Process and machine technology of manmade fibre production

Dr. rer. nat. E. Welfers

Classification

1. Rheological processes in spinning

The formation of the filament below the spinneret is a complicated process of fluid mechanics, consisting essentially of deformation, a series of various reactions and in melt spinning the cooling of the raw material too. In principle the following processes are differentiated in filament formation:

- Dry spinning
- Melt spinning
- Flow of the melt in the spinneret
- Processes in the spinneret ducts
- Behaviour of the melt after emerging from the spinneret
- Behaviour of the still fluid and little solidified filament under drawing
- Coagulation and/or decomposition (regeneration), cooling, solidification
- Drawing the consolidated filament – deformation processes

Depending on the spinning technique the flow processes are very different. For the processes named above and the subsequent drawing, the following parameters are decisive:

FM = delivery (g/min or cm³/min)
N = number of spinneret holes
d = spinneret hole diameter (mm)
f = single hole cross section (mm²)
F = total exit cross section (mm²) = N · f
SG = extrusion speed

$$SG = \frac{FM}{F} \text{ m/min}$$

A_1 = haul-off speed
A_0 = delivery speed

$$\text{Extrusion ratio} = \frac{A_1}{SG}$$

$$\text{Draw ratio} = \frac{A_1}{A_0}$$

Negative draw = stuffing

The extrusion drawing may be expressed as a simple numerical value (e. g. 10), as a ratio like the drawing, or else as a percentage. If the extrusion rate is equal to the haul-off speed, the extrusion ratio is 1 : 1. Normally it is higher than 1. If however the take-up speed drops below the extrusion speed, ratios below 1 result (negative drawing or stuffing).

Stuffing has special importance in certain wet spinning routes. The rheological flow processes taking place during the formation of the filaments may be regarded as two processes: the inner and outer spinning processes. Significant here is the fact that the hydrodynamic conditions inside and behind the spinneret differ decisively.

While the flow velocity is constant over the length of the spinneret duct, it differs over the cross section – from zero at the edge to its maximum at the middle. Inside the spinneret there is a radial, behind it an axial velocity gradient. In the hauled-off filament the velocity is constant over the cross section but varies with the length of the molten thread (fig. 1).

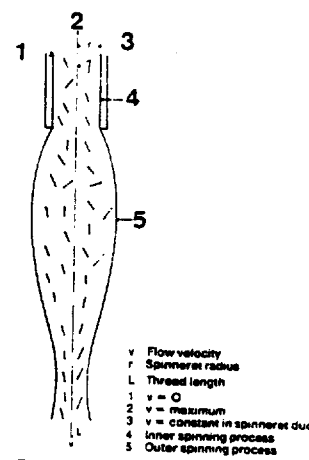

Fig. 1
Flow conditions in the spinneret and in the nascent thread (after SCHURZ [1])

The parameters listed here play a special part for the individual spinning processes, and must be adapted to each other according to denier and spinning conditions. They influence the fibre properties to a large extent.

2. Producing staple fibres

2.1 Viscose staple

The viscose spinning solution or viscose for short – a cellulose dissolved as xanthate in dilute caustic so-

solution with a concentration of to 9 % – serves to produce viscose taple fibres. The deaerated viscose ready for spinning is forced hrough gold/platinum spinnerets nto a coagulating bath containing ulphuric acid, sodium and zinc sulphates (fig. 2 and 3).

ig. 2
Vet spinning process for viscose
Spinning
Drawing
Stapling or tow treatment
Washing, desulphurizing, bleaching, finishing
Drying
Bales

he spinning temperature is 40 to 0 °C, the precipitation or coagulation distance 25 to 80 cm, depending on the process and spinning peed (70 to 100 m/min). With regard to the colloidochemical behaviour of the viscose it may be regarded as the aqueous solution of an anionic colloidal electrolyte with structure-linked groups (xanthate) and non-ionogenic hydrophilic oxy (hydroxyl) groups. For filament formation in spinning the coagulation

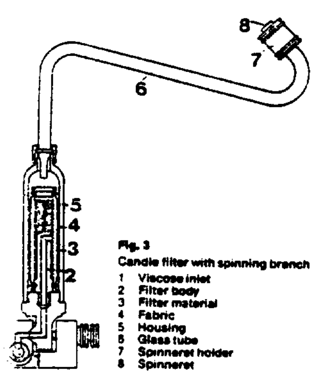

Fig. 3
Candle filter with spinning branch
1 Viscose inlet
2 Filter body
3 Filter material
4 Fabric
5 Housing
6 Glass tube
7 Spinneret holder
8 Spinneret

phase is critical. Coagulation is to be understood as the solidification of the colloidally dispersed system. The more or less freely mobile molecular chains or associates in the dispersion join up into larger groups. Coagulation may be induced by withdrawing solvent for instance, or by adding electrolytes (salts). The purpose of the spinning baths is to convert the sodium cellulose xanthate emerging from the spinneret in the form of a fluid viscose jet into a cohesive gel thread by coagulation, transforming the soluble xanthate in this gel into insoluble hydrate cellulose. Thus colloidochemical and purely chemical processes take place side by side and successively. The spinning baths must therefore contain both salts with coagulating action and acids with decomposing action as reagents.

After neutralization of the free caustic soda solution, decomposition of the xanthate proceeds via the free cellulose xanthic acid stage. This results when the pH value drops from 14 to about 2 due to the diffusion of H+ ions. While this acid is formed very quickly, its decomposition is relatively slow. In addition secondary reactions take place which are not without importance to the fibre formation and fibre structure (fig. 4).

The presence of zinc in the spinning bath influences not only the formation of zinc cellulose xanthate, which is insoluble in water and difficult to decompose, but

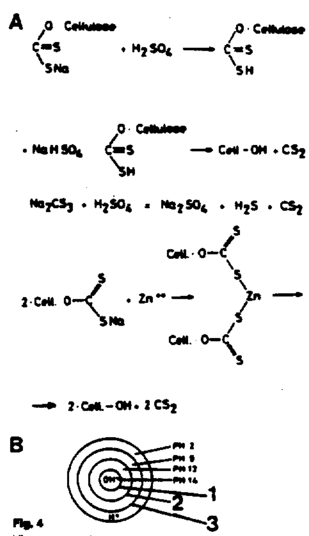

Fig. 4
Viscose reaction spinning
A Sequence of reactions
B Sulphuric acid diffusion in viscose solution, behaviour of pH values
1 Coagulation line
2 Neutralization line
3 Acid limit line

also the secondary reactions, because zinc can react with a number of the sulphurous by-products present in the viscose and formed by the decomposition of xanthate. The zone in which the zinc ions react has a different structure to that of the core, hence the distinction between covering layer and core cellulose. The outer layer is more densely packed, as can be shown with dyestuff (Hermann's Victoria blue method). The core and outer layer structure is the reason for particularly marked crimping, which with any viscose staple fibre can be traced to the differential shrinkage and tension between the two zones. Of importance is the formation of zinc trithiocarbonate ($ZnCS_3$) and zinc sulphide (ZnS).

Through these processes the hydrogen ion diffusion in the gel thread is slowed down, and a buffering necessary for the formation of the fibre structure occurs. Experience has shown the properties of the viscose regenerated fibres to be improved as the decomposition of the xanthate in the spinning bath is slowed down in relation to the coagulation, or that for good coagulation the decomposition should be slow. These chemical reactions (thread formation with a decomposition or regeneration process) are accomplished about 80 to 90 % in the primary or spinning bath. Further treatment of the filament bundles from the large-size spinnerets of a spinning machine, united into a tow, takes place in a second bath. Here at 92 ... 95 °C residual decomposition and drawing (60 to 100 %) take place. This second or plasticizing bath contains only 20 to 25 grams per litre sulphuric acid and salts entrained with the filaments.

Apart from the standard viscose staple fibres, special items are produced. For these either spinning baths containing zinc are used, or coagulation baths which first merely neutralize the alkali of the thread. After drawing outside the primary bath, decomposition and regeneration ensue only in the second bath. The spinning baths must always have constant acid and salt contents. The large amount of water brought into the bath with the viscose is removed again by enormous spinning bath evaporators, and the temperature is kept constant by spinning bath preheaters. The viscose spinning baths are as given below:

Acid bath:
Sulphuric acid, sodium sulphate, zinc sulphate
Coagulation bath:
Ammonium sulphate, sodium sulphate, little acid
Coagulation – drawing – decomposition
Preparation of the spinning bath:
a) Regeneration:
Repulsion – correction of acid and salts
b) Spinning bath regeneration by evaporation:
Evaporation of water from viscose and neutralization, correction
Sodium sulphate crystallization – calcination
Spinning bath deaeration – filtration
Heat input via heat exchangers

Post-treatment of spun fibres

Before the filaments from the spinning machine become finished products they must undergo a series of purifying and finishing stages (post-treatment). The first of these (washing) may be applied in the fleece or tow form. The tow from the spinning machine is led to a cutting head and converted to the desired staple length (for stapling unit see 2.2).

Today the fibre material is generally washed after conversion into flock (fleece) form. Tow washing is reserved for special cases (table I, fig. 5).

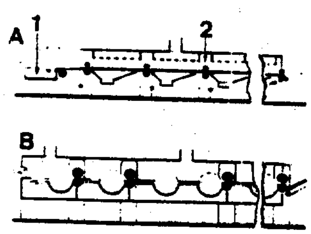

Fig. 5
Post-treatment of viscose staple fibres (Fleissner GmbH)
A Sieve belt washing (Fleissner system)
B Sieve drum post-treatment, gentle material transport, short overall length
1 Suspension bath
2 Squeeze roller

In the first post-treatment stage, deacidification of the freshly spun fibres takes place (water temperature 85 ... 90 °C). Here the fibres cut to staple length and in flock form are deposited on suitable conveying arrangements as a uniform fleece. This washing machine, consisting of a conveying system and

Table I Production and post-treatment of viscose staple

Staple fibre line	Tow line	Tow and staple fibre line
Spinning	Spinning	Spinning
Drawing	Drawing	Drawing
Stapling	Folding/buckling	(Stapling)
Washing	Washing	Washing
Fleece formation	Folding/buckling	(Fleece formation)
Pre-(wet)-opening	Drying	(Opening)
Drying	Conditioning	Folding/buckling
Intermediate opening	Coiling	Drying
Drying		Conditioning
Conditioning		(Fine opening)
Fine opening		Packing/coiling
Packing		

an endless metallic screen belt, is divided into individual sectors in which the appropriate treatment fluid is sprinkled or sprayed onto the fleece. Between the separate treatment stations the fleece is led through a pair of rollers to squeeze out the treatment fluid.

Desulphurization is the next treatment stage, performed with either sodium sulphide or caustic soda solution and sodium sulphide, followed by washing. After this comes bleaching, depending on the degree of whiteness desired. The following processes are used:

- alkaline hydrogen peroxide bleaching
- acid hydrogen peroxide bleaching
- sodium hypochlorite bleaching
- sodium chlorite bleaching

According to the end-use of the fibres, optical brighteners are applied to the flocks together with the finish. Finally the post-treatment ends with finish application to the fleece.

The behaviour of the fibres in spinning is influenced decisively by the finish applied. The nature and quantity of the product applied depend on the fibre type, its properties and the spinning conditions.
After the post-treatment comes drying (fig. 6). To avoid having to evaporate excessive quantities of water, the fleece is first dewartered by squeezing. Drying imparts to the fibre the structure with which it undergoes further processing.

The drying behaviour is determined by the amount of the primary gel swelling, since the formation of the fibre structure in drying generally follows the phenomena observed in the shrinkage of gels. Only a simple contraction is involved here,

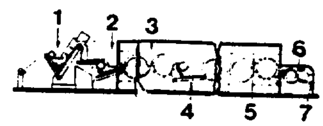

Fig. 6
Drying (Fleissner GmbH)
1 Hopper feeder
2 Wet opener
3 Drum dryer (shortened)
4 Intermediate opener
5 Conditioning chamber
6 Opener
7 Packing press

however, because ordered and unordered zones are present. Between the molecules or parts of these, new adhesion points are formed, which in turn result in further links between the crystallites and determine the strength and structure. A large part of these adhesion points are reversible, i. e. there is no bond or link by hydrogen (repeated wetting and drying, alteration of swelling index). To avoid fibre deterioration, drying in the fleece form must be performed gently and evenly. On modern high-performance plants therefore, the material runs first through a pre-drying zone, followed by intermediate opening (i. e. turnover) of the material, post-drying and finally conditioning. The conditioned fibres are led by a belt conveyor and an air current to the automatic baling press for packing.

The production of the individual types and modified fibres, which are set out below, cannot be dealt with in detail here.

- Normal cotton, wool and carpet types, bright, dull and spin-dyed
- High-tenacity types (high zinc sulphate), low wet modulus, no dimensional stability, low swelling, high dry and wet extension
- Polynosic fibres, high-modulus (coagulation) fibres, low swelling, low dry and wet extension, dimensionally stable

- Coagulation fibres (coagulation – drawing – decomposition) with surface effect, e. g. marks.
- Special high-tenacity types. Zinc sulphate baths and modified viscoses, retarded decomposition, influencing of the chemical reactions
- Special types from modified viscoses, incorporating chemical substances (low flammability) from post-treatment baths with aldehydes, fibres drawn in alkaline baths, graft fibres.

2.2 Cellulose acetate staple

Fibres based on cellulose 2½-acetate and fibres of cellulose triacetate are commercially available today only to a limited extent. They differ chemically in their content of combined acetic acid. In cellulose triacetate all six OH groups of the fundamental cellobiose building block are esterified with acetic acid; it contains 62.5 % combined acetic acid. Reduced to an acetic acid content of about 54 % by hydrolysis, the cellulose acetate becomes soluble in acetone, which is employed preferentially as solvent for dry-spinning cellulose acetate. Of the original six ester groups, five remain on the basic cellubiose molecule, i. e. 2 ½ per glucose unit – hence the name 2 ½ – acetate.

The production of cellulose 2 ½ – acetate and triacetate starts off with very pure bleached pulps, obtained by the sulphite process. Earlier cotton linters were used too. The cellulose is suspended in acetic acid. To this suspension an esterification catalyst is added, as a rule sulphuric acid, and then acetic anhydride as acetylating agent. Acetylation may be performed continuously or discontinuously; it proceeds heterogeneously at first. Cellulose triacetate is soluble in acetic acid. After reaching the triacetate state there is a homogeneous solution, from which the triacetate can be precipitated. Cellulose triacetate is spun wet or dry. For spinning the economically more important acetate fibre, a corresponding amount of water and sulphuric acid is added to the triacetate solution to initiate the hydrolysis mentioned. When hydrolysis has progressed sufficiently, the cellulose 2 ½-acetate is precipitated by adding more water. The aqueous acetic acid is restored to pure acetic acid free of water in an auxiliary plant, and the recovered raw material goes to the solvent plant, where it is mixed intensively with acetone into a 25 % solution, which after careful filtration passes via an intermediate tank into a distribution pipe. The solution is then supplied to the spinning (metering) pumps under pressure (fig. 7).

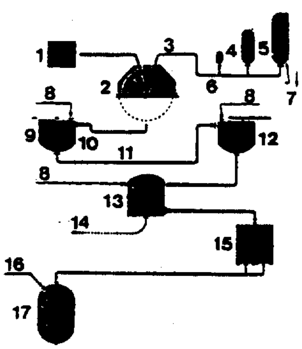

Fig. 7
Acetate fibre spinning process
1 Cellulose
2 Acetylation
3 Catalyst (H_2SO_4)
4 Acetic anhydride
5 Acetic acid
6 Triacetate, soluble in acetic acid
7 Precipitation
8 Water
9 2 ½-acetate
10 Saponification
11 Hydrolysis
12 Precipitation
13 Washing-out
14 Acetic acid recovery
15 Drying
16 Acetone
17 Dissolution (25 % spinning solution)

2.3 Polyester staple

Thermal deformation: spinning and drawing

Of all the melt-spun fibres, polyamide 6.6 is the oldest. The spinning (melt) grid process was devised for it, though its importance is now very small. Because at the present state of the art polyamide 6.6, 6 (Perlon) and Quiana can also be spun by the extruder process, the production of polyester staple fibres may be taken as an example of thermal deformation. Minor alterations of the spinning conditions with polyamide will not be enlarged upon here. Exceptions among the polyamides are Nomex and Kevlar, which are wet-spun. The spinning processes for the various polyamide types are as follows:

PA 6 (»Perlon«)	melt-spun
PA 6.6 (»Nylon«)	melt-spun
PA 11 (»Rilsan«)	melt-spun
»Quiana« (PA 472)	melt-spun
»Nomex«	wet-spun
»Kevlar«	wet-spun

Example: »Kevlar«:

Solvent:	sulphuric acid (H_2SO_4) 98 % and more
Concentration:	20 % by weight of the polymers
Temperature:	90 ... 100 °C
Spinning bath:	cold water

Washing, rinsing, drying

Fig. 8
Chip transport and storage room (Hoechst-Uhde International GmbH)

Commercial polyester fibres consist in nearly all cases of polyethylene terephthalate or modifications of this. Spinning is done almost exclusively with extruders. The properties, especially of the modified raw material, call for special process stages. On account of their susceptibility to hydrolysis the polyester chips are dried continuously at high temperatures, usually by means of hot air at 160 to 180° directed against the material in inclined rotating tubes. The chips are then filled into special transport containers which are mounted on the spinning heads, or else conveyed pneumatically into elevated silos, from which they are taken (fig. 8).

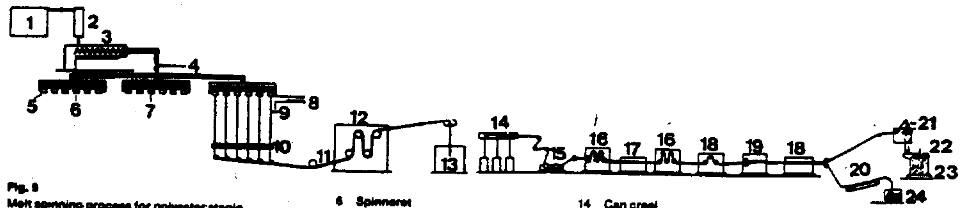

Fig. 9
Melt spinning process for polyester staple

1 Chips
2 Dryer, 180 °C, residual moisture 0.02 %
3 Extruder
4 Or direct spinning, spinning manifold
5 Filtration, coarse and fine sand, metallic strainers
6 Spinneret
7 Conventional haul-off
8 Blowing air
9 Spinning shaft, solidification
10 Finish application wall
11 Tow
12 Haul-off unit
13 Fibre can
14 Can creel
15 Finish
16 Drawing
17 Heating zone
18 (setting)
19 Crimping
20 Tow
21 Stapling (setting)
22 Flocks
23 Bale press
24 Carton filling

Residual moisture must not exceed 0.02 %, moreover air must be strictly excluded during the melting process. Consequently the dried chips are filled and processed under nitrogen atmosphere (fig. 9).

A slight degradation cannot be avoided entirely, however, and this nuisance is encountered particularly with modified raw materials or those with extremely high degrees of polycondensation. The dried chips are melted and homogenized in the extruder (fig. 10).

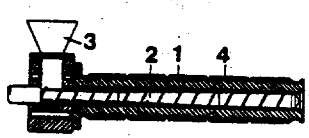

Fig. 10
Section through an extruder (Barmag)

1 Housing wall
2 Screw
3 Filling hopper
4 Heating elements

There is a particular advantage in feeding the spinning plants with the polyester melt from a polycondensation plant operated continously. This process plays a big part today, on account of both quality and economics. With these modern processes the viscosity of the melt is a critical factor. The average molecule length is adjusted according to the end-use of the fibres or the type of modification. The melt is metered exactly and forced by spinning pumps through the spinnerets.

As with all processes, here too special care must be given to the filtration in the thermal route. Sand filters with special layering and grain size have proved particularly effective. A coarser sand is followed by a finer one, and this in turn by a number of metal strainers with particularly fine, increasingly close mesh (fig. 11).

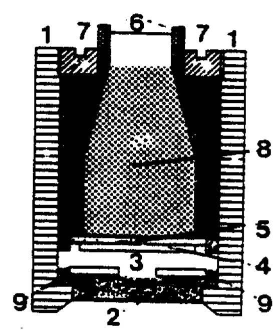

Fig. 11
Spinning unit assembly with spinneret

1 Base
2 Spinneret
3 Perforated plate
4 Supporting sieve
5 Sieve round
6 Sand container
7 Screw connection
8 Sand filter
9 Seals

Spinning temperatures are 280 to 300 °C according to raw material, and graded by different zones. The spinnerets have 300 to 800 holes (over 10 000 in the latest development) ranging from 0.2 to 1 mm in size.

In contrast to the melt grid (pressure pump) the pressure is generated by the extruder in conjunction with the sand pack, while the spinning pump is responsible for metering. Solidification of the filaments is induced by blowing them with cold air. The filaments are led in shafts or ducts, whose length depends among other things on the spinning capacity of the spinnerets and the haul-off speed, and ranges from 4 to 10 metres (fig. 12).

Fig. 12
Polyester filament spinneret in operation

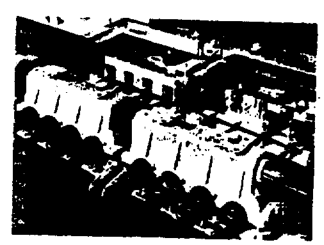

Fig. 13
Spinning manifold with spinning pump drive; detail view with pump drive, distributor block and spinning pumps, four spinning positions per manifold, 8 spinnerets per position, 4 pumps per position (Reifenhäuser KG)

A number of spinning positions or heads with spinnerets are combined into a distributor block or spinning manifold (box) with sets of spinnerets (fig. 13).

After applying a fibre finish the filament bundles from the spinnerets of one unit are gathered together, hauled off and coiled into spinning cans.

The undrawn filaments have little preorientation and are non-crystalline. Conventional haul-off speeds lie between 1000 and 2000 m/min, going up to 5000 m/min on the latest machines. In present high-speed spinning, however, the orientation increases with the haul-off speed, requiring only partial post-drawing. Usually a medium haul-off speed is still adopted today, followed by post-drawing as usual. It is important to know that the further processing of the filaments depends crucially on the preorientation, because this already anticipates part of the total drawing. The operations following upon spinning usually take up more time and space. One of the most important processes after spinning and coiling into cans is this drawing. Only through this does the thread acquire the necessary strength. Depending on the process and the [redacted] its [redacted], e. g. [redacted] are [redacted]

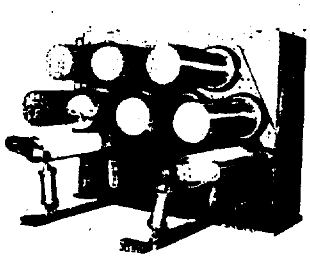

Fig. 14
Drawing system (Fleissner)

Here th[redacted]or [redacted] The [redacted] may be [redacted] the c[redacted]ning may be up to about 100 ktex. On account of the heavy tow weights and the high drawing forces entailed by them (typically 60 kN for 100 ktex undrawn), and the high torques at speeds around 300 m/min, the individual machine components must be of appropriately rugged design.

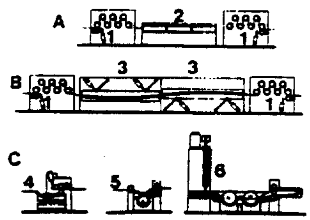

Fig. 15
Drawing and finish application on a tow line (Fleissner)
A Hot drawing (H)
B Hot drawing (B), setting; instead of the flatiron calenders may be used too
C Finish application
1 7-roll drawing stand (septet)
2 Heating duct
3 Flatiron
4 Immersion rod finishing station
5 Sieve drum finishing station for tows running through lengthwise
6 Sieve drum finishing station for tows folded crosswise, replaced by a sieve belt wash for polyamide

The tow can be drawn by the re-[redacted]g friction, or by wrapping friction alone using a number of rollers. [redacted]be [redacted] roller is pressured hydraulically or pneumatically onto a wrapping roller. The nip roller is then not driven but merely entrained. With the quintet arrangement there are two pairs of nip and wrapping rollers. Thus for pure wrapping friction, only sextets can be used. Depending on the process the roller surfaces may be heated electrically, by steam or heat transfer oil, to temperatures of 80 ... 180 °C according to fibre type, tow weight and speed. In the conventional hot drawing of polyester the tow may be drawn through a heating duct (heated by steam, hot air or radiation) placed in the drawing stand, or by a flatiron contact heater. Using heating ducts the temperatures are 130 ... 180 °C, with flatiron contact heaters 170 ... 180 °C (fig. 15).

Besides this conventional spinning process, which will also be dealt with further below, high-speed spinning processes have now been developed, allowing haul-off speeds up to 5000 m/min and more with can coiling. Barmag has developed a high-performance can coiler for this.

The basic development trends here are characterized by the desire to rationalize the process, raise performance and cut costs. The new can coiler works with cans of 4 ... 10 m³ capacity. The tow is blown into and through a coiler by an air injector, and emerges spirally, assisted by an air blower. In this way the tow emerging downward from the coiler forms a helix, thereby lowering the impact velocity of the tow. The can rotates, and at the same time either the can or the coiler performs traversing movements. Can changing is fully automatic.

Compared with conventional spinning the high-speed process brings the following advantages: Higher production, low capillary denier – hence better heat transfer in drawing, simplified drawing system (temperatures), less water application

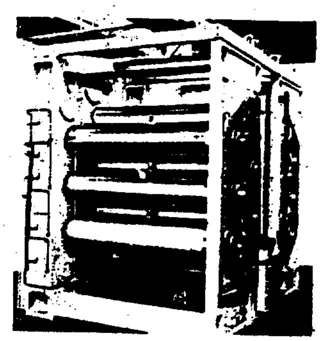

Fig. 16
Drawing system US 10 with six or seven rolls (sextet or septet), bearings at both sides, traction 80 kN (8000 kp) for conventionally or high-speed-spun filament sheets up to 3.3 mio. dtex at 300 m/min (mechanically up to 500 m/min), automatic lap removal by traversing cutter (accident protection), superheated steam heating, dull, high-lustre-polished, fluted, automatic threading device with compressed air (Barmag)

(finishing) – hence less evaporation energy, fewer outside-inside effects in the can, with capillary breaks lower denier at the broken end (e. g. polyamide 6 carpet fibres without subsequent drawing, polyester cotton type with subsequent drawing only 1 : 1.6 without intermediate heating), trend to higher speeds, less subsequent drawing.

Another new plant component that will revolutionize staple fibre production is the new US 10 drawing system from Barmag (fig. 18).

The system consists of drawing levels arranged horizontally or to save space vertically (6 or 7 rollers with the same angle of wrap). A Barmag invention is the pneumatic threading device which leads the filament tow automatically round the rollers of the draw stands up to the crimping device. Furthermore an automatic lap remover eliminates all the disadvantages otherwise inherent to drawing systems employing horizontally disposed rolls. This drawing system therefore also satisfies all requirements of accident safety.

Setting

The setting treatment given by the manmade fibre producer serves to minimize the stresses imparted during drawing and crimping, by controlled thermal and hydrothermal action. However this is no substitute for the finished goods setting applied by the finisher, which eliminates the stresses resulting anew from the downstream processing into wovens and knitteds. Autoclave setting belongs to the past, and may be forgotten.

Continuous setting

Due to the high speeds on the tow lines (up to 300 m/min), in order to attain the necessary dwell times the tow or staple fibre fleece must be deflected a number of times, or the tow cross-folded (i. e. buckled operation, lead). Besides the belt conveyor system and calender (contact) setting, the sieve or perforated drum technology has acquitted itself and found acceptance in continuous setting. It offers uniformity, turnover of the fibre material and modest energy and space demands (fig. 17).

In continuous (hot-air) setting by the perforated drum technique, the tow is able to shrink on account of the lead. With contact drying on the other hand the tow is kept under constant tension. Depending on the process and fibre type, setting may be done after stapling too. For this the fibre fleece is taken by a duct onto the sieve or perforated drum.

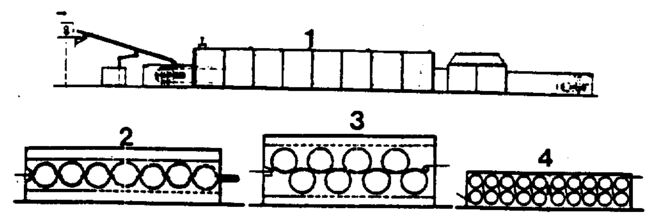

Fig. 17
Setting polyester tows (Fleissner)
1 Slat conveyor dryer with cooling zone for crimp setting, cooling zone 5 . . . 10 °C above room temperature
2 Hot air setting with sieve drum dryer, free shrinkage, lead up to 1000 %
3 Hot air setting allowing for shrinkage curve with sieve drum dryer
4 Contact setting with calender under defined tow tension (before crimping)

Fibre finishes

Here the term «finishing» means the application of spinning finishes and lubricants on the tow line in order to secure optimal running behaviour during the production and downstream processing of manmade fibres. The finish ensures good running on the tow line itself, and also assists drawing thanks to its softening action. Adequate filament adhesion assures good closure of the filaments, thus preventing gumming or breaking of the individual filaments, which otherwise leads to lap-ups on the drawing systems. Moreover a certain filament-to-metal friction is desirable, in order to obtain slip-free drawing. It is not proposed to enlarge here upon the application of finish to assists further processing of the fibres. Finish application on the tow line may be effected by means of rolls or by spraying. Other processes practicable on major installations are shown in fig. 15 among others.

In immersion rod finishing the tow is pressed into the bath by rods; with sieve drum finishing the finish flows through the entire tow.

Crimping

Staple fibres are characterized by a particular length and irregular waviness – the so-called crimp. Crimp and staple length are familiar features of natural fibres.

In the course of the development of the textile industry its machinery and equipment have been matched to the properties of the natural fibres, and analogously the manmade fibres were adapted too. Accordingly a distinction is made between cotton and wool types. The crimp is crucial to the achievement of a satisfactory yarn. It occurs in coarse – and fine-waved forms. Besides its outer form its stability is of special importance, because the fibres are exposed to very strong tensile forces during processing. In principle crimping may be achieved by two routes: exploiting small differences in the inner structure of the fibre, or external mechanical action.

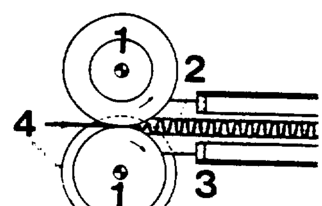

Fig. 18
Diagram of a stuffer-box crimping system
1 Rollers for introducing the tow
2 Stuffer box
3 Tempering (only with certain types)
4 Tow

In the former case structural differences cause stresses, which when released lead to differential contraction and hence to irregular kinks (see viscose staple crimping or bicomponent fibres). In melt-spinning such structural differences may be induced among other ways by means of a cold air blast from one side under the spinneret. Two methods are employed in practice: stuffer-box crimping **(figs. 18, 19)** and the now little-used gear crimping method. Worldwide the greater part of the thermoplastic spinning fibres are crimped by the stuffer-box route. By this process a pair of heavily loaded, partly watercooled steel rollers delivers the tow at high speed into a duct-shaped champer adjustable in volume, causing buckling of the tow accompanied by pressure build-up. In this way the crimped tow is forced through the narrowing end of the chamber and led off continuously.

Fig. 19
Double crimping unit (after Fleissner)
1 Entry
2 Exit

The theoretical explanation of this process is extremely complicated, consequently the various constructions are mostly based on empiricism. Though the crimp form yielded by the stuffer-box process is unfavourable, considered mechanically, on account of the sharp kinks, it is preferred on the strength of the high production attained. For that reason continuous endeavours are being made to effect improvements by examining the process parameters, such as the influence of the flap loading, stuffer-box geometry, overall and individual denier, nature and quantity of finish application, fibre stiffness (drawing process), fibre cross section etc.

Stapling

The type of a spinning fibre is governed primarily by its length. The average cut length with the crimp drawn out is generally termed the staple length. This value is a mean emerging from the so-called staple diagram. For producing spun yarns and electrostatically flocked articles, industry demands staple lengths of typically 0.1 mm for flocks, up to 200 mm for carpet yarn spinning. The individual fibre deniers range between 1.2 and 20 dtex, and like the staple lengths they are also matched to the conditions of the particular yarn spinning operation. In the case of blends with natural fibres like wool and cotton, they are adapted to these likewise.

At the high tow speeds (up to 380 m/min), exacting demands are placed on the uniformity of the cut length. Cutter life also plays an important part. Fibres dulled with titanium oxide shorten the cutter life. Blunt cutters result in fusions or overlength fibres. There are three basic stapling methods:

- A revolving tow is cut by stationary knives.
- A tow running through is cut by moving (rotating) cutters.
- A tow wound onto a revolving knife drum is cut by the knives **(fig. 20)**.

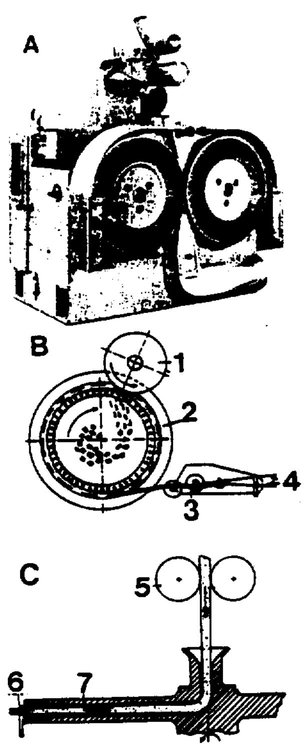

Fig. 20
Three different stapling methods
A Stapling machine Type Gru-Gru with slotted wheels and cutter head, running tow and rotating cutters (Neumag)
B Stapling machine on the Kodak principle, with tow on rotating drum and stationary cutters
C Modified stapling machine on the Beria principle, with tow rotating and fixed cutters

1 Press roll
2 Cutting wheel
3 Adjustable tow guide
4 Tow
5 Delivery
6 Cutter
7 Rotor

Two designs tracing back to BERIA and GRUNERT and developed originally for rayon serve today, after various improvements, for stapling synthetic filament tows.

Staple converting machines are made by Barmag, Day Mixing, Duranitre, Fleissner, Krupp Spinnbau, Lummus Industries, Neumag, AT. Pierret S.p.r.l., Rieter AG, Sant' Andrea Novara etc.

After cutting, the staple fibres drop into a hopper and are then conveyed pneumatically (maximum draw-off speed 380 m/min). Handling a tow weight up to 220 ktex, the cutting speed is 150 m/min, which constitutes a performance of about 2000 kg/h. After stapling, the fibres are either opened or conveyed straight to the bale press, where they are pressed into bales weighing 200 . . . 300 kg.

Processing polyester wastes

According to experience the production of staple fibre is accompanied by 5 . . . 10 % waste fibres. Whereas polyamide wastes can be remelted and processed into low-grade fibres or plastics, direct re-use of polyester waste is not possible on account ot its thermal instability. One practicable method is to split the polymeric polyester molecule into its two component monomers by cracking the characteristic ester groups with the aid of suitable saponification reagents. This can be accomplished with the following processes:

1. Cracking hydrolysis by means of water and forming terephthalic acid and glycol.

2. Saponification with cracking by inorganic acids or fatty acids, again yielding terephtaltic acid.
3. Saponification with caustic soda solution or sodium carbonate and isolation of terephtalic acid.
4. Alcoholysis with ethylene glycol with formation of monomeric terephthalic acid diglycol ester.

Reprocessing is justified by ecological as well as economic grounds.

As with any industrial product, quality control and grading play a major part in the production of polyester staple and filament yarns too. Production control starts with the spinning and runs through all production stages. The assessment of the strength, crimp, coloration, cut length etc. at the end-product acceptance provides the yardstick for quality grading.

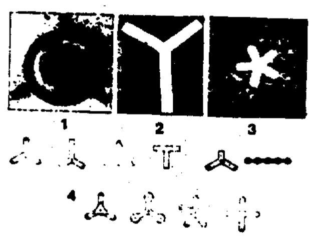

Fig. 21
Spinneret hole shapes for melt spinning (Heraeus)
1 Hollow section hole
2 Y section
3 Pentagram section
4 Various sections

Among the synthetic fibres, polyester has the widest variation range thanks to its universal properties. Besides the main types – the cotton, wool, filling and carpet fibres and those for technical applications – there are modifications for special purposes and application areas. Denier and cut length are the primary distinguishing features. A substantial part is played also by the strength, pilling and shrinkage behaviour, fibre cross section, dyeability with and without carrier and with various dyestuff classes, and resistance to physical, chemical and biological influences. Individual fibre denier lies between 1.2 and 20 dtex, cut length between 0.1 and 200 mm. The fibres may be spun from round or special spinneret orifices (figs. 21, 22).

Tows for processing via converters may be produced in weight of 100 ktex and more.

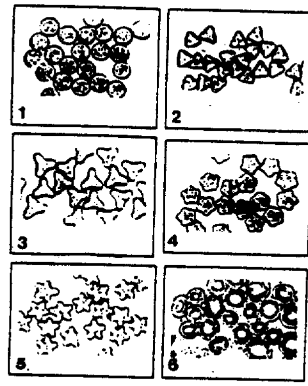

Fig. 22
Cross sections of polyester staple fibres
1 Round
2 Triangular
3 Trilobal
4 Pentalobel
5 Pentagram
6 Hollow

2.4 Dry- and wet-spun polyacrylonitrile staple

Polyacrylonitrile may be spun only from solution, because decomposition of the raw material ensues already before the melting point is reached (330 °C). The term »polyacrylonitrile fibres« covers all fibres consisting of at least 85 % polymerized acrylonitrile. Most fibres contain 89 . . . 95 % ternary copolymers and 4 . . . 11 % of a non-ionogenic comonomer with a sulpho or sulphonate group. The composition of the copolymer determines the dyeing behaviour. As internal softeners the non-ionogenic comonomers raise the dye uptake speed, while the iogenic ones allow dyeing with brilliant basic dyestuff thanks to their sulpho or sulphonate groups. Basic comonomers allow dyeings with acid dyestuffs.

The term »modacrylic fibres« is applied to fibres containing between 85 and 50 % combined polyacrylic. Fibres with flame-retardant properties are obtained for example with 50 . . . 60 % vinyl chloride polymerized-in or 30 . . . 40 % vinylidene chloride.

Dry spinning

As solvent for the powder polymer, dimethylformamide (DMF) is used exclusively. Fig. 23 shows a dry spinning plant schematically. A few technical details of it are given below:

1. Preheating of the polyacrylic spinning solution (25 . . . 30 % DMF only) (heat exchanger 110 . . . 120 °C)
2. Heated metering gear pump, 10 . . . 15 bar, temperature up to 130 °C
3. Spinning shaft 4 . . . 8 m, annular spinneret with prefiltration, inner and outer flow of hot gas for gelling, 300 . . . 2000 holes. Literature: 2 . . . 8000 (15 000 ?)
4. Hot gas flow 310 . . . 400 °C, O_2 ——→ absent DMF evaporation in shaft: 70 . . . 80 % DMF evaporation at shaft end: 10 . . . 15 % (vacuum in shaft)
5. Enclosed tow guiding in water (recovery)
6. Haul-off: 250 . . . 500 m/min by roll trio or quartet
7. Can coiling

After degassing and filtration the 25 . . . 30 % solution is first kept between 70 and 100 °C, because after a certain time the solution

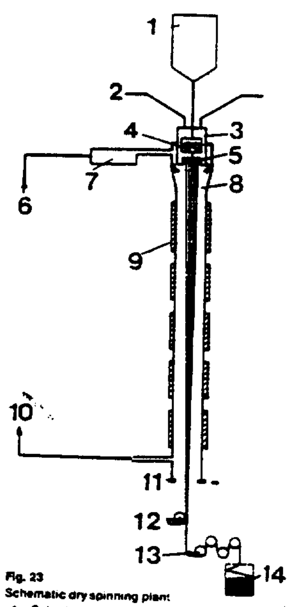

Fig. 23
Schematic dry spinning plant
1 Spinning tank
2 Cooling water supply
3 Spinning head
4 Gear spinning pump
5 Annular spinneret
6 Carrier gas
7 Gas heater
8 Spinning shaft
9 Shaft shell
10 Solvent recovery
11 Orifice
12 Finish application rolls
13 Haul-off rolls
14 Can coiling

starts to gel both above and below this temperature range. Prior to spinning, the temperature of the solution is raised up to 150 °C, and can then be extruded through the spinneret plate with up to 2000 holes.

In the direction of the emerging solution a hot inert gas is blown at 300 ... 400 °C. The solvent evaporates, causing the filaments to solidify. The filaments run through the vertical spinning shaft, whose walls are heated to 150 ... 220 °C, and are hauled off at 200 ... 500 m/min, treated with spin finish below the shaft and coiled into cans. The DMF entrained by the inert gas is condensed in coolers and thus recovered. The filaments still contain some 7 ... 30 % DMF, which is washed out in the post-treatment and likewise recovered by distilling the wash liquor.

The spinning conditions, e. g. solvent, shaft and spinning gas temperatures, gas flow rate and haul-off speed, determine the properties for downstream processing, i. e. drawability, strength and extension.

Table II Advantages and disadvantages of high-speed spinning

Process stage	Advantages	Disadvantages
Spinning	Higher throughput per spinning position, godetless spinning possible up to 4000 m/min, savings, smooth thread run in spinning shaft, better uniformity of the filament yarn.	Smaller maximum number of threads per spinning position, starting problematic with fine deniers, 16, maybe only 4, 6 or 8 filament yarns per position possible, more expensive take-up unit, delicate, loud, wear-prone, more waste when doffing.
Storage and transport	Better storage life, 4 weeks at 25 °C, 65 % r. h., undrawn 1 ... 2 weeks, more stable and harder spinning packages, better packing and transport.	
Drawing	Eliminated, specially suited for simultaneous draw-texturing, spinning package instead of drawn caps (savings).	

Wet spinning

Whereas only one solvent (DMF) is used for dry spinning, various pure organic substances are employed in wet spinning as well as mixtures and solutions of acids or salts in water (table II). This table also gives the concentrations of the spinning solutions, the composition and temperature of the precipitation baths and the breakdown of total production between the various processes. The spinning solution is extruded through spinnerets with 3000 ... 50 000 holes into the precipitation bath, which generally consists of the solvent diluted with water. Haul-off speed is 5 ... 20 m/min, ranging up to 70 m/min according to recent claims. Precipitation or coagulation ensues by diffusion of the solvent out of the thread into the bath, and by diffusion of the precipitant water into the thread. In the process a highly swollen gel thread results at first, which has to be densified in the post-treatment still (fig. 24). The process stages for wet spinning are set out below.

1. Polyacrylic solution, 20 ... 25 %, 18 ... 25 °C
2. Candle filters, spinning branches, pressure 7 ... 12 bar (see viscose)
3. Precipitation bath DMF/H_2O (approx. 50/50 %), temperature 18 ... 35 °C
4. Number of spinneret holes 3000 ... 60 000, 100 000 and more according to the literature, hole diameter 0.07 ... 0.2 mm
5. Haul-off rolls: 5 ... 20 m/min, 70 m/min according to the literature
6. Wet drawing: 1 : 6, 1 : 8 etc., 2nd bath DMF/H_2O, temperature 80 ... 90 °C without contact drawing (hot air)
7. Washing by tub washer or perforated drum
8. Contact drawing

9. Shrinking (hot water)	Shrinkage sector
10. Crimper (wet tow)	Finish application
11. Stapling	Steaming
12. Dryer belt	Crimping
13. Opener	(Stapling)
14. Bale press	Packing press or carton filling

Between the processes employed mostly there is a wide variation in the percentage composition of the precipitation baths and in the temperatures applied. Thus by appropriate choice of the coagulation conditions in the precipitation bath the core-sheath structure of the filaments can be developed, the fibres made more or less porous, and the cross section varied from round to kidney-shaped.

Post-treatment

The post-treatment endows the fibre material with the technological properties needed for downstream processing, and with the textile properties required for the end use. Both dry- and wet-spun fibres require the following process stages:

washing – drawing – finishing – crimping – drying – stapling – packing.

While dry-spun filaments are first gathered together as tows of 40 ... 100 g/m (40 ... 100 ktex) and coiled into cans prior to post-treatment, wet-spun filaments are post-treated continuously from the precipitation bath (fig. 25).

From can storage the tow (0.8 ... 2.5 mio. dtex) is led to washing in a multicompartment or perforated drum washing machine. Here the rest of the DMF (2 ... 4 %) is washed out at temperatures of 50 ... 80 °C. This may be followed by wet drawing or finish application. After finishing comes drying on a roller dryer at 120 ... 180 °C, calendering and drawing with ratios from 1 : 2 ... 1 : 5 and more. After this three different process routes are possible:

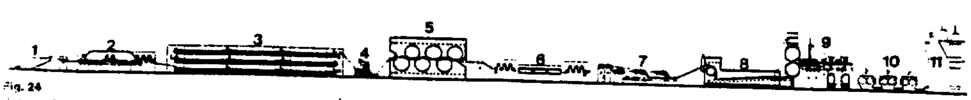

Fig. 24
Polyacrylonitrile wet spinning process
1 Spinning
2 Wet drawing
3 Washing (perforated drum wash)
4 Finish application
5 Drying
6 Wet drawing
7 Crimping
8 Steaming
9 Cooling
10 Stapling
11 Bale press

Fig. 25
Polyacrylonitrile dry spinning process
1 Can feed
2 Wet drawing
3 Washing
4 Finish
5 Drying
6 After-drawing
7 Crimping
8 Stapling
9 Steaming
10 Cooling
11 Carton filling (folding)

1. Shrinking Cooling Steaming Crimping Stapling Packing	2. Cooling Steaming Crimping Stapling Steaming Packing	3. Steaming Shrinking Drying Opening (tensioning) Crimping steaming Carton filling

Steaming may be applied with heated rollers, in steaming chambers, perforated drum dryers or sieve belt dryers.

Dry and wet spinning compared

Polyacrylonitrile fibres spun by the wet and dry routes are equivalent in quality and differ only in the cross section (fig. 26), handle and lustre of the fibres. Dry-spun fibres have more sheen and softer handle.

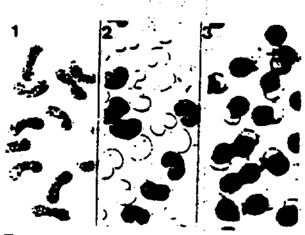

Fig. 26
Polyacrylonitrile fibre cross sections
1 Dry-spun filaments
2 Wet-spun filaments
3 Bicomponent filaments

These properties are important only from the fashion aspect, depending on the article. The somewhat faster dye uptake by the wet-spun fibres is explained by the slightly higher comonomer content of 7 . . . 10% compared with 5 . . . 7% in the dry-spun material. The concentration of the spinning solution in dry spinning is 25 . . . 30%, which together with the rapid evaporation of the solvent and the speedy formation of an already preoriented fibre structure allows high haul-off speeds and direct coiling into cans.

In wet spinning, out of the 20 . . . 25% solution a highly swollen, hardly oriented gel thread is formed first; its fibre structure emerges only after washing out the residual salts and drawing, which explains the continuous further processing and the low haul-off speeds.

The post-treatment stages have been set out briefly, and it is not proposed to go into details here insofar as the processes involved are applicable to other synthetic fibres also. Only a few special features and data will be given. Draw ratio ranges generally from 1 : 2 . . . 1 : 10, with wet-spun fibres requiring a higher draw on account of the reasons already quoted. Drawing is accomplished mainly in baths with entry and exit quintets or septets, with hot water as medium. After drying, the fibres have a boil shrinkage of 15 . . . 45% depending on the amount of drawing. Blending fibres with different boil shrinkage enables bulked yarns to be produced. The dry and wet spinning processes described are used also for producing bicomponent staple fibres and tows. The essential differences are the type of spinneret and method of crimping, which may be induced by steam, moist heat or hot air.

Crimp is imparted by the stuffer-box method, and may be applied before or after drying. Drying is applied down to 1 . . . 2% moisture content. In tensionless drying the shrinkage is included automatically, so that the fibre is stabilized or set. Otherwise steaming must be applied for this purpose (fig. 27). Spin-dyeing in the spinning solution (spinneret dyeing) is possible, as well as dyeing of the spun material, which gives rapid dye uptake especially in wet spinning with the highly swollen gel threads. Drying is performed with perforated drums for wet-spun, dull types in particular, while calender drying is used for bright types.

End products of polyacrylonitrile fibre production are tows for conversion on stretch-breakers, or cut fibres pressed into bales. Usua fibre lengths lie between 30 anc 150 mm depending on the application area.

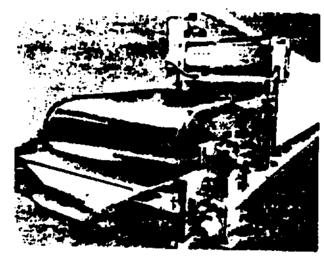

Fig. 27
Sieve-drum perforated belt steamer (Fleissner)

Packing

All presses apply a pre – and a post – or final pressing. By prepressing the material is condensed. Post-pressing reaches the final bale weight while the pre-press is already being filled again.

3. Filament yarn production

3.1 Viscose filament yarns

Spinning filament yarn

The treatment of the viscose spinning solution and the spinning or thread formation have already been dealt with at length under 2.1 (viscose staple production). The normal spinning bath has the following composition:

100 . . . 125 g/l sulphuric acid H_2SO_4
230 . . . 250 g/l sodium sulphate Na_2SO_4
5 . . . 10 g/l zinc sulphate $ZnSO_4$

The coagulation zone is normally about 25 . . . 40 cm long, though it may measure 60 . . . 200 cm according to process and spinning speed. In fig. 28 the production stages for viscose filament yarns are shown schematically.

iscose filament yarns are normally pun with one bath. In high-speed r continuous spinning a second r even a third decomposition bath s used, a third decomposition bath s used, in order to accelerate the ecomposition reactions. The importance of zinc sulphate in the pinning bath and the chemical actions associated with it have en mentioned already under 2.1.

1. 28
duction stages for viscose filament yarns
Spinning (take-up)
Post-treatment
Coning
Packing

ith the classical process – in contrast to continuous spinning – the ecomposition or regeneration process is accomplished 80 . . . 90% in e first or primary bath. Residual ecomposition takes place on the ackage or in a second bath. For ontinuous spinning even a third ath is employed for decomposition. ith regard to concentration, evaporation and preparation of the rayon spinning bath, the same procedures are followed as for rayon aple. The draw filament yarn is her taken up on a package ackage spinning) or else in the rm of a spinning cake by a revolvg spinning pot (6 . . . 1200 rpm). l modern machines are equipped th godets. In the package spinng process the thread guider and averse motion play a special part assuring perfect yarn build. With gard to package spinning it must said also that apart from the noral treatment the package undergoes only deacidification, after hich the non-desulphurized yarn dried. Further treatment is then plied to a yarn package produced twisting machines. A wash with t water is always given between e two treatment stages.

art from the old, familiar package nning process (see under Posttment), modern spinning machi- are presented in figs. 29 and 30.

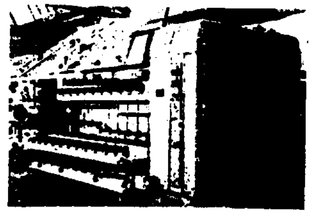

Fig. 29
Centrifuge spinning machine (A. Maurer S.A.)

Fig. 30
Continuous spinning plant for viscose filament yarns (Enka AG)

Post-treatment of filament yarns

The various post-treatment baths do not differ essentially from those used in rayon production (see 2.1). In contrast, however, various possibilities are open depending on the spinning process. The treatment stages are listed below.

Treatment baths

1. Packages – vacuum and pressure wash, inside ⇄ outside
2. Spinning cakes – pressure wash, inside ⟶ outside
3. Continuous: individual or group treatment

Drying

Drying on spinning package, only partially deacidified ⟶ followed by twisting package + finish, drying

Drying spinning cakes
Drying running filament yarns in the continuous process
Drying channel
Belt dryers
Vacuum drying
High-frequency (tunnel) dryer
Drum dryer (continuous)
Conditioning

The take-up arrangements for the filament yarn spun determine the various forms of post-treatment too. In discontinuous post-treatment, trucks with boxes or rods loaded with spinning or twisting packages or spinning cakes are taken to the individual washing stations with the appropriate connections for the individual post-treatment baths (fig. 31). To protect the yarn build the spinning cakes and twisting packages are provided with sleeves and knitted nets.

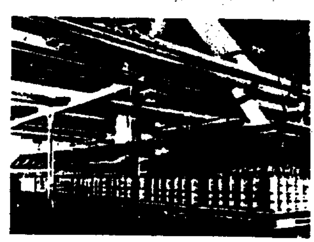

Fig. 31
Package washing plant (Enka AG)

Final textile operations

After completing the chemical post-treatment and drying, which is crucial to the internal and external shrinkage equalization, the yarn is brought into sales form ready for dispatch. The individual production operations are attuned to the spinning process. Continuous machines usually deliver a material ready for dispatch. The cakes from the centrifuges can be dispatched after post-treatment in many cases. The package process entails a lengthy post-treatment. Twisting is followed by shrinkage on the twisting package, immersion in finish and drying once more. For processing viscose filament yarns the thread closure by twisting is practically indispensable. The various twisting possibilities are:

- twisting in the spinning pot
- twisting with ring spindles
- twisting with cap spindles
- twisting with uptwisters
- twisting on two-for-one twisting machines.

This is followed by:

- shrinking the twisting packages (without package centres)
- winding (cones, cheeses) or
- production of spinning cakes ready for dispatch
- production of twisting packages ready for dispatch
- sorting
- packing and
- winding thread sheets onto warp beams or section beams.

Despite the warp beam make-up, cones are still the predominant dispatch form for viscose filament yarns. The cones are wound on standardized tubes of impregnated cardboard or plastic. Under circumstances, twisted yarns produced by the continuous route may undergo no further post-treatment at all if the original packages are fit for dispatch. Textile viscose filament yarns are generally rewound onto cones or dispatched on warp beams.

3.2 Polyester filament yarns

Like the staple fibres, polyester filament yarns consists in nearly all cases of polyethylene terephthalate, their modification of polybutylene telephtalate. Raw material production and extrusion have been described largely for the production of staple fibres. On the other hand the spinning technology has undergone fundamental innovations compared with classical spinning. Fig. 32 provides an overview of filament yarn production.

In the production of filament yarns special requirements are placed in the way of raw material purity and filtration. Besides the proven sand filters (see 2.2), sintered metal filters or multilayer fabric filters of metallic fibres have been used recently. The spinnerets normally have only 4 ... 48 holes, in contrast to the big spinnerets used for staple fibres (fig. 33).

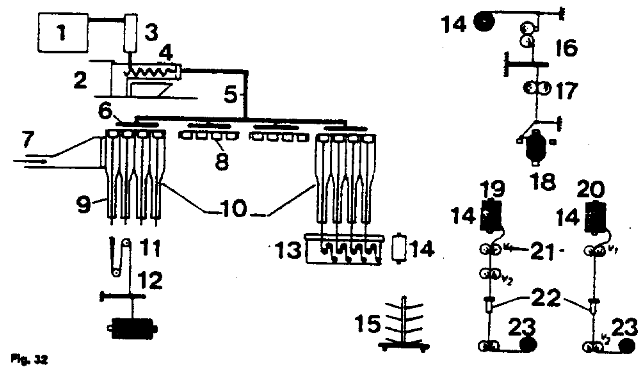

Fig. 32
Schematic melt-spinning process for polyester filament yarn

1 Chips
2 Direct spinning from the melt
3 Dryer
4 Extruder
5 Spinning manifold
6 Spinning heads
7 Blowing air
8 Spinnerets
9 Spinning shaft
10 Solidification
11 Spin-drawing
12 High-speed spinning
13 Take-up
14 Spinning package
15 Package trunk
16 Classical draw-twisting
17 Drawing
18 Draw-texturing
19 Sequential process
20 Simultaneous process
21 Drawing unit
22 Twist imparter
23 Texturing package

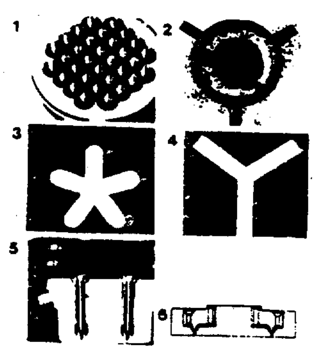

Fig. 33
Spinneret shapes (Heraeus)

1 Spinning plate with 32 holes
2 Hole for hollow-section fibres
3 Spinneret for pentalobal fibres
4 Spinneret for trilobal fibres
5 Hole plate with 8 holes (cut off)
6 Section through bicomponent spinneret

Solidification of the filaments is effected in special blowing and spinning shafts; the length of these depends on the haul-off speed among other things and ranges from 4 ... 10 m. Special guide plates are needed also, for optimal flow conditions in the blowing shaft.

The layout and subdivision of a spinning plant have already been dealt with in 2.2. In the production of filament yarn, however, a need has arisen recently for great flexibility in the spinning plant, in order to keep the denier range in line with the changing demands of the market. No production must be sacrificed when spinning fine deniers: the number of filament yarns in the tow is increased instead. The spinning manifold in fig. 13 is designed to allow 1, 2, 4, 8 etc. filament yarns to be spun optionally at each spinning position. Only the pump block and spinneret blocks are changed.

Fig. 34
Conventional take-up unit (Hoechst-Uhde International GmbH)

In filament yarn production, further processing of the yarns is given singly after leaving the spinning shaft and finish application on the running roller. In classical spinning, which is now limited to a haul-off speed of about 1500 m/min, the filament yarn is taken up on spinning packages and taken on special trucks to the draw-twisting or draw-winding machine (figs. 34, 35).

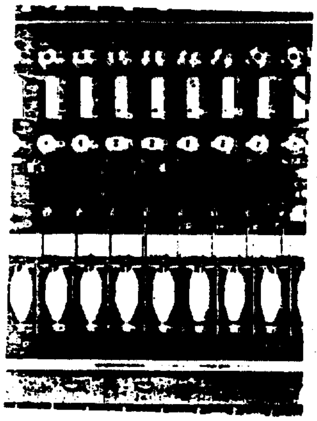

Fig. 35
Classical draw-twisting machine with heated upper godet and block heaters, delivery 1200 m/min (Rieter Ltd.)

Here after a drawing of 1 : 3 ... 1 : 3,5 the yarn is taken up on drawn cops with a twist of 5 ... 20 T/m (heated godets 80 ... 110 °C).

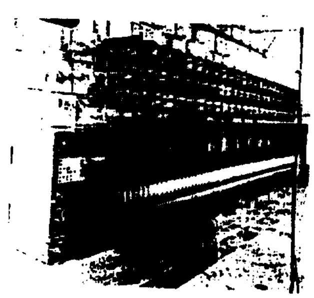

Fig. 36
High-speed draw-twisting machine with delivery 2000 m/min (Rieter Ltd.)

These drawn cops weighing 2 ... 3 kg pass to further processing. Depending on the application area of the filament yarn a high twist between 350 and 1000 T/m may be imparted. This highly twisted yarn is put through a setting process lasting 1 ... 2 hours at 110 ... 120 °C (steaming). Generally rewinding from draw-twisting cops onto cones takes place (figs. 36, 37).

Fig. 37
Precision cross winding machine KEK-PN (Schweiter Ltd.)

Current new developments

By new developments in machinery for the spinning and texturing of synthetic filament yarns, during recent years the foundations have been laid for an improved process technology, and substantial advances have been achieved in the designs of spinning installations. Starting from conventional spinning with initially 800 m/min, attemps have been made to link up spinning, drawing and texturing. The main development emphasis has been on spin-drawing, i. e. spinning combined with drawing, followed by so-called high-speed spinning for modern texturing processes. One prerequisite for the achievement of an economical spin-drawing process is a take-up system with a working speed far superior to the performances of the spinning take-up positions for the discontinuous process. Because of this, spin-drawing was first developed to technical maturity. With this process, prior to take-up the filament yarn runs over godets turning at different speeds, drawing it as on a draw-twisting machine (figs. 38, 39).

Fig. 38
Spin-drawing machine with delivery up to 3000 m/min (Rieter Ltd.)

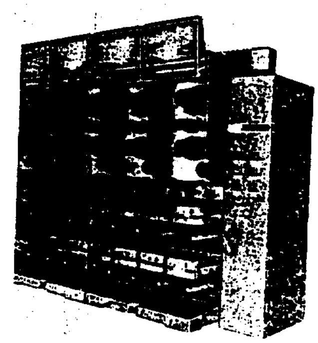

Fig. 39
Spin-drawing machine SW 4 S with delivery up to 4000 m/min (Barmag)

Spin-drawing is employed today primarily for the production of bright filament yarns which undergo downstream processing without texturing. Since with this process the spinning rate is reduced in relation to the take-up speed by the draw ratio, progress and profitability depended only on the advent of new-type high-speed winding heads. This gave birth to the idea of combining spinning, drawing and in part texturing too into one continuous process. The result is the present high-speed spinning of POY (partly oriented yarn). At the present state of the art, six spinning processes may be distinguished:

1. conventional or classical spinning (1200 ... 1500 m/min)
2. medium-speed spinning (1800 ... 3000 m/min)
3. high-speed spinning (3000 ... 4000 m/min)
4. super-high-speed spinning (5000 ... 6000 m/min)
5. spin-drawing (up to 4000 m/min)
6. high-speed spin-drawing (5000 ... 6000 m/min)

By raising the take-up speed the thread tension is increased in relation to the drawing resistance, air drag, inertia resistance, surface tension and filament yarn weight. The development of the high-speed winding heads has resulted from spin-drawing technology (1000 . . . 4000 m/min).

The modern high-speed spinning processes were preceded by some special developments. Extruders, available on the market in various sizes, are employed almost exclusively for melting. The short and equal dwell time of the product due to transport by the screw is decisively important especially for large delivery rates. The grouping of a number of spinnerets into spinning positions and several of these into one spinning manifold has made possible or simplified large-volume spinning. Throughput for a given floor space has been boosted substantially, especially in high-speed spinning. The spinneret assemblies already mentioned consist essentially of the spinneret plate and filter. The special blowing shafts arranged under the spinning unit cool the filament yarns by laminar airflow (cross current).

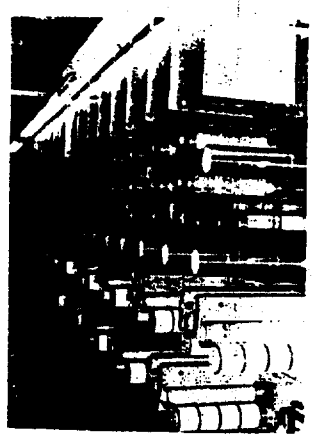

Fig. 40
Take-up machine for delivery of 2500 m/min (IWKA)

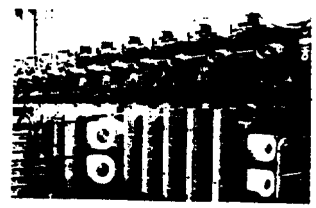

Fig. 41
Take-up machine for delivery of 3000 m/min, package doffing, four packages per spinning position (IWKA)

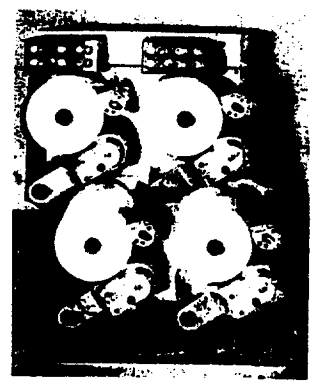

Fig. 42
High-speed take-up with four winding positions, friction roller and traverse motion, for delivery up to 5000 m/min (Rieter Ltd.)

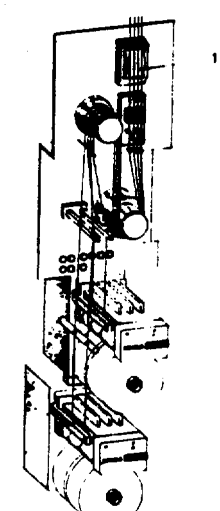

Fig. 43
High-speed spinning machine SW 4S with delivery 4000 m/min (Barmag)
1 Finish roller

To improve the take-up processes, machinery has been introduced allowing higher package weights and at the same time a number of filament yarns per spindle (e. g. 8 packages weighing 8 kg each on each spindle) (fig. 40).

On the other hand there are machines on the market winding fewer packages but with heavier package weights, e. g. two-tiered arrangement with four packages per winding position (packages weighing 10 . . . 30 kg, weight diminishing with increasing number of packages) (figs. 41 . . . 44).

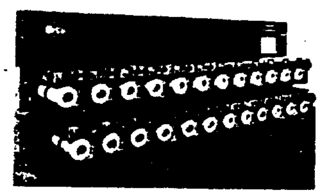

Fig. 44
High-speed winder DSG 4000 as double winder for haul-off speeds up to 4000 m/min (Alucolor)

The winding heads with high draw-off speed employ friction drive without exception. At the texturer's the spun packages running out one by one on the creel must be knotted. The so-called transfer tail is provided for this. The winding machines are equipped with a device which first winds on the transfer tail when the thread is placed on, offset axially in relation to the package. When spinning without godets the filament yarn coming from the spinning shaft must first be taken up on a waste winding until the correct denier is established, only then may the transfer tail be wound on.

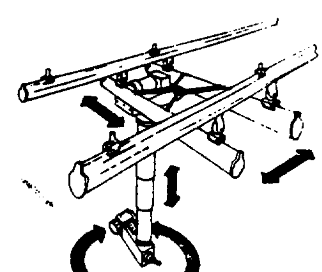

Fig. 45
Pneumatically controlled doffing device (Liebherr)

With large package weights (e. g. 15 kg) mechanized doffing devices are indispensable. Most of the doffers now in use are operated manually, but pneumatically controlled doffing appliances are already on the scene (fig. 45). (See Bulletin 1/78, page 72).

Nowadays high-speed winding systems are being used increasingly for the high-speed spinning of POY (partially oriented yarn), especially polyester (3000 ... 4000 m/min). These yarns are particularly suited for draw-texturing (simultaneous process). Development here is by no means at an end.

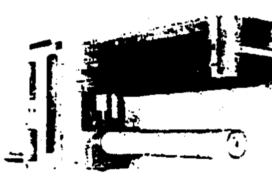

Fig. 46
High-performance winding head SW 46 SSD for delivery speeds up to 6000 m/min (Barmag)

Fig. 46 shows a winding head designed for speeds up to 6000 m/min. The filament yarn comes from above, over the preliminary traversing device in the form of a reversing thread shaft and the grooved roller, to the take-up package held centered on the spindle. The package is driven by the friction roller, which is supported in a common housing together with the grooved roller and reversing thread shaft. As the package diameter grows, this housing travels upward in precision ball guides, unloaded by two extremely easy-moving air cylinders so that the required pressing force is obtained.

The winding head is controlled by a pneumatic logic circuit which triggers the necessary sequences of motion semi-automatically after the start and stop signals.

With rising spinning (take-up) speed the throughput rate per filament yarn increases, typically by about ?% from 1200 ... 3500 m/min. At 3500 m/min the increase in the throughput rate already flattens off considerably, however. It does not rise proportionally with the spinning speed, on account of the growing molecular orientation in the spun filament yarn. The greater the spinning orientation is, the lower the draw ratio is, in other words it becomes necessary to adopt a finer spinning denier.

The thread tension in spinning is the product of drawing resistance, air drag, inertia resistance, surface tension and thread weight. The first three parameters increase with the thread speed. In conventional spinning on the other hand it reaches the necessary take-up tension or even exceeds it.

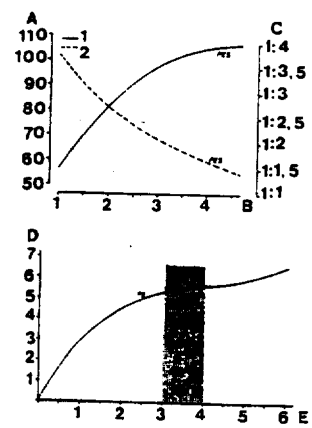

Fig. 47
Throughput rate per thread and draw ratio vs. spinning speed for polyester yarns
A Throughput/thread (grams/min)
B Winding (spinning) speed for a drawn denier of 167 dtex (1000 m/min)
C Residual drawing (stretch factor)
D Spinning speed x drawing (1000 m/min)
E Spinning speed (1000 m/min)
1 Throughput rate
2 Residual drawing

In high-speed spinning the take-up tension ranges between 20 and 50 cN. By coping with the parameters up to 3500 m/min the greater part of the possible production increase is already accomplished (fig. 47). The advantages and disadvantages of high-speed spinning are set out in table II.

The take-up tension in high-speed spinning is higher than that used in conventional spinning, with the result that harder and very stable packages are produced. The spun packages can be packed and dispatched with confidence. Unsusceptibility to storage and aging increases with the spinning speed and hence with the orientation compared with conventional undrawn filament yarns. Aging itself is accelerated by higher temperature and air humidity (storage up to 4 weeks).

Table III Textile-physical properties of POY filament yarns

Spinning speed (m/min)	Density (g/cm³)	Crystalline percentage assuming amorphous density* 1.331 g/cm³	1.338 g/cm³
1200	1.338	6	2
2500	1.341	8	4
3000	1.343	10	6
3500	1.344	11	7
drawn (85/180 °C)	1.378	40	37
simultaneously draw-textured (190 ... 210 °C)	1.390 ... 1.395	50 ... 54	47 ... 51

* a crystalline density of 1.455 g/cm³ has been assumed for calculation.

The high thread tension in high-speed spinning brings a smoother thread run in the blowing and spinning shaft, so that a more regular yarn results.

Though filament yarns spun at high speed may be processed on draw-twisting or draw-winding machines, they are employed preferentially for draw-texturing, so that the drawing operation prior to dispatch is dispensed with. Theoretically up to 16 filaments per spinning position may be produced by the high-speed process, though with fine deniers this poses difficulties when starting. For the time being, 4 ... 8 filaments are regarded as optimal.

The high speeds call for a very stable and precise assembly of the winding machine; the traverse mechanism is very complicated. On account of the very high noise generation, remedies are awaited from the makers of winding machinery and take-up tubes.

With high-speed spinning every package change is accompanied by considerable waste, while with godet spinning there is the risk of lap-ups. Resort may be had to a device for automatic doffing without losses, though of course this entails commensurately higher investment.

Physical properties of POY

The throughput rate per polyester filament yarn depends on the spinning speed. With higher speed the draw ratio diminishes too, while the double refraction and density vary correspondingly. The stress-strain curves lie between those of a conventionally spun and a drawn yarn. Depending on the spinning process the preorientation must be determined by double refraction, sonic speed, breaking extension, natural draw ratio, residual draw ratio and drawing force at constant draw ratio (fig. 48, Tables III and IV) [2].

Table IV Characteristic data of polyester POY, state of the art for simultaneous draw-texturing

	Examples:
Denier (dtex) (total range 80 ... 600)	285 ... 330
Residual draw ratio	1 : 1.6 ... 1 : 2
Double refraction ($\Delta n \cdot 10^3$)	50 ... 30
Tenacity (cN/dtex)	2.4 ... 2.0
Breaking extension (%)	110 ... 190
Density (g/cm³)	1.343
Uster evenness (U %) (normal operating mode)	<1.0

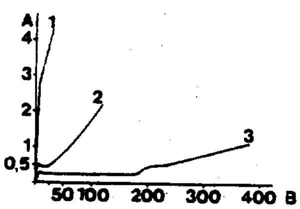

Fig. 48
Stress-strain diagrams for polyester yarns, drawn denier 167 dtex f 32
A Stress (cN/dtex)
B Strain (%)
1 Normally spun (1300 m/min) and drawn
2 High-speed-spun (3500 m/min)
3 Normally spun (1300 m/min)

Processing polyester wastes

In the production of polyester filament yarns as staple fibres, according to experience 5 ... 10 % fibre waste occurs, which cannot be used for further processing. As mentioned previously in 2.3 under the same heading, there are several ways of cracking the polymer polyester molecule into its monomer constituents.

Quality and types

As with every industrial product, quality control and grading play a decisive part in the production of polyester filament yarns too. Production control starts at the spinning machine and runs through all stages of production. The assessment of the strength, coloration, package build, extension, shrinkage etc. at the end-product acceptance provides the yardstick for quality grading.

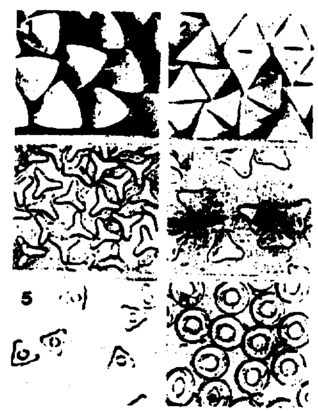

Fig. 49
Filament yarn cross sections
1+2 Triangular
3+4 Trilobal
5 Hollow section
6 Cross section of a hollow filament

Among the synthetic fibres polyester filament yarns offer a wide variation range thanks to their universal properties. Thus filament yarns are spun from round and special spinneret holes (fig. 49).

They are supplied bright, dull, extra-dull, partly spin-dyed and black-spun. The yarns are untwisted, entangled or twisted, bright or textured when delivered. The textured types are stabilized or unstabilized according to the application area. Deniers extend from 30 ... 300 dtex. Besides normal polyester types there are also chemically modified ones, such as specially deep-dyeable, basically dyeable, capillary melange, disperse dyeable, yarns with differential capillary shrinkage and with special effects, loop yarns, carrier-free-dyeable and low-flar mable types as well as other item Polyester filament yarns have four large-scale use in knitting, hosie and weaving.

3.3 Polypropylene filament yarns

During recent years, extensive wo has been done on the developme of film tape and film fibre produ tion. Most of these articles are use to produce technical textiles an carpet backings. In the meantir the production of melt-spun pol propylene fibres and filament yar has arrived. Chief application area are household textiles (e. g. upho stery or furnishing fabrics), worl wear, outerwear, technical fabric rope articles and carpets. In som cases the production and applic tion of these items is shifting ste dily into the developing countries.

In contrast to melt-spinning plant for polyamide and polyester, thos for polypropylene are equipped les elaborately. Total investments ar much lower, while production cost are no higher. In many cases thes fibres are used at their place c production, cutting-out marketin costs. Already small, low-cost plant have been engineered which ope rate economically from 100 kg pe hour.

In principle all plants work on th familiar extrusion spinning systerr As on the major installations fc melt spinning, here too the proces stages are granulate feed, coolin and take-up. The modular desig allows these plants to be extende in series at will, if large-scale prc duction with major installations i not envisaged from the outset. A the mode of operation of thes plants is similar or identical to tha of the melt-spinning plants describ ed, there is no point in enlargin upon the separate items or equip ment and processes.

Here too the take-up units hav been developed to the point wher package weights of 40 kg are attain ed. Although the melting range o polypropylene lies between 163 an

Continued on page 26

Knitted fabrics from HSO filaments reveal a soft hand and good drape. Dye uptake is very uniform, and dimensional stability after washing is excellent.

The hihger output in spinning, lower energy and labour costs and reduced waste yield conversion costs substantially lower than those of conventional spin-draw processes.

The economy calculation for nylon 6 filaments, untextured, is based on 8-end spinning at 4000 m/min, though the equipment is capable mechanically of delivery up to 6000 m/min. Spin finish is applied by means of metering pumps and perforated guides.

Take-up is without godets. Two winders are provided for each position, each forming 4 packages, i. e. 8 packages per spinning position. The daily capacity of 7 tonnes is achieved with 40 positions. Cost calculations are based on caprolactam, i. e. chip-making equipment is included. With this capacity the conversion costs for producing HSO yarns of 44 dtex from caprolactam work out at about DM 2.80 per kg.

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170 °C, spinning temperatures of 275 . . . 290 °C must be employed in the extruder, on account of the proportion of chains with particularly high polymerization (isotactic polypropylene).

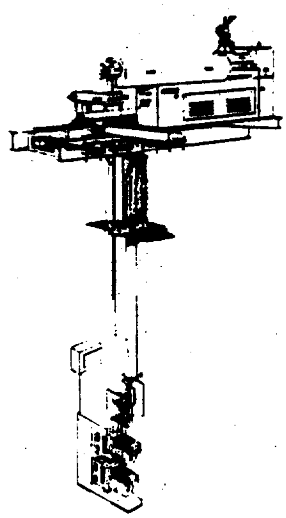

Fig. 50
Spinning plant with take-up for polypropylene filament yarns (Barmag).

Polypropylene production centres mainly on staple fibres and carpet filament yarns for texturing, in the 500 . . . 4000 dtex range. Textile filament yarn production is still modest, and is at an early development stage. Deniers of 120, 165, 210, 330 and 470 dtex have been reported in some cases (fig. 50).

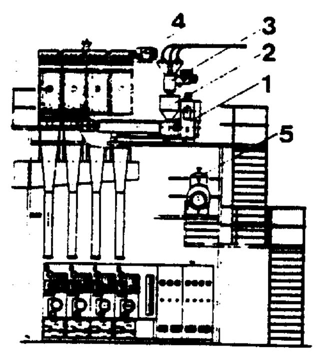

Fig. 51
Spin-texturing machine with platform (Reifenhäuser KG)

1 Extruder
2 Granulate hopper
3 Granulate metering
4 Main drive to spinning pumps
5 Diphyl vapour generator

Figs. 51 and 52 show a few production machines for polypropylene filament yarns. Though the new spin-draw-texturing process is being used only for polypropylene carpet yarns at present, it should be mentioned on account of its novelty.

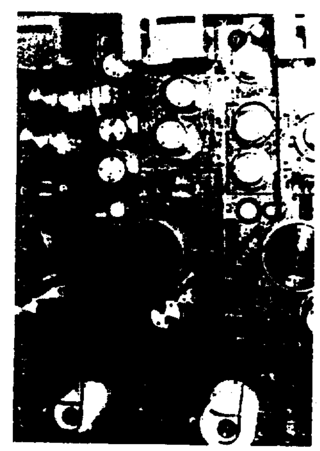

Fig. 52
High-speed draw-texturing machine NPT 2000, with pneumatic stuffer box for 500 . . . 4000 dtex, texturing speed 2 to 2500 m/min (Neumag)

4. Summing-up

The three familiar spinning processes – wet, melt and dry spinning – have been presented in the form of examples from viscose, polyacrylonitrile and polyester production. The processes described represent the latest state of the art. In addition developments have been mentioned which in some cases will become the production technology of tomorrow. All other manmade fibres have been ignored. Finally the production of polypropylene filament yarn is described.

5. Development trends

The present state of the manmade fibre industry, viewed worldwide, makes it difficult to venture a forecast. The current situation in many countries is characterized by plants operating below capacity. Nevertheless world output of manmade fibres has been rising again since 1976, and is now higher than before the energy crisis even at 12.3 mio. tons. However in Western Europe, the USA and Japan, production has not yet recovered to the 1973 level. On the other hand the rest of the world has continued to boost its production, and since 1975 it has attained 25 % of world output (e. g. polyester). Some countries in the rest of the world are expanding their share still further, and with their relatively large-scale export-oriented textile and apparel industries they are steadily narrowing the outlets for manmade fibres from the traditional industrial countries.

New polymers or synthetic fibres which might supplant the three main groups (polyamide, polyester, polyacrylonitrile) are not to be expected for the time being. An exception are the new polymers with specific properties for limited application areas. In the next few years it is pretty sure that research will be focused on chemical and physical modification of the existing raw materials and fibre types. The entire spinning and post-treatment technology will have to be aimed at production with good quality but still lower costs, though engineering has its limits too.

The medium- and long-term market prospects for manmade fibres may be assessed optimistically. By the mid-1980's manmade fibres could overtake cotton on the textile market. Compared with the other manmades, polyester fibres will continue to gain still more ground. The importance of viscose fibres will diminish further, owing to raw material problems, ecological reasons and higher production costs. Based on a world fibre usage of 22 million tons and a per-capita increase of 2%, an increase may be expected from about 8 mio. tons to a total of 30 mio. tons by the mid-1980's.

6. Bibliography

[1] SCHURZ, J.: Lenzing-Berichte 10, 5. (1961)
[2] WULFHORST, B.: Stand und Zukunft der Texturierung. 1975. Deutscher Fachverlag, Frankfurt/M

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D-7500 Karlsruhe, FR of Germany

H. Liebherr
D-7950 Biberach/Riss, FR of Germany

A. Maurer S.A.
CH-3013 Bern, Switzerland

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D-2350 Neumünster, FR of Germany

Reifenhäuser KG
D-5210 Troisdorf, FR of Germany

Rieter Ltd.
CH-8406 Winterthur, Switzerland

Schweiter Ltd.
CH-8810 Horgen, Switzerland

Author's address:

Dr. rer. nat. E. Welfers
c/o Hoechst AG
Anwendungstechnische Abteilung Textil
D-6230 Frankfurt/Main 80
FR of Germany

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Textile management

K.-H. Müntefering, T 66 in the series of handbooks for textile engineers and textile tecnicians, 350 pages, numerous illustrations, tables and charts, small format, plastic-covered binding, DM 48,—, Spohr-Verlag, 1977, Frankfurt/M., FR of Germany, in German only.

Production of needlefelts with modified needling geometries and investigation of their properties

Prof. Dr.-Ing. J. Lünenschloss, Ing. H. Külter, Institute für Textiltechnik at the Rheinisch-Westfälische Technische Hochschule Aachen, Research Report No. 2699 of Land North-Rhine Westphalia, FR of Germany, Fachgruppe Textiltechnik, 85 pages, 49 illustrations, paperbound, DM 20.–, 1977, Westdeutscher Verlag, Opladen, FR of Germany, in German only.