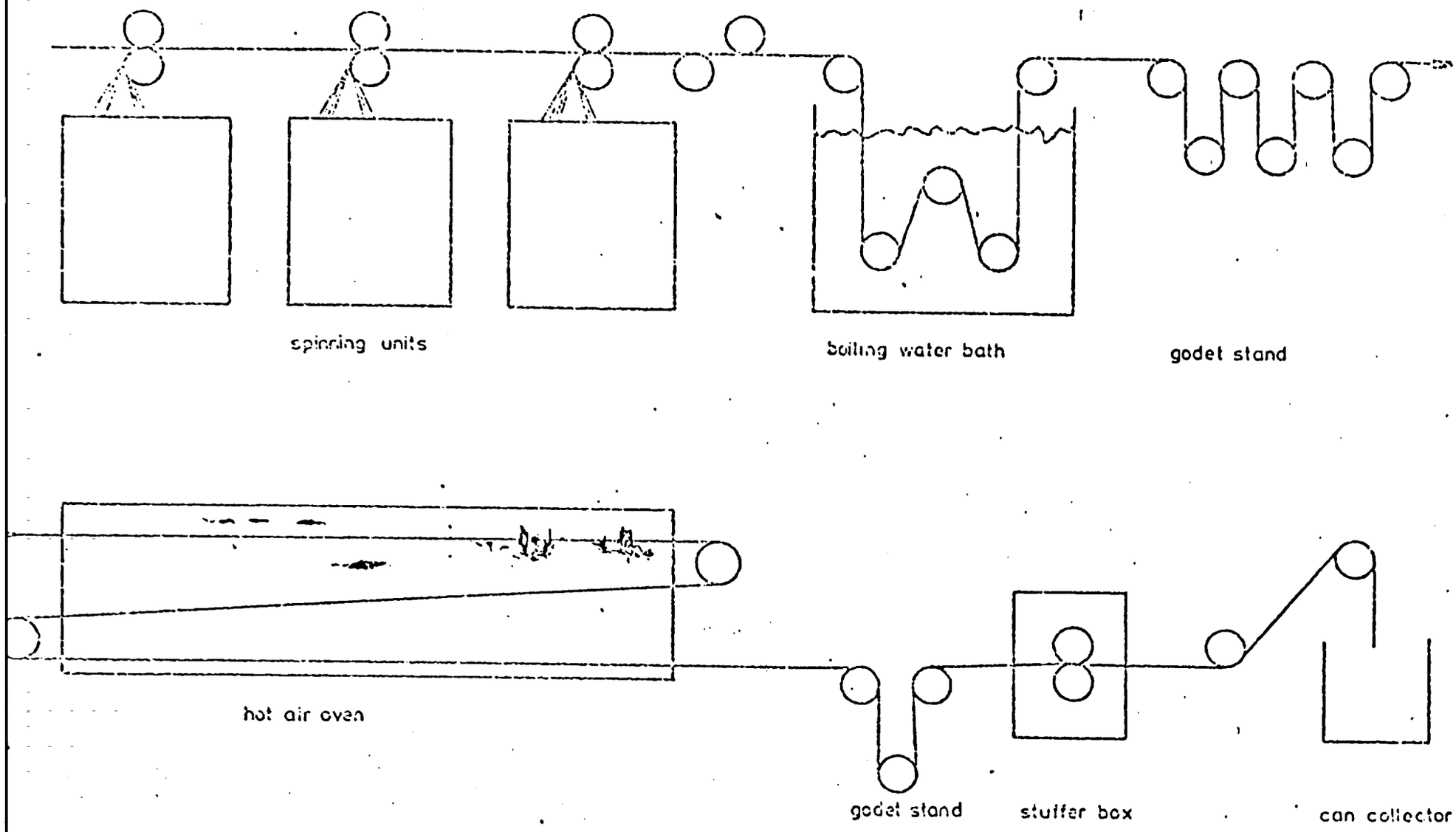


Figure 18 - Mackie process

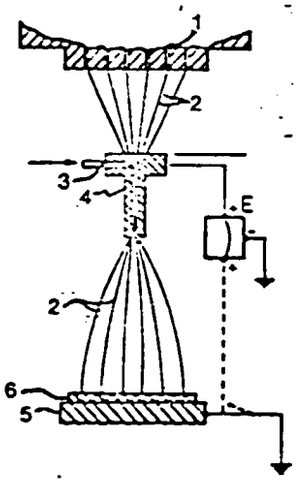


Figure 19 - Spun bonding process

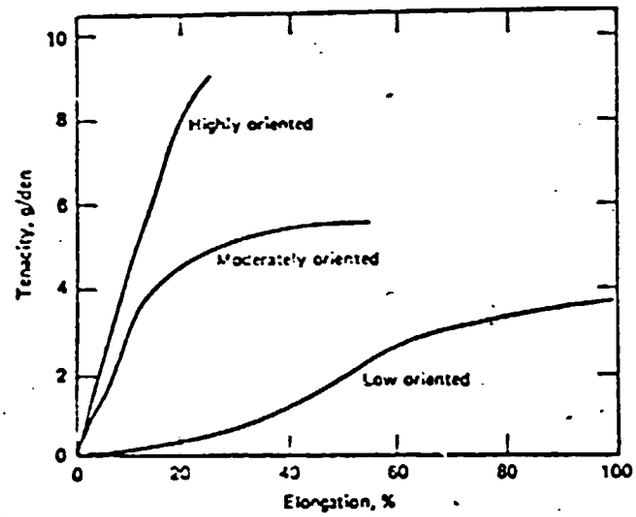
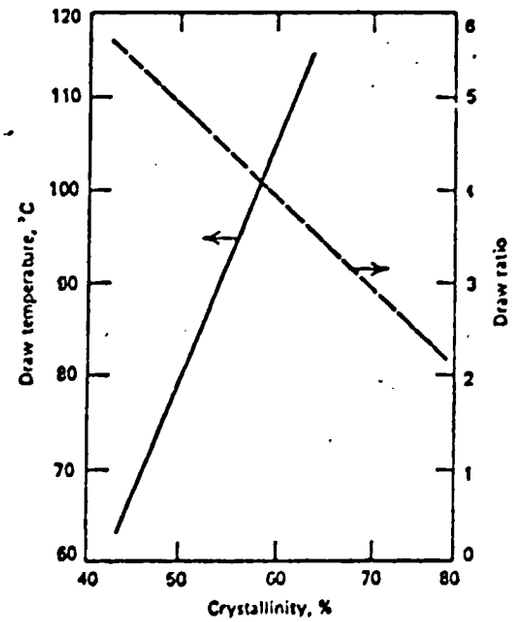


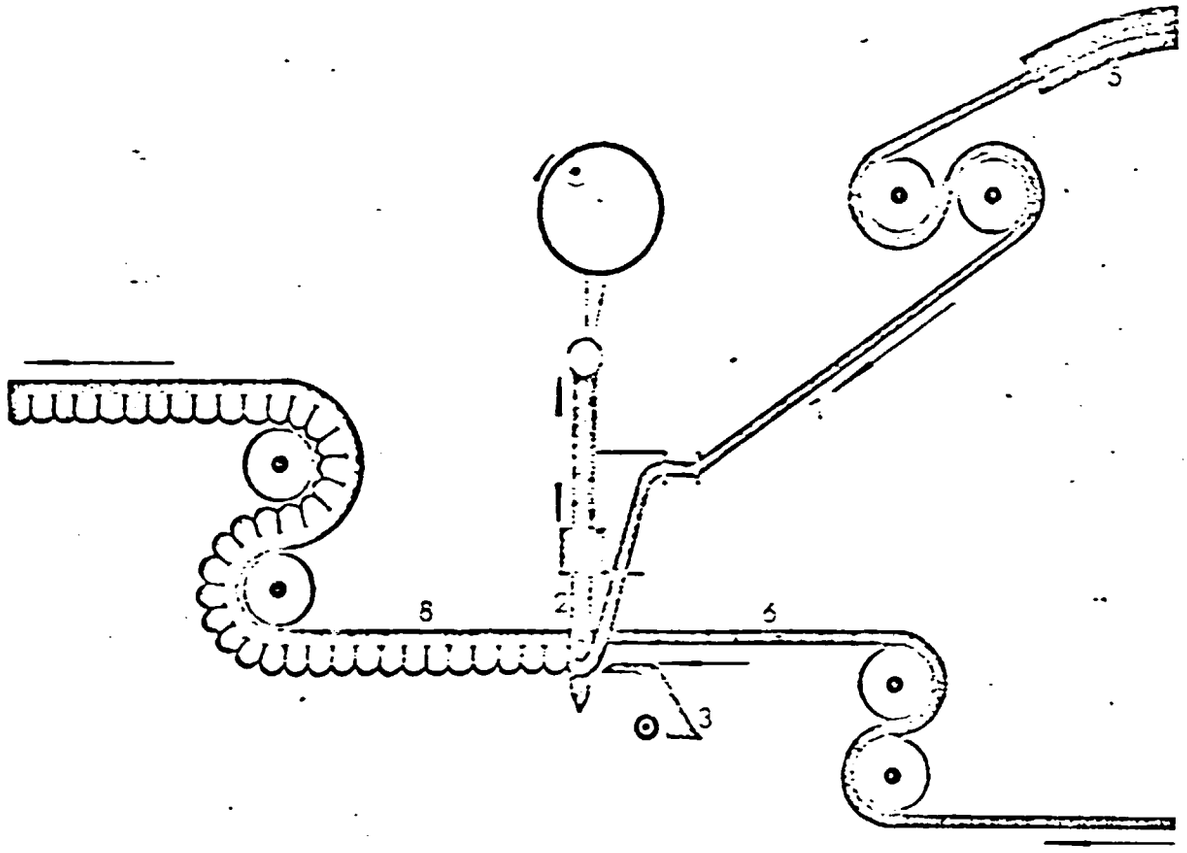
Figure 20 - Effect of orientation on tenacity of yarn



--- draw temperature 100° C

—— draw ratio 1:4

Figure 21 -- Effect of darw ratio and temperature on crystallinity of PP fibre



Legend: 1 needle drive, 2 needle, 3 looper, 5 creel, 6 carpet backing, 7 tufting yarn, 8 carpet

Figure 22 - Schematic diagram of the tufting process

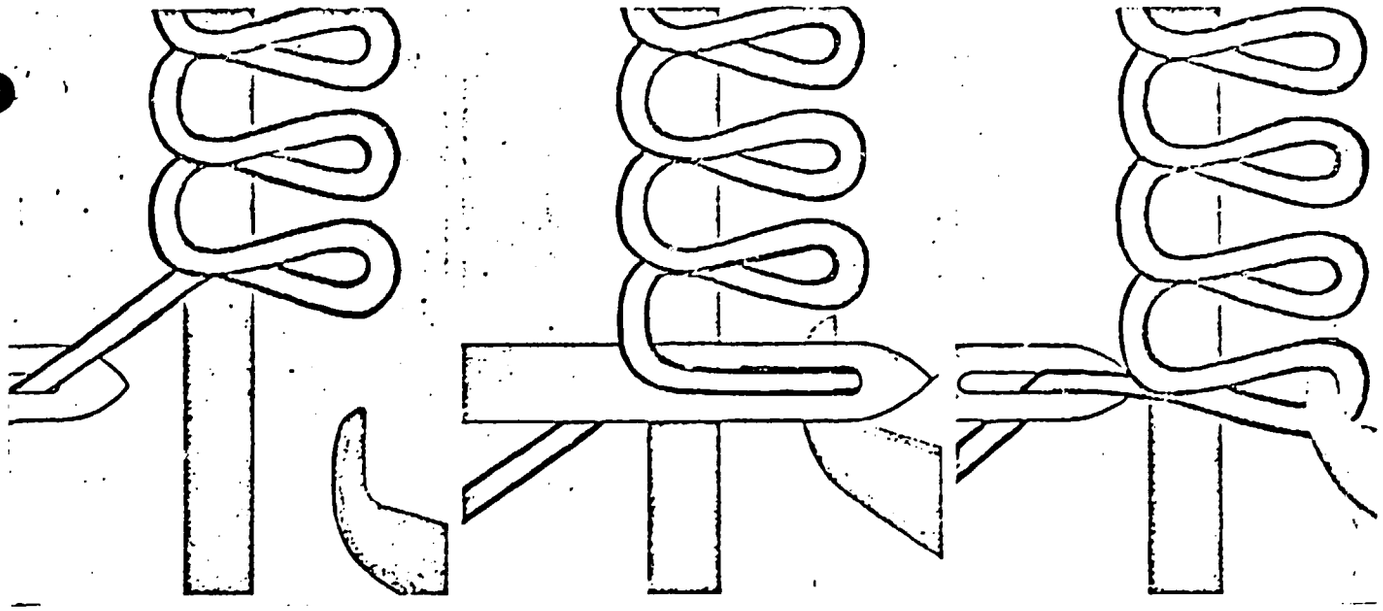


Figure 23 - Function of the looper

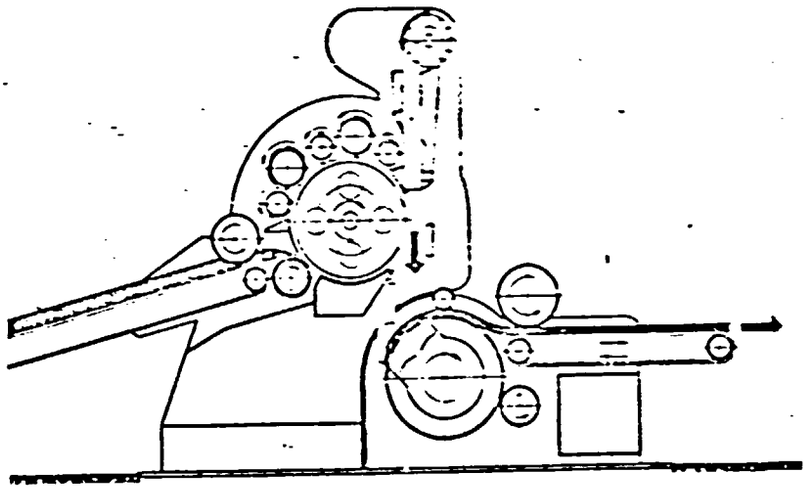


Figure 24 - Carding machine

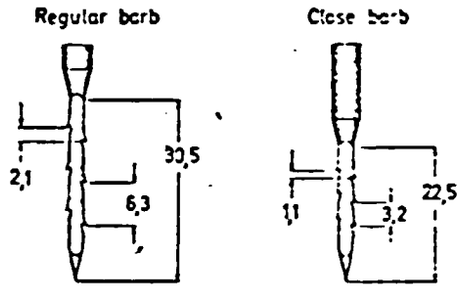


Figure 25 - Punching needles

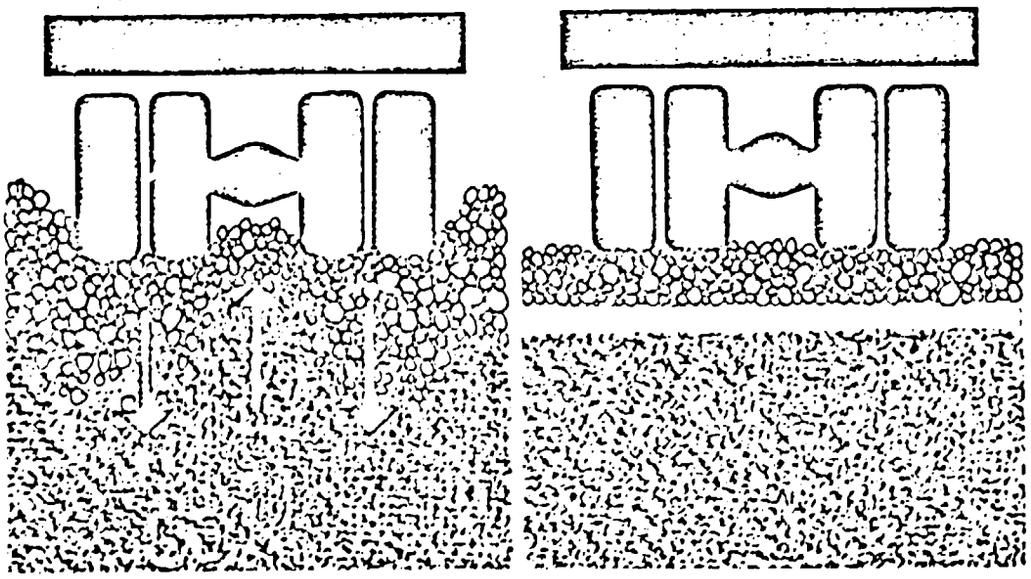


Figure 26 - Function of spunbonded sheet in road construction