

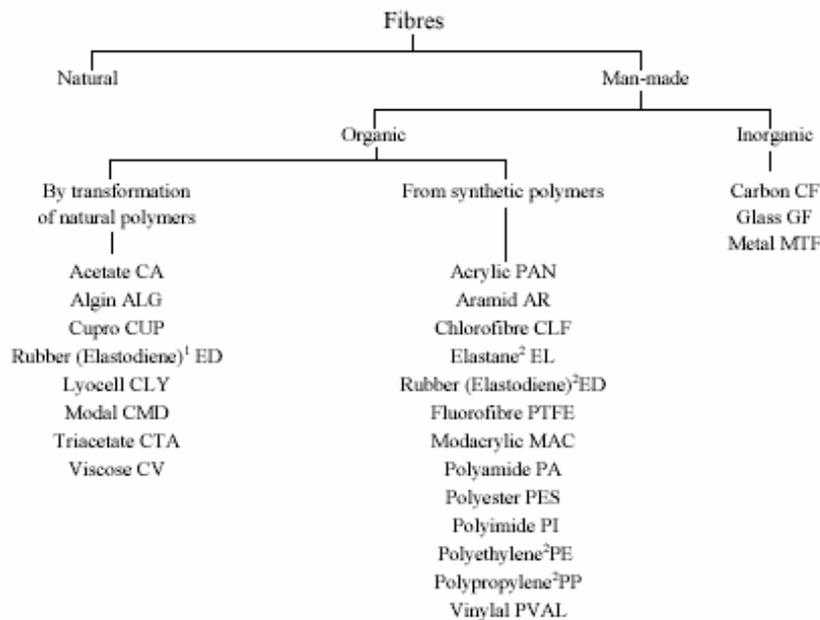
# CLASSIFICATION OF MAN-MADE FIBERS

The norm ISO 2076-1999 (E) provides a list of the denominations commonly used to designate the different categories of man-made fibers which are usually produced on industrial scale for textile uses and other applications.

Every common denomination is defined through attributes, normally based on chemical differences expressed with chemical formulas, which often have different distinctive properties (see list below).

In order to facilitate the technical and commercial exchange of information, the fibers have been identified with codes or abbreviations, based on their common names and composed by letters (from 2 to 4).

We wish to point out that generic fiber names, as used by the legislation for fiber content labeling, have to be distinct and not confused with the trade marks which each producer is free to use for the identification of his own product.



<sup>1</sup> Previously called elastofibers

<sup>2</sup> Also called polyolefins

– Classification chart of man-made fibres

# PRODUCTION PROCESSES

There is no substantial difference in the structure of natural fibers from that of man-made fibers: both fiber categories are composed of macromolecules or by linear polymers, that is by the repetition of several simple molecules (monomers).

Natural fibers are essentially composed of atoms of various elements, such as carbon, hydrogen, oxygen, sometimes of nitrogen and other elements (sulphur) in lower quantities; during their biological growth, these elements form the rings of long molecular chains.

The development of man-made fibers was based on the knowledge acquired with natural fibers, which structure was taken as a model; the difference between the two fiber categories is that natural fibers form macromolecules through biological growth; while the growth process of man-made fibers is driven through technical equipment (artificial fibers use instead natural polymers).

## Polymerization

The term polymerization defines the process of macromolecules formation through repetition of basic units: it of course applies only to fibers produced by synthesis. In general, polymerization reactions are activated and controlled during the process by various parameters, as temperature, pressure, catalyses, and reaction stabilizers.

The number of repetitive units is termed **degree of polymerization**, which is a parameter of great significance for the setting of fiber properties. As the length of the single molecules is not constant, but varies according to a statistical model, the degree of polymerization or the correspondent molecular weight has to be considered as an average value.

Depending on the various fiber typologies, the average degrees of polymerization may range from some hundred units in the case of polymers obtained through condensation (PA, PES) to some thousand units in the case of polymers resulting from poly-addition (PAN, PP). Under a production and application point of view, the degree of polymerization is controlled by measuring following parameters:

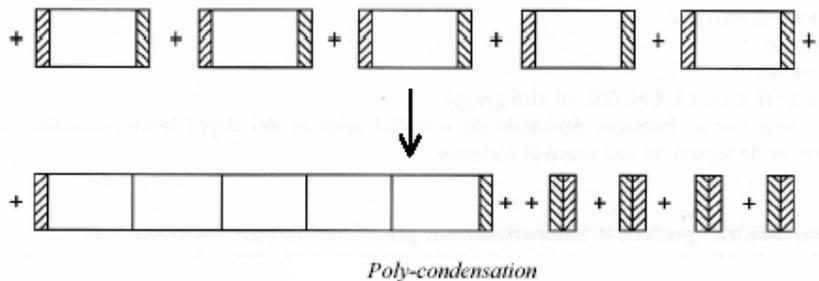
**Relative viscosity**  $\eta_{rel} = \text{solution viscosity} / \text{solvent viscosity} = \text{flow time } t_1 / \text{flow time } t_2$

**Intrinsic viscosity**  $\eta_{intr} = \eta_{sp}/c \rightarrow 0$  (concentration vanishing)  
Where  $\eta_{sp}$  (specific viscosity) =  $\eta_{rel} - 1$

**Melt flow index** MFI = speed rate of the melted polymer at pre-established conditions

Relative viscosity is a parameter which is mostly used to identify nylon, intrinsic viscosity (obtainable from the relative viscosity also by means of formulas) is used for polyester and Melt flow index is used to identify polypropylene. There are basically two mechanisms of chemical reaction available for the synthesis of linear polymers:

a) *Poly-condensation*: with this operation, molecules of same type or of different types are joined together to form macromolecules through removal of simple secondary products as water, hydrochloric acid, alcohol.



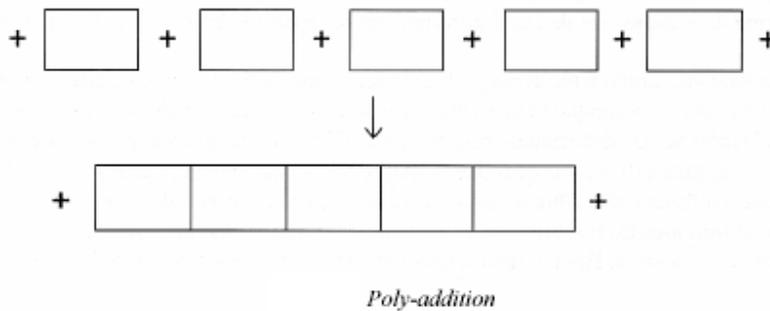
The prerequisite for reactions of this type is the presence in the molecule (monomer) of two terminal reactive groups with functional properties. The molecules composed of 2,3,4...n monomers are named dimers, trimers, tetramers (oligomers)...polymers.

Some of the mostly used monomers are:

- Aliphatic di-acids  $\text{HOOC-R-COOH}$  (used for nylon 6.6)
- Aliphatic di-amines  $\text{NH}_2\text{-R-NH}_2$  (used for nylon 6.6)
- Aliphatic amino acids  $\text{H}_2\text{N-R-COOH}$  (used for nylon 6)
- Aromatic di-acids  $\text{HOOC-Ar-COOH}$  (used for polyester)
- Diols (bi-functional alcohols)  $\text{HO-R-OH}$  (used for polyester)

Thus formed polymeric chains contain, besides carbon atoms, also various atoms (etero-atoms) resulting from the condensation reaction of the functional groups (e.g. nitrogen for polyamides, oxygen for polyester).

b) *Poly-addition*: this operation joins together several molecules and redistributes the valence links existing in the monomers, however without removing secondary products. Many unsaturated compounds which are characterized by the presence of a double link between two adjacent carbon atoms as ethylene and its derivatives, polymerise according to this reaction; within this category fall e.g. acrylic and polyolefin fibers.



Among the most used polymers there are ethylene derived molecules with one or more substitutes of hydrogen atoms.

For example:  $\text{CH}_2=\text{CHX}$

Where  $\text{X}=\text{H}, \text{CH}_3, \text{Cl}, \text{CN}, \text{OH}$  and other groups.

The chains which are thus formed originate from simple openings of double ethylene links and are therefore characterized by the presence of links only among carbon atoms.

### **Difference between addition and condensation polymerization processes**

Through poly-addition not only secondary substances are removed: the reactions follow a chain process, are quicker, highly exothermic and usually require lower temperatures. Molecular weights (degree of polymerization) are higher and it is more likely to have chains with cross or branched links.

Polymerization, once it is completed, does not leave behind polymers of intermediate length (oligomers), but only non-reacted products (monomers). Poly-condensation, on the contrary, is a process in several stages which leaves behind, among reaction products, also polymers with low molecular weight (oligomers).

### **Polymerization techniques**

From a processing point of view, the polymerization can be carried out by mass treatment, solution or dispersion (suspension, emulsion). From the engineering point of view, the process can be:

- discontinuous, where reagents are entirely pre-loaded into the reactor and, as soon as the polymerization is completed, the products are completely unloaded. The “batch” technique is used in particular for the production of small lots or of specialty items.

- continuous, where reagents are introduced from one end and reaction products come out from the other (this process is used especially for large productions). The reaction can also take place within a stationary phase (as typical for poly-additions) or at subsequent stages (as in poly-condensations).

Whichever polymerization method is applied, the reaction products (polymers) can appear as follows:

- in form of a solution to be conveyed to the spinning department;
- in form of a melted polymer to be conveyed directly to the spinning department or to be transformed into grains (chips) for subsequent use ;
- in form of a suspension, from which the polymer is separated and conveyed to the spinning department;

Along with the chemical reactants (monomers and possible catalysts) during the polymerization stage or anyway in a stage preceding spinning, other additives can be added in order to provide the fiber with certain properties: a product of particular importance is a white dulling agent (titanium dioxide in grains), which is added in small quantities in order to give the fibers a “dull” appearance, which distinguishes them from the untreated fibers which, owing to their brighter and “synthetic” appearance, are named “bright”. Under this point of view, the fiber is termed on the basis of the added quantity of titanium dioxide (dullness degree) as follows:

- bright fiber: a fiber without or with minimal quantities of titanium dioxide;
- semi-bright fiber: a slightly delustred fiber
- semi-dull fiber: usually terms delustred fibers with 0,25-0.5% titanium dioxide contents
- dull fiber: fiber with 0,5-1% titanium dioxide
- superdull fiber: fiber with 1-3% titanium dioxide

| Fibre          | Degree of polymerization | Average molecular weight                                  |
|----------------|--------------------------|-----------------------------------------------------------|
| CV             | 250-700                  | 40.000-100.000                                            |
| CUP            | 500-600                  |                                                           |
| CA             | 220-300                  |                                                           |
| PA (6 and 6.6) | 100-180                  | 15.000-30.000                                             |
| PES            | 130-220                  | 17.000-20.000 (textile fibre)<br>28.000-40.000 (HT fibre) |
| PAN            | 1000-2000                | 30.000-70.000                                             |
| CLF            | 1300-1800                | -                                                         |
| PP             |                          | 200.000-350.000                                           |
| EL             |                          | 50.000-100.000                                            |

*Table 3 Average degree of polymerisation and average molecular weights (indicative figures)*

## Spinning

The term spinning defines the extrusion process through bored devices (spinnerets) of fluid polymer masses which are able to solidify in a continuous flow. The spinning process is sometimes designated as “chemical or primary spinning” to distinguish it from the “textile or mechanical or secondary spinning”.

The polymer processing from the solid to the fluid state can take place with two methods:

1. by melting: this method can be applied on thermoplastic polymers which show stable performances at the processing temperatures (this method is used by 70% of the fibres)
2. by solution: the polymer is solved in variable concentrations according to the kind of polymer and of solvent, anyhow such as to produce a sufficiently viscous liquid (dope) (this method is used by 30% of the fibres)

Spinning via melting is definitely preferable as it entails a simple transformation of the physical state, however it can be applied only to polymer having a melting temperature (PA 6 an Pa 6.6, PES, PP), whereas spinning by solution is used in case that the polymers attain a thermal degradation at a temperature lower than melting temperature (cellulose fibres, PAN). This last method is evidently more complicated than melt spinning, owing on one hand to the necessity of dissolving the polymer in a proper solvent, and on the other to the necessity of removing and recovering the polymer after extrusion.

In the case of melt spinning, the extruded polymer, owing to its fast cooling, is transformed directly into a filament while keeping substantially unchanged the form of the cross-section resulting from the filament geometry; on the contrary, in the case of solution spinning the extruded filaments are subject to considerable structural changes brought about by the process for solvent extraction from the polymer mass.

Solvent removal can take place in two ways:

### *Dry spinning*

Solvent is removed through flows of warm gas suitably directed to the extruded filaments; gas temperature should be higher than the boiling temperature of the solvent, which will be extracted from the filaments, recovered and recycled. Filament solidification proceeds according to the extent of solvent evaporation; it takes place faster on the external yarn layers (thus creating a crust or skin), and successively slows down while proceeding towards the interior. As a consequence of the mass exchange, the original (round) cross-section of the filament undergoes a contraction, thus generating cross-sections which characterize the various kinds of fibres and spinning processes.

### *Wet spinning*

This spinning method is based on the introduction of an extruded polymeric viscose into coagulation baths where the liquor, usually water, behaves as a solvent towards the polymer solvent and as a non-solvent towards the polymer mass. Practically the solvent which is contained in the fibre in amorphous state (gel) is spread towards the liquor and at the same time the liquid of the bath is spread towards the interior of the fibre. The processing speeds are dependent on several parameters, as type and concentration of the polymeric solvent and of the liquor, which give rise to structural variations in the fibre.

In particular the formation of an outer, gardened and more compact cortex (skin), similarly to what happens in dry spinning, slows down the coagulation mechanism of the inner filament portion (core), thus creating unevenness with a more or less porous structure (voids formation). The fibre cross-sections result more or less modified, from the original round form to a lobated form, with a wrinkled surface.

### **General flowchart of the spinning process**

The flowchart which applies to the various kinds of spinning methods (see Fig. 13) is the following:

The fluid polymer mass (melted or solution mass) is guided, through distribution lines, to the metering pumps (gear system), which guarantee a constant flow rate to the spinning positions, composed of a series of filters which purify and distribute the polymer; these are coupled with perforated plates of variable thickness and size, which are usually circular and made of special stainless steel (for melt spinning), but also of precious metals or of vitreous material (for solution spinning).

The holes (capillaries), the number of which on the plate varies depending on the kind of fibre and can reach several thousands, can have circular or special cross-sections (shaped or hollow sections). The filaments extruded from the spinnerets, after being converted back to their original state of solid polymer, are interrupted and taken up in suitable packages (bobbins, cans) or conveyed directly to subsequent processing phases.

In the case of melt spinning, if the polymer does not derive already in melted state from polymerisation, the fluid polymer mass is obtained through melting of the solid polymer grains (chips). This operation was originally carried out inside containers (pipes) which were electrically heated and equipped with grids to separate solid grains from the polymer during melting (grid melting device). The use of such system is at present limited only to few applications and has been replaced by more reliable and efficient devices (screw extruder). The relations which connect some spinning parameters one another (and are calculated for melted polymers) are the following:

*Polymer flow rate:*

$$mF = VF T_{sp}/10,000$$

where:

mF = polymer quantity for each yarn (g/min)

VF = take-up speed (m/min)

T<sub>sp</sub> = linear mass of taken-up yarn (dtex)

If we know the linear mass of the drawn yarn (T<sub>d</sub>) and the draw ratio R, the relation becomes:

$$mF = VF T_d R/10,000$$

*Extrusion speed of the melted polymer*

$$VB = 4 mB/\pi d^2 \rho \quad VB = \text{extrusion speed at spinneret hole (m/min)}$$

mB = polymer quantity per spinneret hole (g/min)

d = hole diameter (mm)

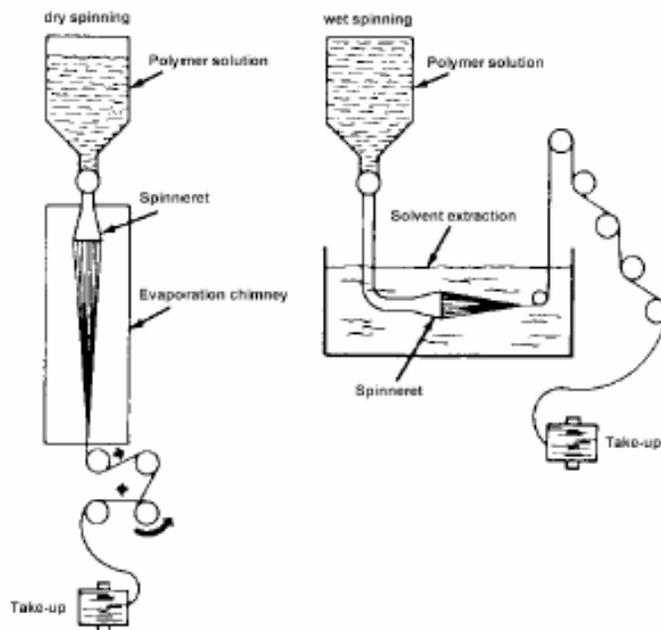
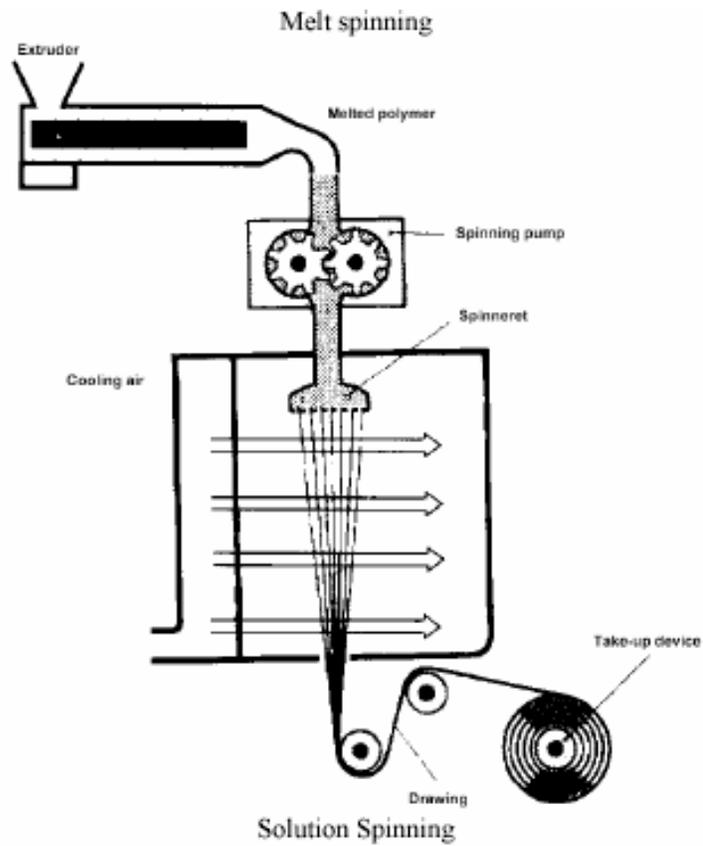
ρ = density of melted polymer (g/cm<sup>3</sup>)

*Spinning ratio*

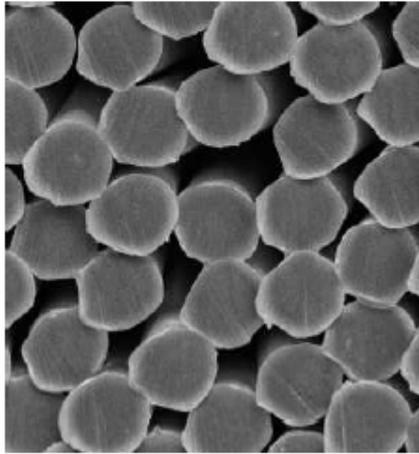
$$Q = VF/VB$$

|                        | Melt spinning                                                              | Solution spinning                                                                 |                                                       |
|------------------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------|
|                        |                                                                            | wet sp.                                                                           | dry sp.                                               |
| Principle              | Thermic exchange at temperature higher than melting point                  | Mass exchange                                                                     | Thermal exchange + mass exchange                      |
| Polymer mass viscosity | High                                                                       | Medium                                                                            |                                                       |
| Operating pressures    | High (100-300 bar)                                                         | Medium-low up to 20 bar                                                           |                                                       |
| Spinnerets             | Steel of proper thickness (2 mm and more):<br>Hole diameter : 0,15- 0.5 mm | In various materials (steel, noble metals, glass)<br>Hole diameter: 0,025-0.25 mm |                                                       |
| Spinning speed         | High<br>Yarn: up to 6,000-7,000 m/min<br>Tow: up to 1000-1500 m/min        | Slow<br>Yarn: < 200 m/min<br>Tow: 5-40 m/min                                      | Medium<br>Yarn: up to 1000 m/min<br>Tow=200-600 m/min |
| Fibre morphology:      |                                                                            |                                                                                   |                                                       |
| Cross-section          | Follows capillary profile                                                  | Usually deformed (from round to lobated)                                          | Usually deformed (from round to lobated)              |
| Structure              | Compact with smooth surface                                                | Micro-porous with rough surface                                                   | Micro-porous with compact surface                     |
| Fibres                 | PA, PES, PP                                                                | PAN, CV, CUP, CMD, EL                                                             | CA, CTA, EL, PAN                                      |

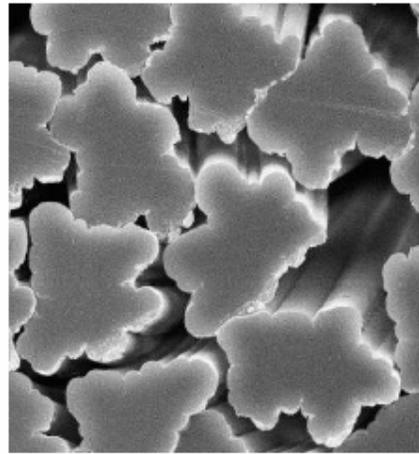
*Table 4 Comparison between the different spinning systems*



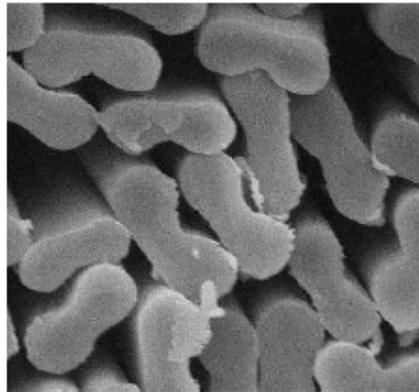
*Fig. 13 Man-made fiber spinning systems*



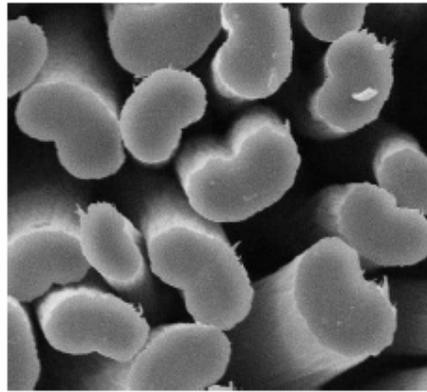
*Round cross-section of melt-spun thermoplastic fibres*



*Multi-lobal cross-section of wet-spun viscose*



*Lobed (dog-bone-shaped) cross-section of dry-spun acrylic fibre*



*Lobed (kidney-shaped) cross-section of wet-spun acrylic fibre*

*Fig. 14 Typical cross-sections of fibres produced with different spinning processes*

## **Drawing**

The polymer extruded by the spinnerets in form of filaments has not yet the properties which are typical of a textile fibre: in fact the polymer mass (solidified through cooling or solvent removal) is characterized by a mass of disorderly placed molecular chains (in amorphous state) which provides the material with poor thermal and chemical stability, low resistance to ageing, high plasticity and deformability and consequently insufficient physical/textile properties.

If we take natural fibres as models, we need to orientate the molecular chains (orientation phase) in the direction of the fibre axis and at the same time or successively activate or increase the ordered arrangement of the intermolecular structure (crystallization phase).

This process can be partly activated during spinning by increasing the ratio between the take-up speed and the extrusion speed from the spinneret (spinning ratio) but, excepted in the case of high speed spinning of continuous filament yarns, the process needs to be completed by an additional operation of mechanical drawing.

The process entails winding the yarns on rollers or cylinders running at ever increasing peripheral speed and can be carried out continuously on filaments coming from the spinning chamber (single-phase process) or on filaments coming from an intermediate phase in respect to spinning (two-phase process).

The speed ratio between delivery or drawing rollers on one side and feeding rollers on the other is the draft ratio ( $R$ ). The mechanical configuration of the rotating devices and the filament path are designed in order to ensure the equivalence of fibre speed with the speed of contact organs.

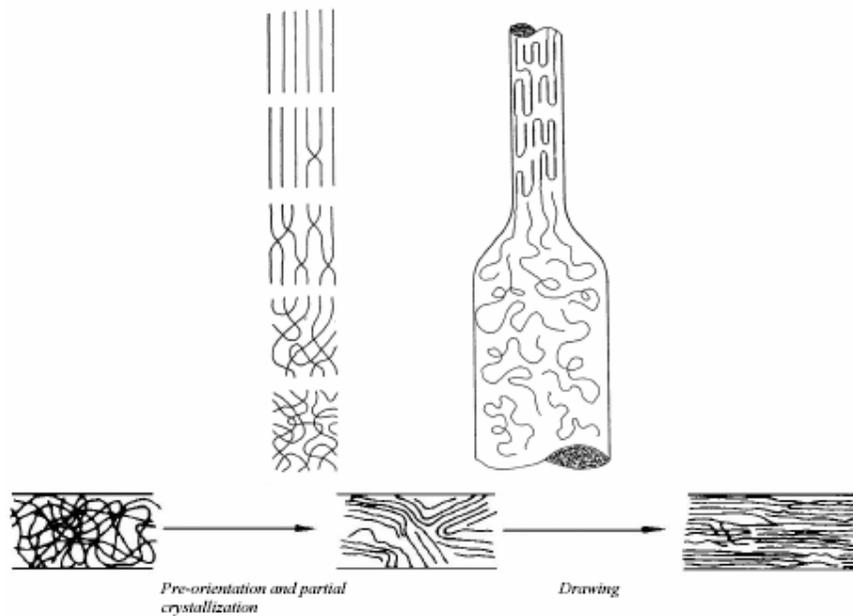


Fig. 15 Molecule orientation during drawing

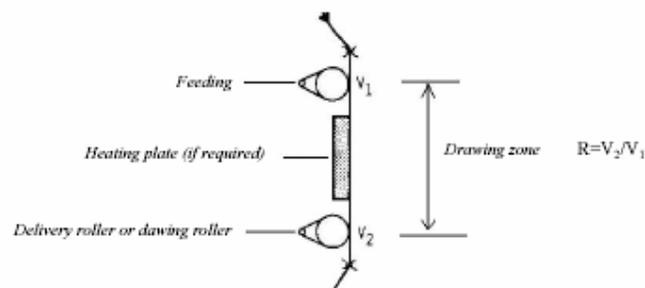


Fig. 16 Drawing principle

Draft ratio levels are variable and depend on the fibre typology, on the production process and on the end-use characteristics: they can fluctuate between values slightly higher than 1 ( $\approx 1,2$  for traditional cellulose fibres) and max. 10 (for acrylic fibres). Usual ratios for thermoplastic fibres are situated between 3 and 5; higher values identify fibres for technical applications.

Optimal conditions for fibre drawing are attained when the molecular chains show high mobility and creep; this result is in practice attained by increasing temperature to levels higher than glass transition and by introducing plasticizers which can make the structure more deformable and can reduce glass transition temperature (generally by acting upon the system water/humidity or using spinning solvents).

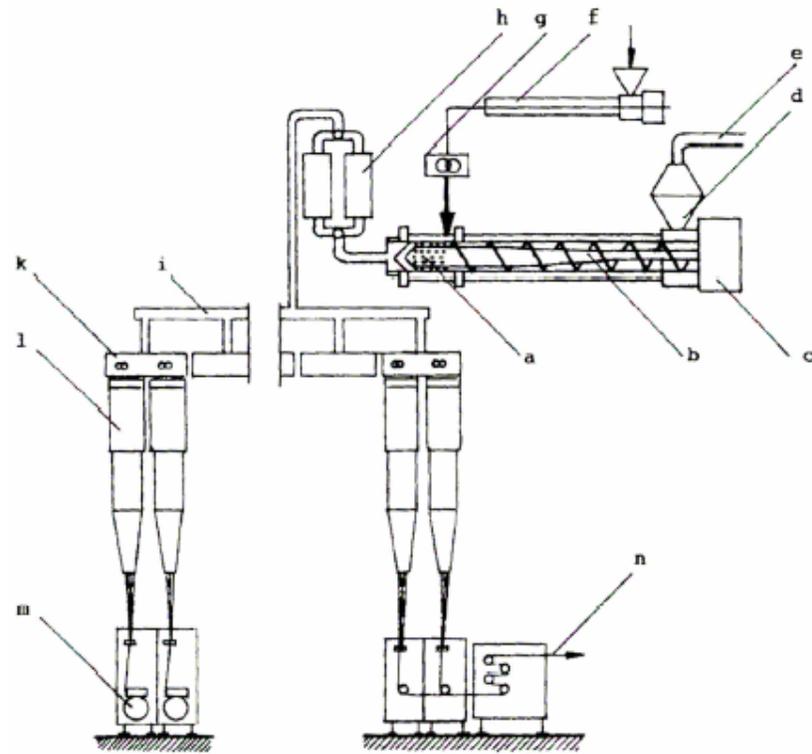
From an operational point of view, the draft zone can operate at room temperature (cold drawing) or at heated conditions (hot drawing) and consists of rollers, contact plates, heated air chambers or steam chambers and of immersion baths. In order to provide the drawn fibres with thermal stability, these fibres usually undergo also a treatment at temperature higher than drawing temperature, under controlled tensions or in a free state, with the objective of eliminating internal tensions through readjustment of the intermolecular chemical links and of the crystallization degree.

### **Production technologies for continuous filament yarns and discontinuous (staple) fibres.**

As already mentioned, from a morphological point of view fibres can be divided into discontinuous fibres and continuous filaments. This distinction applies also to natural fibres, although they have only one single case of continuous filament: silk, which is moreover available in nature only as monofilament and in limited quantities.

Only with the introduction of man-made fibres, continuous filaments took on importance and gave rise to innovative transformation processes and application sectors; at present the market of man-made fibres is roughly divided equally between the two forms of fibre. Theoretically, every fibre can originate continuous filaments or staple fibres; actually however production and application reasons have conditioned the use of one fibre form or of the other: elastane is produced exclusively as continuous filament, and nylon mostly in this form; polyester, polypropylene and viscose are produced in both forms, that is as continuous filament and as staple, whereas acrylic is produced almost exclusively in staple form.

Although the production principles are identical for continuous filament and for staple fibre, the two processes differ considerably in terms of plant engineering (Fig. 17).



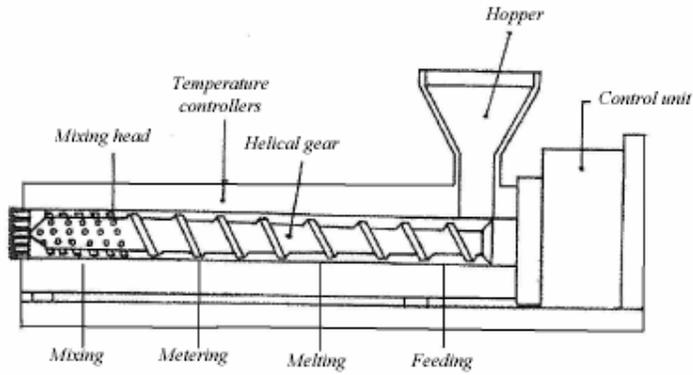
A) Continuous filament yarns

B) Tow for staple fibre production

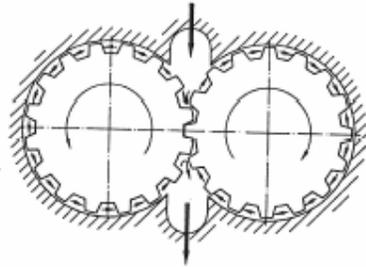
- a) mixer
- b) extruder screw
- c) main extruder
- d) hopper
- e) chip feeding line
- f) side extruder
- g) rotary gear pump
- h) continuous filter
- i) distribution line (manifold)
- k) spinning position
- l) cooling chamber
- m) take-up head
- n) tow for staple production

Fig. 17 Melt spinning lines for continuous filament and staple fibre

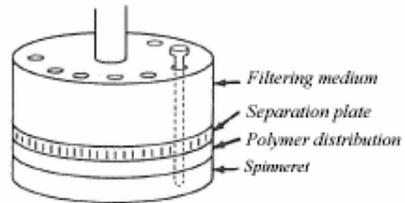
**EXTRUDER**



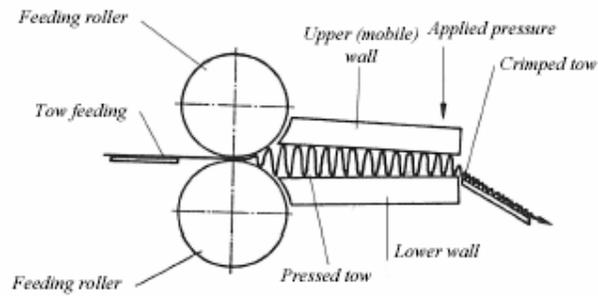
**ROTARY GEAR PUMP**



**SPINNING AGGREGATE**



**CRIMPING CHAMBER**



*Fig. 18 Mechanical elements characterizing a production process*

## Continuous filament yarns

Continuous filament yarns can be composed of a single filament (monofilament yarns) or of several filaments (multifilament yarns) and are described through abbreviations, the first figure of which indicates the total linear mass (expressed in dtex or, less usually, in den), the second figure indicates the number of filaments and a third figure, if any, shows the twists per length unit (turns/m) imparted to the yarn.

Monofilaments for traditional textile uses have linear masses ranging from 10 to 50 dtex approximately; monofilaments with larger linear masses on the contrary find use in technical applications and are identified with their thickness expressed by the diameter of the round crosssection (0.06–2 mm).

Multifilaments have variable filament number (up to 300 filaments for traditional textile uses, up to 1000-2000 for technical uses and floorcovering) and the linear mass of each filament ranges from 0.4 to 5 dtex.

If a yarn is declared as microfilament (i.e. when the linear mass of its single filaments is lower than 1 dtex), the number of filaments results into being higher than the linear mass of the yarn (e.g.: 200 dtex/220 filaments).

When the yarn is extruded by the spinneret, it presents smooth and parallel filaments (flat and parallel yarn).

Owing to processing and application requirements, parallel filaments are mostly tied together by means of entangling points (entangled yarns) or of twists (twisted yarns); on the other hand there are flat filaments, characterized by rigidity and poor covering power, which can be converted into curly or crimped yarns (textured yarns).

The spinnerets which produce continuous filament yarns have usually a number of holes equal to the number of filaments composing the yarn; there are however also some cases in which the spinneret produces several yarns, which are successively wound on separated bobbins (multibundle spinnerets), or cases in which several spinnerets produce a single yarn which is wound on a single bobbin.

A spinning line of thermoplastic polymers (Fig. 17A) consists in general of:

- . one or more units, each composed of a screw extruder
- . distribution system (manifold)
- . spinning head or spinning position
- . metering pumps
- . spinnerets (up to 8 or 8x2 per position)
- . spinning chimneys
- . take-up units (winders for up to 8 bobbins)

In a first zone placed upright under the spinnerets, the filaments are struck crosswise by flows of cold and controlled air (cooling zone) and thus cooled and solidified; in a second zone the filaments are assembled, lubricated by contact or spray devices and, if necessary, linked one another through entanglement points (produced by air nozzles) and wound on cylindrical bobbins.

The take-up speed plays a role of primary importance in establishing yarn characteristics. As far as traditional spinning is concerned, spinning speeds vary, depending on the fibre, from 1000 to 1800 m/min; under these conditions, the polymer remains substantially amorphous, scarcely oriented, with high propensity to degradation and ageing, and requires consequently to be quickly (i.e. within few days) processed.

By increasing spinning speed, the yarn is subjected to an increasing stress (due essentially to air resistance and to force of inertia) with consequent higher level of orientation and crystallization.

Therefore, depending on the various speed levels, fibres with different characteristics can be produced; these are identified with following English acronyms, which are conventionally used to distinguish the single processes:

| Type of yarn                         | Speed (basis PES) |
|--------------------------------------|-------------------|
| LOY (Low Oriented Yarn)              | 1000-1800 m/min   |
| MOY (Medium Oriented Yarn)           | 1800-2800 m/min   |
| POY (Partially or Pre-Oriented Yarn) | 2800-4000 m/min   |
| HOY (High Oriented Yarn)             | 4000-6000 m/min   |
| FOY (Fully Oriented Yarn)            | > 6000 m/min      |

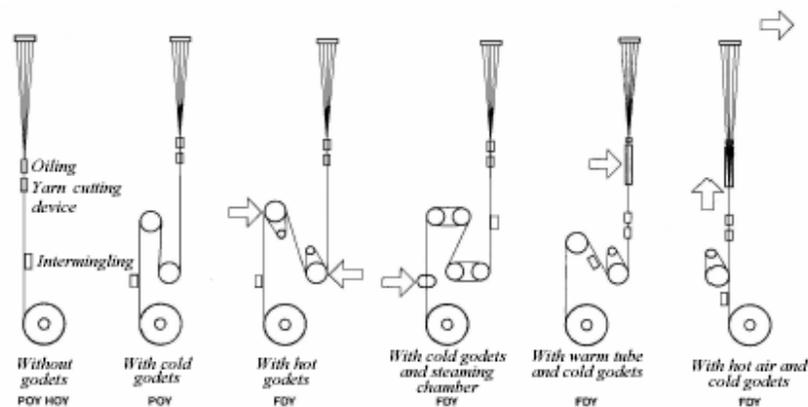


Fig. 19: Basic configurations of different spinning technologies for continuous filament yarns

Yarns produced with high speed spinning (HOY and FOY) show some qualitative and technological problems and found therefore up to now a limited diffusion on processing and application level.

An advanced form of LOY, which needs to be submitted to a drawing process in order to be usable, is POY, a yarn characterized by about 100-120% elongation at break. This yarn is widely used thanks to its good stability to ageing and, although not directly usable in the production of textile items, to its suitability to undergo intermediate processes which combine a specific process (warping, sizing, etc.) with a complementary drawing process; in fact this yarn finds wide use in draw-texturization, but also in draw-warping and in draw-sizing. Yarns originated by a complete drawing process, performed either directly in spinning or successively in a separate phase, are named "fully drawn yarns" (FDY).

### **Techniques for additive feeding in the spinning process**

The selection of the most suitable technology depends on the demanded flexibility level: the market offers on the one hand lines designed for the production of mass quantities with constant properties, and on the other single units which operate in a way completely different from others (Figures 20, 21).

The flexible solution is preferred especially in the case of extremely diversified productions (as e.g. in the case of dope dyed fibres) which require a cost optimisation related to the produced fibre quantity. The techniques for the feeding of additives (dyestuffs, dulling agents, polymer stabilizers) can be schematised as follows:

- addition of additives in solid state or in form of masterchips to the granules of the basic polymer during the feeding phase of the extruder; metering is carried out with a volumetric or gravimetric system, mixing takes place inside the extruder and usually continues in the melted state in a subsequent mixer.
- injection of additives in melted or liquid state into the flow of melted polymer; the additive in melted state is obtained by masterchips treated in a separate (secondary) extruder, while the additive in liquid state is prepared inside a tank.

Metering is ensured by metering pumps and the injection points are placed on the main extruder or on the main spinning line, or even right before spinning pumps. The technique of additive feeding near the single spinning positions is increasingly widespread as, besides ensuring flexibility to the plant, it reduces the waste caused by frequent lot changing due to small productions and improves the quality of the fibre, owing to its reduced permanence time in melted state (thermal stress).

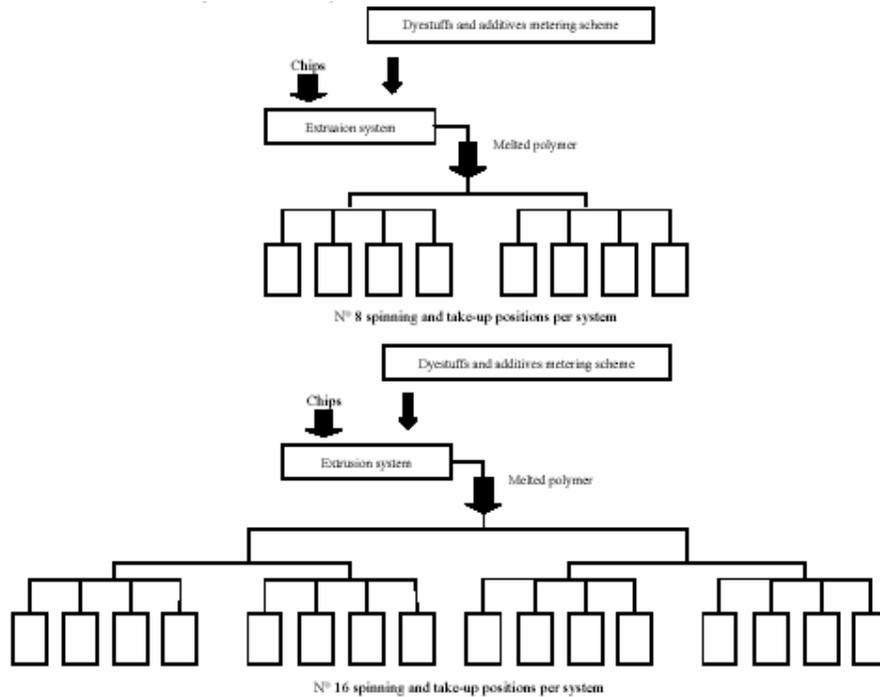


Fig. 20 Typical configuration of a traditional spinning line from chips (N° 8 and 16 positions)

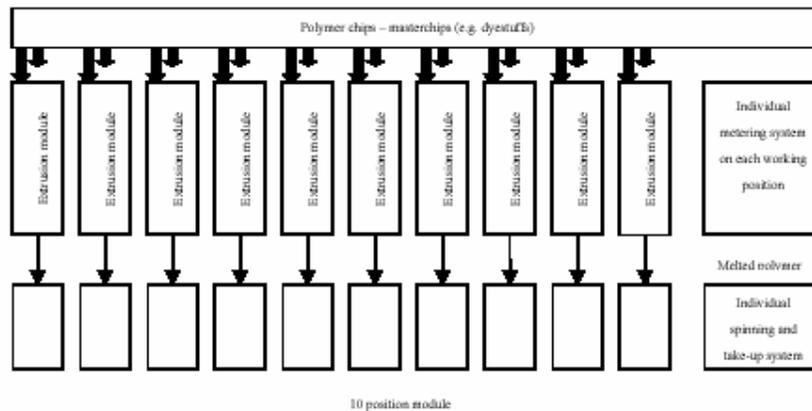


Fig. 21 Typical configuration of a spinning line with independent feeding (polymer + additives) on each working position

## Drawing process

A fully drawn yarn (FDY) can be obtained with two different techniques:

### Two-stage process

This technique can be applied to yarns which are not fully drawn (LOY, MOY, POY). With the old traditional plants, the bobbins of LOY yarns were drawn in a suitable department by machines named “draw-twisters”.

On these machines the yarn runs along a vertical path composed by the feeding system (with bobbins in upper position), by the draft zone and by a winding device similar to

the one of a ring twister (Fig. 22 a). During the winding on a stiff tube, the yarn is provided with a light twist originated by the rotation of the ring around the spindle.

The speed of current machines can range between 600 and 1500 m/min depending on the yarn type, and the weight of the yarn packages (cops) can reach up to 4 kilos; in order to increase productivity and to reduce costs, the machines can be equipped with automatic doffing device. The 1980's recorded the development of a new type of drawing frame (draw-winder), in which the winding on spindles was replaced by a take-up system on bobbins with cross-winding (Fig. 22 b).

This system permits a higher winding speed (up to 2000 m/min), the production of packages with higher weight (10-15 Kg) and, from the quality point of view, of a yarn with more uniform properties thanks to a more accurate control of the variations in the winding tensions (the winding frame with spindle winding can cause tension peaks).

Yarns wound on spindle present a twist which binds together and protects the filaments; on the contrary the filaments of yarns wound on bobbins are parallel so that, to make up for this deficiency, an intermingling device (a nozzle with intermittent flow of compressed air) placed before the winding device can be provided. For some applications like technical uses, additional cylinders (some of which heated) are positioned after the main drawing zone, with the aim of stabilizing the yarn and of fixing a prearranged thermal retraction (Fig. 22 c).

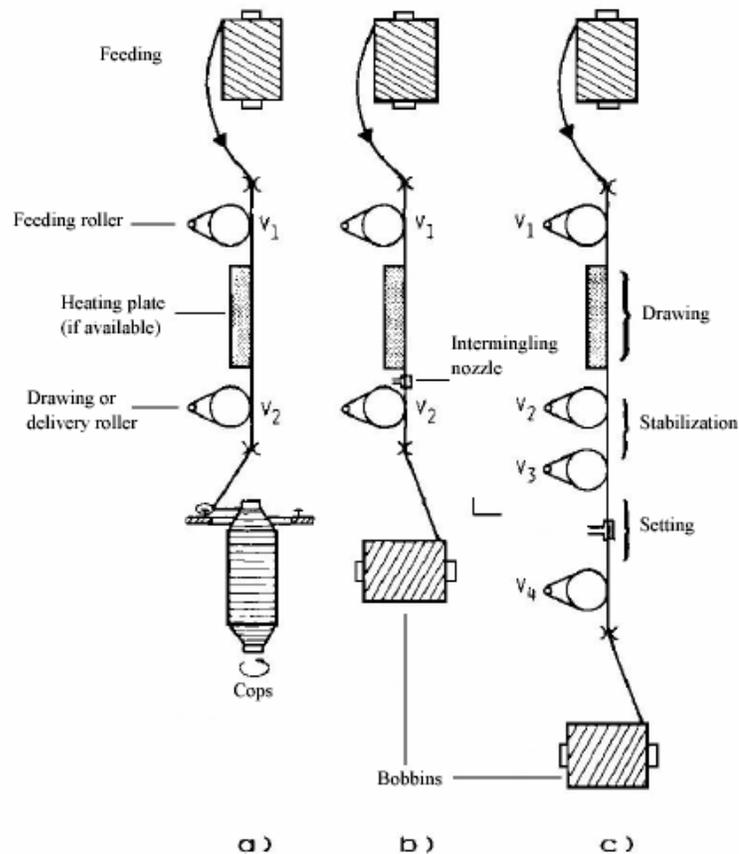


Fig. 22 Principles of two-phase drawing

### *Single-phase process*

The increase of spinning speeds (4000-5000 m/min) set as its additional target, besides a higher productivity, the drawing of the continuous filament yarn right during the spinning process (Fig. 19 – FDY configurations).

The spinning configuration may be modified on the basis of the various fibre typologies and technologies; in any case the yarn needs, before its take-up, to undergo the action of a drawing unit composed of one or more drawing zones placed between godets and moreover of heating sources, such as the heated cylinders themselves, or steam/air heated tubes, or chambers positioned before or after the cylinders.

The requested yarn characteristics (tenacity, elongation, tensile modulus, thermal retraction) can be modified to a large extent through various adjustment possibilities. Usually yarns coming from the same spinning position are drawn by just one drawing unit, and are successively again separated during winding on the various packages composing the winding unit.

A comparison between the two drawing processes highlights clearly the fact that the singlephase process is an integrated process characterized by high productivity, low labour costs and reduced space requirements, whereas the two-phase process presents a simpler technology and higher flexibility in terms of product range extension and of productivity.

### **Discontinuous fibres (tow and staple fibre)**

This kind of production takes place in plants which are conceived in a completely different way from those designed for the production of continuous filaments.

The basic concept is that of obtaining from spinnerets a high number of parallel filaments (spinning tow or tow) to be delivered to subsequent textile processes (Fig. 17B).

The tow must therefore be considered as an intermediate step in the production line of discontinuous fibres, which are designed to feed subsequent textile processes (spinning and nonwoven sectors); it is characterized by a considerable linear mass (up to 150 ktex) and is composed of filaments with the same range of counts as the standard range for staple fibres (from a 0,4 dtex micro-fibre to 17 dtex staple fibre for carpeting).

### *Production lines*

Excepted variations due to the different nature and typology of the fibre, the transformation process is essentially made up of following processes: spinning, drawing, heat-setting, oiling, crimping, drying, cutting into staple (if necessary), baling (in form of tow or of staple fibre). The processes can be carried out by means of production lines which transform without any interruption the fibre delivered by the spinnerets until the end-phases (continuous single-phase lines), or in alternative by means of lines in which the flow of the

fibrous material is interrupted after spinning and is recovered later with a subsequent feeding step (starting from drawing) until the lines of final conversion (discontinuous two-phase lines).

#### *Continuous single-phase lines*

Continuous single-phase lines are used for the production of fibres, in which the flow rate of the material can be balanced through the various transformation phases; a typical application of these lines is the wet spinning process (for acrylic and viscose fibre spinning), but their use has also been recently extended to the compact spinning process for thermoplastic polymers. The limited spinning speeds of these processes are compensated by the high flow rates of the spinnerets. The final speeds of the lines (composed of 1 or more tows) can reach 50-200 m/min.

#### *Discontinuous two-phase lines*

These lines are used when there are differences in operating speeds between the different phases. This occurs in processes in which spinning speeds are higher than in subsequent processing stages. This is the case of processes traditionally used for thermoplastic fibres and dry spinning processes, in which spinning speeds (over 1000 m/min for thermoplastic polymers, 400-600 m/min for PAN dry spinning) are higher than speeds of downstream processes (which final speeds result from initial speeds and from a drawing ratio of about 200-300 m/min).

One of the most specific technological differences between staple fibre spinning and filament spinning is to be found in the characteristics of the spinnerets. In fact, in the case of continuous filaments the number of holes per spinneret is relatively low and closely connected with the number of filaments in the yarn, whereas in the case of tow production the spinnerets are bigger and have a higher number of holes.

The nature of the material and the configuration of the spinnerets must anyway take into account the rheological properties (viscosity) of the polymer mass as well as the spinning typology. Spinning parameters must ensure an even solidification of the polymer mass after extrusion, without varying textile properties and without originating physical imperfections (drops, badly drawn yarn pieces, stuck together fibres, broken filaments, etc.) in the filaments.

As to wet spinning (PAN, CV), owing to the low extrusion speed and to the coagulation process, spinnerets with round cross-section are usually employed; these spinnerets, which can be made of different materials, show thousands of holes (even more than 100.000). As to spinning from melted polymer, considering the high speeds and the necessity of a quick and uniform cooling of the extruded filaments, different technologies are

used which, as far as traditional discontinuous processes are concerned, fall within following criteria (Fig. 23):

*Rectangular spinnerets with lateral cooling flow*

This structure shows holes positioned on parallel rows of rectangular plates made of special steel, designed in a way that the flow of cooled air comes only from one direction and consequently does not hit uniformly the various filament rows; this fact involves a limit in increasing the number of holes; moreover the system does not ensure an efficient removal of spinning steams (monomers).

*Ring spinnerets (round spinnerets with a large central hole)*

Cooling is carried out by adjusting the air flow (coming from the bottom of the chimney) on the whole filament bundle by means of a flow which is addressed from the outside to the inside of the filament bundle or from its inside to its outside. This system guarantees a more uniform solidification and a more effective removal of vapors and impurities, thus enabling a higher production capacity (up to 4,5-5 kg/min).

In the case of mass productions, the holes per spinneret attain 5,000-6,000 holes (5,250 holes for standard fibres, 6,000 holes for micro-fibres). The bundles of cooled yarns are successively oiled (by means of spray or roller devices) and conveyed in horizontal direction by godets, then combined with other yarn bundles in order to obtain a tow of larger size (or sub-tow) which, in the case of the two-stage process, is collected into cans; these cans are placed in a certain number on the creel to feed the drawing line.

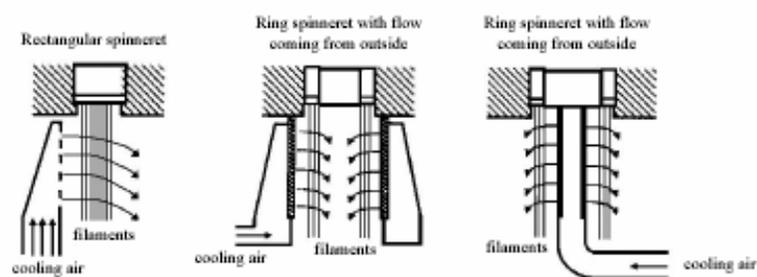


Fig. 23 Technologies of staple fibre spinning

Source : ACIMIT Foundation