6 Auxiliary Plants and Equipment

Trouble-free manufacture of a high quality product requires the use of auxiliary plants and equipment. Such equipment, and its requirements, are outlined in this chapter. The design and supply of such custom-made equipment is best left to specialized firms. Auxiliary equipment begins with granulate transport, package- and yarn handling, includes air conditioning, spin finish- and additive preparation and ends with the very important cleaning plants. Plant-, control- and process compressed air is required practically throughout the plant. The supply of water, steam and electricity, ensured in sufficient quantity, quality and continuity, is not discussed in this chapter. Even frequent storms and lightning strikes in the plant vicinity can cripple the electrical power supply and result in an expensive re-heating and re-starting of the plant, which can only be avoided by the installation of emergency equipment and reservoirs to keep at least the melt heating equipment in operation. An emergency lighting system must also be considered, as the production rooms are normally dark. All this must be carefully considered when designing the plant.

6.1 Package Handling

Owing to increasing package weights and increasing automation, package handling is becoming ever more important:

- rationalization by means of higher package weights results in fewer doff cycles/t yarn, fewer yarn knots and, proportionally, less handling.
- quality improvement through reduced manual handling (less soiling, less yarn damage, at the same running length).
- sorting of packages into full doffs and those having too short a running length, according to weight. Less printing of stickers showing yarn break statistics and yarn break diagnosis.
- saving of paper tubes and packing materials.
- humanization of the work place and avoidance of heavy manual labor.

The force that a person is able to handle is limited: a 10 kg weight held at extended arms' length implies a vertical load of 298 kg on the spine. When the arms are lowered to form a 30° angle between the shoulder and the arms, the force is still 134 kg. Packages of greater than 4...5 kg weight should therefore not be manually handled. All yarn packages should be designed such that no manual contact with the yarn body is necessary.

6.1.1 Simple Yarn Package Transport Equipment

All modern yarn winders have a package push-off device which, at doff end, ejects the packages forwards onto an exactly-centered receiving spindle forming part of a package transport trolley (Fig 6.1 [1]).

In random doffing, the package transport trolley is placed about 1.5...2 m in front of the spinning machine, the package to be doffed is gripped by the spindle of a manual package lifting device (Fig. 6.2), is transported to the package transport trolley and is pushed onto the spindle of the trolley.

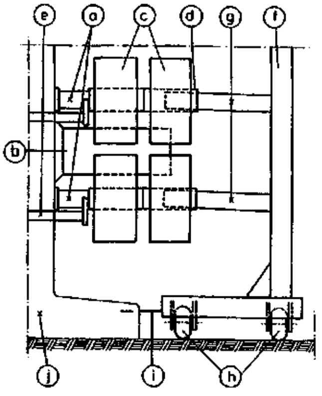

Figure 6.1
Package doffing and transport trolley docked to a winding position at the moment of package transfer [2]

a) Winder spindle (chuck)
b) Friction roll (at take-up machine)
c) Full yarn bobbins and
d) Paper tubes
e) Pneumatic push-off device
f) Transport trolley, with
g) Package transfer spindle
h) Wheels
i) Locating pin
j) Yarn winder

Similar systems can be used in further processing and in packing, where the packages can be classified and those showing, e.g., $\geq 10\%$ underweight and/or having broken filaments or overthrown ends on the package sidewalls can be downgraded. Certain yarn packages—particularly those for tirecord and carpet yarn—must be equilength, as otherwise the weaving warp length is limited by the shortest package, thereby incurring a high level of waste. The above-described package handling and transport systems have their economic upper limit at 1000...2000 packages/24 h [6].

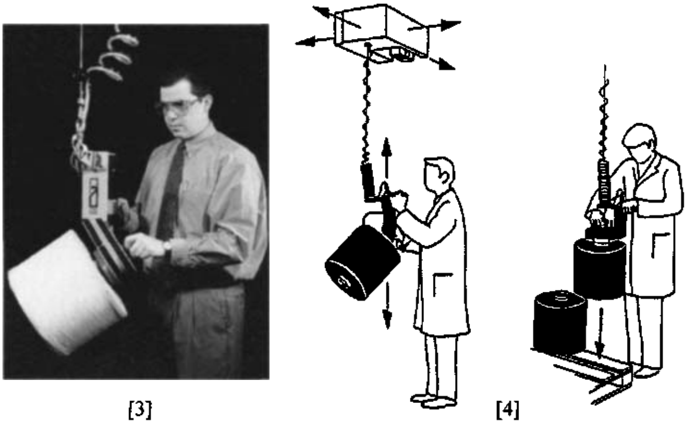
[3] [4]

Figure 6.2
Manual package handling device (Zimmermann) [3] and “Servolift” from Barmag [4]. *left:* engagement; *middle:* transport and turning; *right:* release of package

6.1.2 Doffer Systems

Semi-automatic doffers are available which can be programmed via a keyboard to adjust their position and angle (using a 5-axis system) for (partly) clock doffing [7, 8]. The drive can be achieved by means of servomotors and 4-quadrant thyristor controllers. These doffers are of compact construction and can be fitted to various types of winders. The doffer runs in front of the take-up machine on rails embedded in the floor, or—better still—above the machine. After a programmed transfer of the packages from a winder, the doffer turns through 180° and delivers the packages to a yarn buggy behind the doffer; the buggy may either hang from an overhead transport rail or run on rails embedded in the floor (Fig. 6.3).

Another system can, for example, be fully automated from the yarn winder to the creel of the drawtexturing machine [8]. In the case of non-automatic doffing (i.e., manual) winders, the doffer first cuts and aspirates the running yarn, then does the doff, including the fitting of empty paper tubes and the yarn transfer.

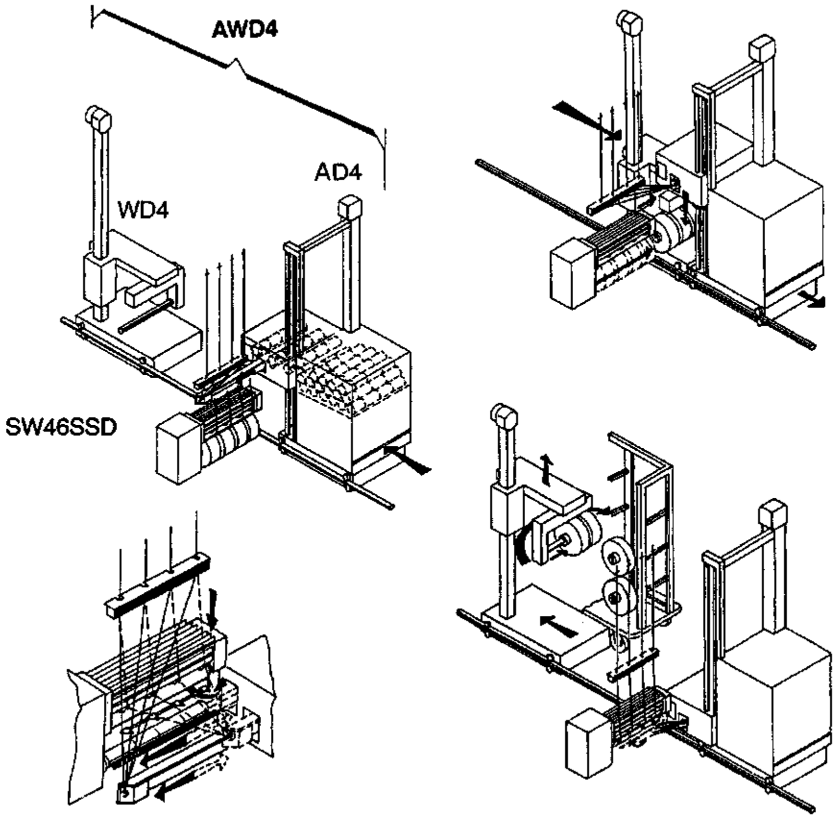

Figure 6.3 Package doffer for high speed winder without turret (i.e., manual winder). *Above:* approach, yarn aspiration and package transfer from Barmag SW 46 SSD winder to AD4 doffer [4]
below, left: pushing empty paper tubes onto the chuck and yarn string-up
below, right: transfer of doffed packages to the creel wagon

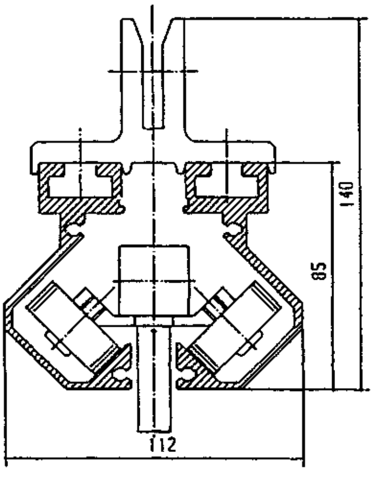

Figure 6.4
Cross-section of an overhead package conveyor system rail [11]

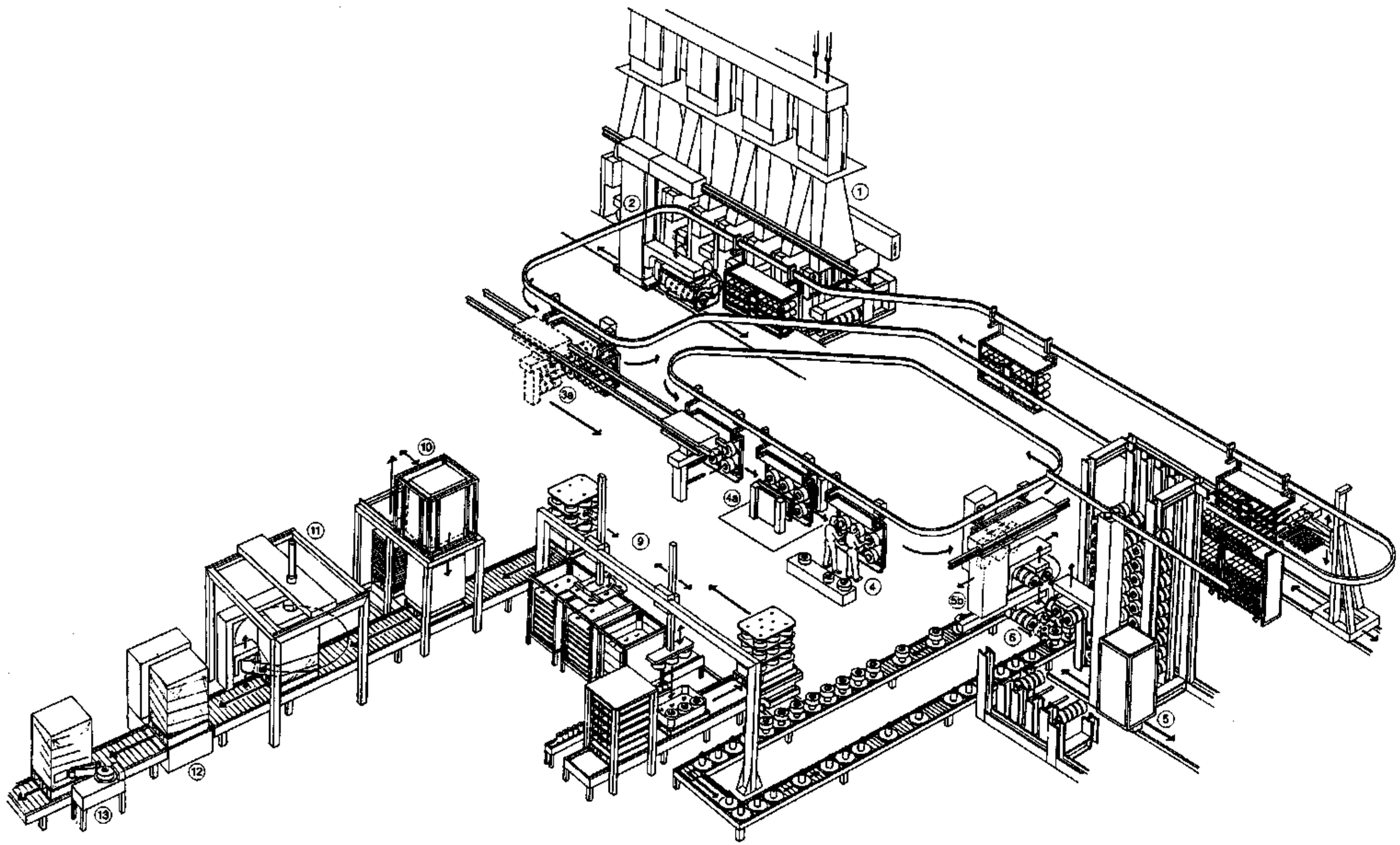

Figure 6.5 Complete transport and packing system for POY packages [4]. (1) POY spinning machine. First transport loop: transport of empty paper tubes to the spinning machine; (2) doffing as per Fig. 6.3; transfer of packages (3a) to inspection (4a) and sorting (4). Transfer and transport (6) to intermediate storage (5) or to automatic packing on pallets (9); fitting a carton (10), baling (10), (11), weighing (12) and identification for despatch (13)

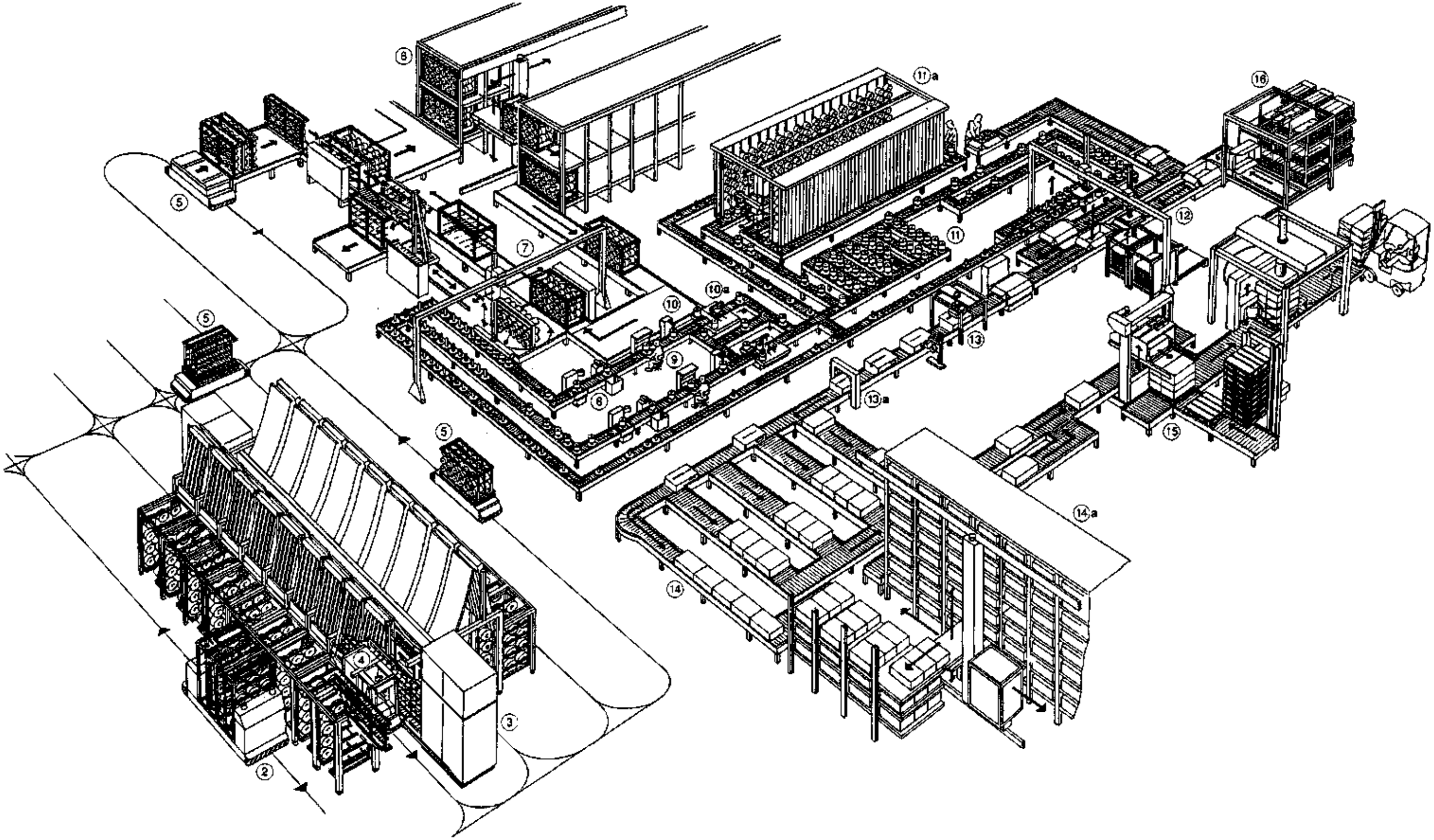

Figure 6.6 Automatic package handling line for drawtexturizing machines, from POY supply through to despatch [4]: POY packages in creel change wagon (2); drawtexturizing machine Barmag FK6 (3); doffer for texturized packages (4); intermediate storage (6); weighing and inspection (7...10); sorting according to quality standards (11); packing, weighing, identification (12, 13); carton storage (14); cartons stacked onto pallets and prepared for despatch (15)

In the case of revolver winders in single—or double deck configuration, the complete doff and package transport, from winder to further-processing creel, can be fully automated. When combined with running length time control on the spinning machine, equilength yarn packages can be produced. By including a weighing machine, titer control can also be realized.

6.1.3 Package Transport, Storage, and Packing

Transport trolleys holding packages can be wheeled, moved by electric forklift trucks or transported by overhead conveyors, to e.g., drawtexturizing—or drawtwisting machines, as well as later to sorting and packing. Similar doffer systems are available for doffing cops of drawtwisters (Section 4.10.2).

For overhead conveyors, double rail systems [11] have proved effective (Fig. 6.4). Here chains are used to pull the trolleys along a closed loop. Using controlled switches (points), one can remove trolleys, lead them into neighboring bays or replace them with the aid of special platforms. Reversal of direction is not, however, possible.

These overhead transport systems also lend themselves to the transport of single packages. According to the literature [9], up to 160 000 packages/24 h can be transported.

Doffing and transport, etc., can be further automated, as shown in Figs. 6.5 and 6.6. In such systems, the POY packages are doffed from the winder, placed on the buggy creels and—after sorting—are sent either to despatch packing or to drawtexturizing. After drawtexturizing, they are then sent to packing and despatch. These systems [4, 10, 11] are presently being developed further to make yarn production more economical and to improve yarn quality.

Finally, Fig. 6.7 explains a palletizing and packing station: alternate layers of packages and corrugated cardboard separator sheets are placed on a pallet, up to 2 m high. The so-formed package is wrapped in film and welded, enveloped in a folded corrugated cardboard carton and is strapped and identified for despatch.

For intermediate storage, either yarn buggies are closely stacked in large area halls or a computer-controlled overhead rack system is used, the latter often part of the overhead conveyor system.

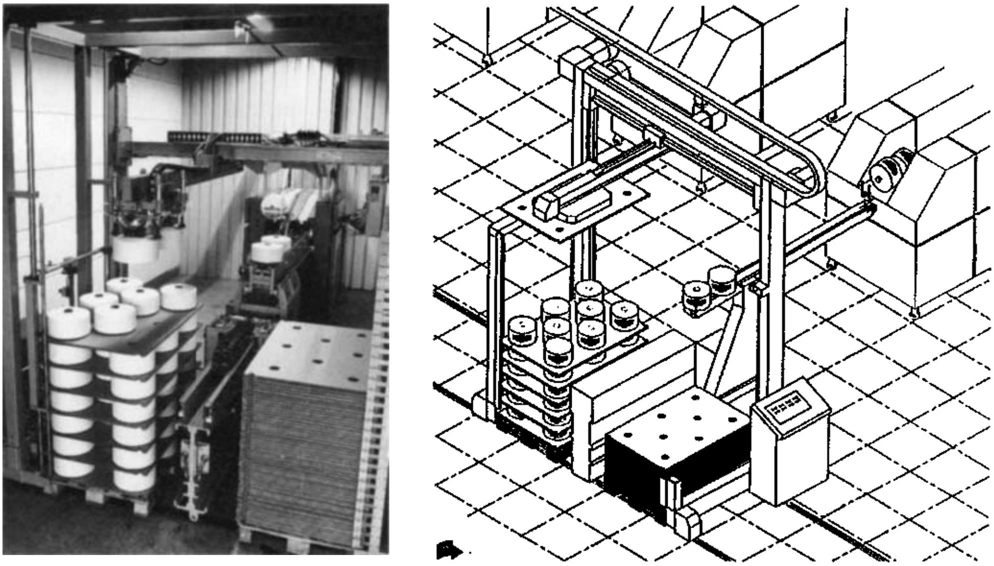

Figure 6.7 Palletizing and packing line for yarn packages (Innovatex [11])

6.2 Air Conditioning: Conditions and Plants

Since man-made yarns and fibers—like other textile materials—are to some extent hygroscopic, they require uniform and optimal air conditions for processing as soon as they come into contact with air. The required air conditions are material—and process specific, and also depend on the spin finish. For these reasons, the planning and construction of air conditioning plants should be left to experienced specialist firms [12]. Reference [13] gives basic information concerning climatic conditions and air conditioning plants.

In the planning and construction of the required air conditioning plants, the plant constructor/end-user must provide and take into account the following:

- buildings designed with $K \leq 0.6$ W/m^2 hK
- outside air conditions, i.e., maximum and minimum dry bulb temperature and maximum wet bulb temperature, both for summer and winter.
- particular external conditions, e.g., solar radiation, prevailing wind conditions, maximum dust or soot content of outside air, etc.
- cooling water conditions, maximum and minimum temperature thereof, and quantity, corrosive properties, chlorine content and/or cooling water analysis.
- room air requirements in individual rooms: target temperature, relative humidity and tolerances, target pressure constancy and possible pressure differences between rooms.
- energy generation in individual rooms, possibly with location of generation specified.
- available energy sources and their specification (allow 80 W/person).

In all areas where fiber does not come into intimate contact with the environmental air—which includes the neighborhoods of processing machines, but excludes the air quenches—it is only necessary to provide comfort air for the workers, i.e., 21...27 °C and 65...55% RH. Where this is not possible, e.g., in polycondensation or drier rooms, or above and below the spinning beams, 32 °C (or in extreme cases, 35 °C) should not be exceeded. The exhaust air ducts—mostly below the deck—are laid out for a maximum temperature of 40 °C. The air exchange rate (= m^3/h circulated air/m^3 room volume) is typically 25–35 fold.

While all other data are location-, plant- and construction-determined, air conditioning firms understandably give no recommendations concerning production-determined air conditions: these are part of the know-how of the planner and end-user. The following sections can give only an initial indication.

6.2.1 Quench Air Conditioning Plants

For cooling the molten filaments down to below the glass temperature (exception: PP), the following relation holds for the quench air supply temperature:

$$T_{\text{QA supply}} \leq T_{\text{glass temp.}} - n \cdot \Delta T_{\text{rows}} - (\text{ca.})10 \pm 1\,^\circ\text{C},$$

with n = number of filament rows behind one another. Too little cooling time is gained by using colder quench air: for a filament having 280 °C extrusion temperature, the use of 20 or 15 °C quench air temperature gains only 2% in cooling rate (or shorter cooling length). In contrast, the effect of the glass temperature is considerable: a PA66 yarn having $T_g \approx 42\,^\circ$C and 6 rows with $\Delta T_{\text{row}} = 2.2\,^\circ$C requires a quench air temperature of $\leq 15\,^\circ$C in order for the furthest filaments to be adequately cooled. Quenching the filaments down to only $\geq 42\,^\circ$C increases—according to experience—the yarn break rate 6 to 10-fold above the optimal achievable rate of < 1 break/t yarn, plus yarn breaks expected during doffing. On this basis, the following guidance values for spinning man-made fibers should be maintained:

For	PET	PA6	PA66	PP	
Glass temperature	70	40	42	5	°C
Quench air					
temperature	23...25	14	14	10	°C
constancy	±1.5	±1	±1	±2.5	°C
Relative humidity	75	85	90	80	%
constancy	±2.5	±2	±2	±3	°C
Air quantity (approx.)	10...20	18...30	18...30	20...34	Nm^3/kg air/melt

The temperature and flow rate of quench air required can be significantly different when only one or two (staggered) rows of filaments are to be quenched, as, e.g., for PA monofil (Table 3.4). Many PA spinning plants operate with a quench air temperature of 20 °C. This can be partly compensated by suitable choice of spin finish, as long as the quench air temperature beyond the filaments remains below 30...ca. 35 °C.

The quench air conditioning plant should be designed for a cross-flow air velocity of at least 0.6 m/s, unless the detailed calculation in sections 3.3 and 4.7 indicate a higher velocity. Strong throttling increases damping, and thereby reduces air velocity variations and turbulence. According to Fourné [14], the maximum supply pressure variation permissible is $\Delta p/p \leq 0.007$. The pressure in the quench cabinet supply duct or at the quench cabinet inlet flange should be between 30 and 100 mm w.g. (according to detailed design) and up to 600 mm w.g. for sintered metal radial quench candles.

The upstream dirt particle cut-off size is not adequate for the quench air supply cleanliness. It is therefore necessary to build into every quench air cabinet inlet a quick-change filter which ensures that <0.3 mg/m^3 of dust of particle size 1...3 μm and 0 mg/m^3 of particle size ≥ 3 μm passes into the quench cabinet. The filter mesh should be of the same material as the finest mesh in the air rectifier, but one size finer. Dust finer than the above has no significance.

The quench cabinets increase the supply of air to the spinning room: the interfloor tubes connect the quench cabinet to the spinning room and the threadlines by their air dragdown pumping action, transfer air downwards. Two configurations are possible:

- tall (old) spinning towers having sealed floors and interfloor tubes as the only connection between the two floors. Here a constant pressure difference must be maintained between the two floors in order to achieve a uniform air flow in the interfloor tubes. Standard conditions are a variable overpressure above of 0.2...0.4 mm w.g. and an air exit velocity of max. ca. 0.5 m/s at the yarn exit flap at the bottom of the interfloor tube. Fourné showed in 1964 (Fig. 6.8, [15]) that a periodic pressure difference of ±0.2 mm w.g. results in corresponding changes in Uster value and dye uptake uniformity in the case of PA6 monofilaments. Pressure equalization between the floors must therefore be done very accurately. This can be achieved either by means of a pressure control valve in an unused interfloor tube or by controlled exhaust of return air out of the spinning tower. Furthermore, airlock doors must be fitted both between the quench floor and the winding room, as well as between these rooms and the outside.
- in compact spinning plants having the spinning and winding sections in one room and large open interconnecting interfloor tubes [14], it is not necessary to have either pressure equalization or airlocks.

The air flow balance between spinning and winding is also influenced by

- monomer extraction below the spinnerets. The air flow rate is determined by (1.2...1.4) × quench air velocity in this region × suction area. This air is contaminated with 0.2...0.5% (based on melt extrusion rate) of monomer in the case of PA and PP; this monomer must be removed by spray water and/or catalytic burning. In the case of PET, not much monomer is evolved, so the extracted air can be led outside the building to reduce odors in the room.
- the air dragged down the interfloor tube by the yarn (see p. 190). In the case of interfloor tubes having closure flaps and a slit for the yarn exit, the dragdown air is ≤ 0.5 m/s × slit area, and can generally

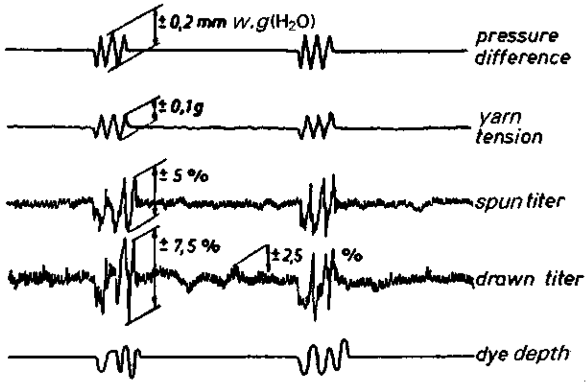

Figure 6.8
Diagram showing the effect of periodic disturbances in the pressure difference between a spinning room and a winding room having a sealed floor, on the yarn tension beneath the quench cabinet, the spun titer of a nylon 6 filament, the drawn titer and the dye depth when dyed with a sensitive metal complex dyestuff [15]

be ignored. The remaining dragdown air—which constitutes the greater part—flows as secondary upward circulation against the walls of the interfloor tube and causes threadline instability.

- saturated steam is often introduced into the interfloor tubes when spinning PA 66. Here condensation in the tube and dripping onto the winders below must be avoided. The surplus steam is aspirated at the bottom of the tube and led outside—see Figs. 4.184 and 4.185.
- when yarn contacts the spin finish either on kiss rolls or in ceramic applicators, particularly at high speed, this generates fine droplets and aerosols in the conditioned air. These sprays/aerosols must be treated either by washing or catalytically before the air streams can be used again or can be exhausted out of the building.

6.2.2 Air Conditioning of the Winding Room

It is important that the air surrounding the winding packages is correctly conditioned, otherwise every friction drive or (heated) godet transfers a large amount of energy to the surrounding air, altering its temperature and relative humidity. The only point of dispute is whether the fresh, conditioned air should be blown from above down onto the winders (which simplifies the aspiration of fluff, fly and dust) or from below up over the winders (which makes construction easier and better when the yarn packages lie below the friction rolls).

The following air conditions are recommended for air surrounding packages of various materials:

For	PET	PA6	PA66	PP	
Air temperature	20...23	20	18...19	20...25	°C
constancy	±1.5	±1	±1	±2.5	°C
Relative humidity	50...55	40...45	40...45	50...60	%
constancy	±2.5	±1.5	±1.5	±3.5	%

Package doffers and -transport systems, located close to the winders, have an unknown energy input into the room, and must also be uniformly climatised. The simplest solution is to encapsulate winders and godets and to provide them with their own internal air flow. The air flow over the heated godets can be maintained so low that the air temperature inside the box is practically the same as the godet surface temperature. This results in a more rapid heating of the yarn, as well as reduced cooling of the heated yarn between godets and/or separator rolls. Encapsulation of the winder also reduces noise levels. Both interiors are supplied with the minimum quantity of the necessary. The air flow through the winder capsule must be calculated exactly, since the amount of heat liberated can be considerable. Furthermore, the insides of the capsules must be periodically well cleaned of, e.g., slung-off spin finish. By these measures, it is possible to keep the number of air changes per hour down to below 40 in the winding room and to below 10 for the godets; the winder encapsulation, however, needs 200 to 500 changes per hour.

The air change rates given above are only rough guide values. Average air conditioning flow rates are given by [21, 23]:

For	PET	PA6	PA66
Nm^3/h × position	1500...2800	500...1500	1000...2000

In small, cramped buildings, spinning POY at 6000 m/min could require 4000 Nm^3/h × position. Based on the room volume, this implies an exchange rate of ca. 400, whereas old, conventional LOY plants winding at up to 1700 m/min require only 25 to 40 changes per hour.

6.2.3 Air Conditioning of Staple Fiber Plants

For extrusion, quench and take-up room, the above criteria are valid. This is also true for cable-laying in the cans, provided that the cable does not need to be extremely moist for good laying. At wet drawing, drying and heat setting, only comfort air conditioning is required for the workers' comfort. The area around the bale press and bale storage area should be air conditioned as described in the next section, even if only to achieve the correct selling weight at the prescribed relative humidity.

6.2.4 Climatization of Other Rooms

For reasons of uniformity, conditions of $(20\ldots27)\pm2\,°C$ and $(60\ldots65)\pm2.5\%$ RH are used practically everywhere, including work stations and in the neighborhood of packages. The constancy of the temperature and relative humidity is more important than their absolute values.

For textile laboratories, BISFA rules [91] require: $T=20\pm1\,°C$ at $65\pm1.5\%$ RH. These values must be strictly adhered to in order to enable comparisons of different results to be made. Before testing, the samples should be conditioned for 24 h to 3 days in the standard climate (see chapter 9).

6.2.5 Dust Content of Conditioned Air

The dust content of the air must be maintained as low as possible, as it can affect the yarn, the fibers, their contact surfaces and the process air:

- as dust, which can adhere to the filament surface, particularly beneath the spinneret, and
- as dust mixed with spin finish and extractables, which can adhere to the filaments, the yarn guides and the draw rolls, making them sticky.

Dust is electrostatically attracted throughout the whole room, therefore it must be aspirated with the room air and washed out before recirculation. This also applies to the outside air (Table 6.1), which is mixed with the recirculated air and washed together with it. Outside make-up air constitutes between 10 and 20% of the air circulation. Dust filtration for the quench air and take-up room air must meet the requirements given in Section 6.2.1.

Figure 6.9 shows the effect of dirt in the quench air supply. Constantly growing islands of dirt form on the finest sieve of the air rectifier; these blockages reduce the local air velocity, lead to turbulence and increase Uster values. Figure 4.177 shows the same effect on another machine. For this reason, a pre-filter is a necessity. Regular screen cleaning at short time intervals is also recommended.

Table 6.1 Average Dust Content of Air

Location	Average dust content mg/m^3
In the countryside: after rain	0.05...0.1
dry	1...5
In towns, depending on traffic	0.3...5
In industrial areas	1...5
Workshops	1...10
Cement factory	100...200
Fuel combustion areas	1000...15000

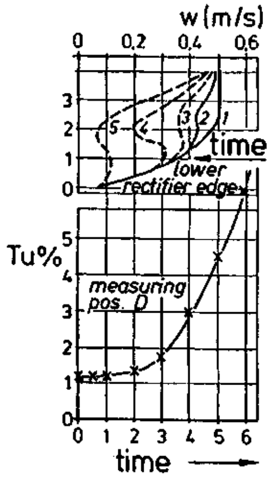

Figure 6.9
Effect of dirt on the quench cabinet air rectifier in terms of quench air velocity profile in the lower section of the quench and turbulence at a fixed spot

6.2.6 Air Conditioning State Plotted on ix-Diagram

The state of the conditioned air and its changes, from outside air through the various processing stages up to exhaust air, can be more easily followed on a Mollier ix-diagram [16, 74]. Here again we must distinguish between two plant configurations: the multi-storey building having a sealed floor between the quench cabinets and the take-up room, and the open, compact plant contained in one room. One must also distinguish between summer and winter operation for most locations. The ix-diagram relates the temperature, the absolute and relative humidity/water content, and the enthalpy of moist air. Two examples are given to explain the use of the diagram:

- the (older) closed system having pressure equalization between the quench floor and the winding room through a sealed interfloor, or a building having an intermediate floor between quenching and take-up, where air conditioning plants for both decks are located:

  Figure 6.10 shows in the upper ix-diagram the changes in air state for spinning and quench: Outside air (1) is humidified in summer, cooling it down to the dew point (2). The quench air component is cooled down further to (3) and is then blown out of the quench rectifiers at 14...20 °C, after which it is heated up to the quench air exit temperature (5) by heat transfer from the filaments. The spinning room inlet air mixes with the quench cabinet exit air, absorbs heat from the machines and reaches the spinning room exhaust air temperature (6) and, in summer, is exhausted to outside (7). In winter, outside air (8) and exhaust air from the quench and spinning room (9) are mixed (10) and humidified to the winter dew point (11). The quench air component is cooled to the quench air dew point (3). The remaing process is as in summer. The spinning room inlet air absorbs the spinning heat load and reaches the spinning room exhaust air condition (12). The quench exhaust air component (5) and the spinning room exhaust air (12) form the mix air point (9) in winter. The number of air exchanges at spinning is ca. 70-fold in this case.

The same diagram also shows the air conditioning changes for the winding room. The outside air state in winter is given by (8) and in summer by (1). The former is brought to state (2) by heating and humidification, the latter by cooling; the air is then heated to state (3), the inlet air condition for the winding room. Through mixing with the dragdown air from the interfloor tubes, the air arrives at state (4). After absorbing the room heat load (motors, lighting, services, etc.), it arrives at a state between (5) and (6). The number of air exchanges in this case is ca. 57-fold.

- In the case of machinery in a single, open building, the correctly conditioned air is led to the winding section (see Fig. 6.10 below), absorbs heat and rises as spinning room air. The quench air is treated as per Fig. 6.10 above to reach state (4). Both are mixed in front of the quench cabinets, and can—depending on summer or winter conditions—be exhausted as outlet air and/or partly used for recirculation air.

In many cases, chillers are required for both the quench air and the winder air. These chillers produce cold water having a temperature of +4 °C, which is pumped into the separate air conditioning systems. The dimensioning of these systems should also be left to the air conditioning firms.

6.2.7 Air Conditioning Plants [12]

Air conditioning plants and air ducts are either part of the buildings, consisting of installed components from machine manufacturers and sheet metal fabricators or, particularly in the USA, comprise prefabricated, compact units which are installed in the various buildings. Figure 6.11 shows an air conditioning plant and air ducts [21] for a POY spinning plant and its associated drawtexturizing. The quench air conditioning plant is, in this case, located on the roof of the spinning tower, and that for the high speed winding room in the cellar. The separate air conditioning plants for drawtexturizing are in an adjoining cellar and at the end of the roof, as is the air conditioning plant for coning and twisting. Air conditioning plants require a large space, and this must be taken into account when planning the buildings. The following points must also be considered:

- building-integrated concrete or cement slab ducts must not release dust into the air flow
- metal ducts, made from, e.g., zinc or galvanized steel sheeting, must be stable enough for the walls not to come into resonance and pulsate
- the air in the ducts must not be able to come into critical resonance
- the air velocity in the ducts should not exceed 5 m/s for comfort air and 8 m/s for industrial applications. In the branched air ducting leading to the quench cabinets, 3...4 m/s should not be exceeded.
- the air exit velocity into the rooms should be ≤ 2 m/sec, and the air velocity within the rooms should be less than 1 m/s. If dust or fluff is present, the air velocities must be reduced to below the critical speeds for these substances.

In order to meet these requirements and to ensure good mixing of the conditioned air with the air in the rooms, air conditioning firms have developed concepts and devices [16], e.g., exit grilles impart a twisting motion to the air. The air flow in front of the quench cabinet doors also needs careful design, as this can influence the quench cabinet and thereby the yarn quality.

Complete air conditioning plants for production plants of ≈ 10 t/24 h capacity require, per plant, ca. (4...5) m width × (12...18) m length × ca. 4 m height. For sizing and planning, the values in Table 6.2 can be used. For the conditioning of quench air and air for the winding room, water chillers are almost always required; these cool the cooling water down to +4 °C.

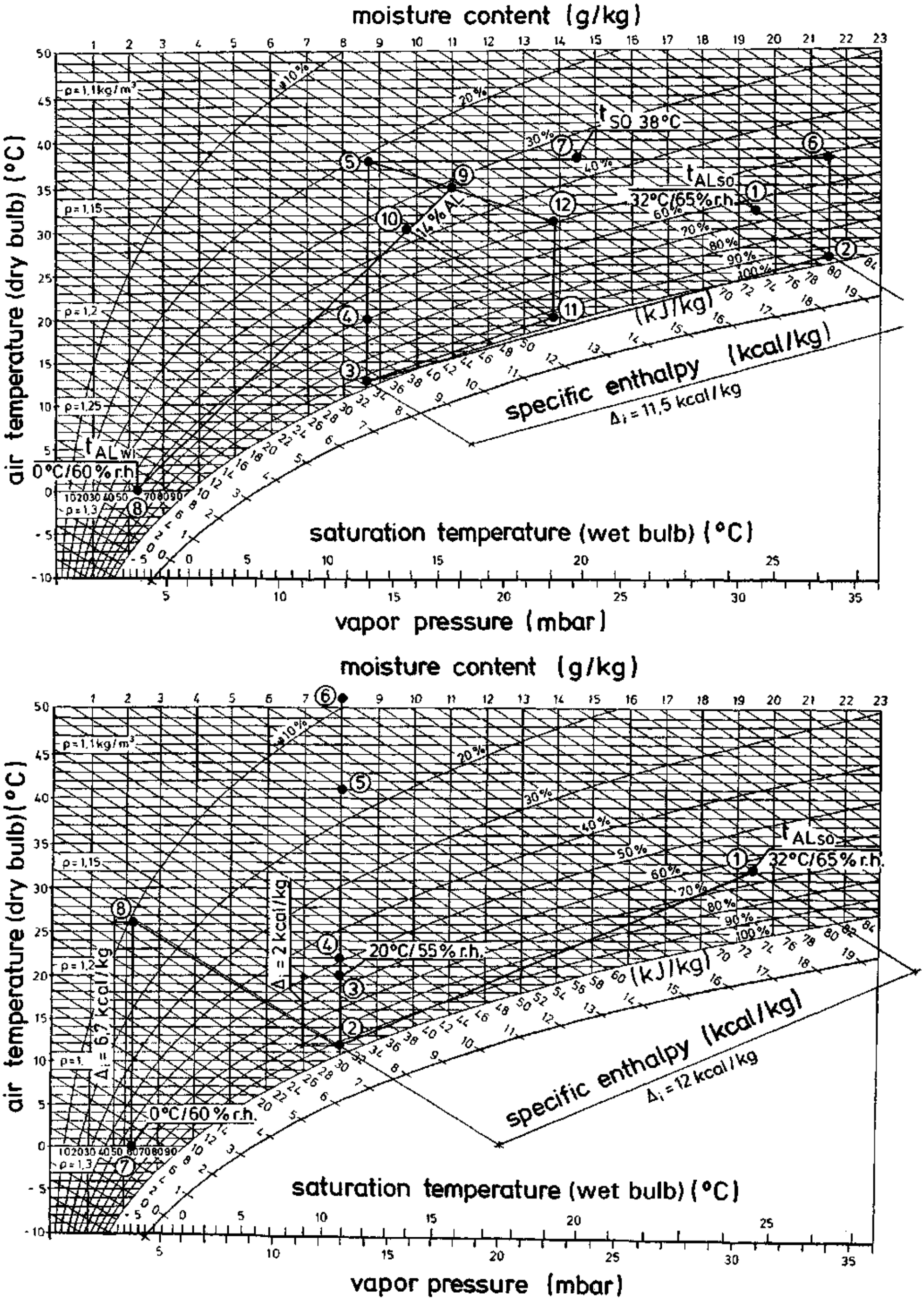

Figure 6.10 Mollier ix-diagram of an extrusion and winding plant (Neumag [74] and Krantz Lufttechnik [16]; see text for explanations); above: for multi-storey buildings having sealed floors; below: for an extrusion/winding plant without sealed floors (i.e., single storey or having open grilles in the floor)

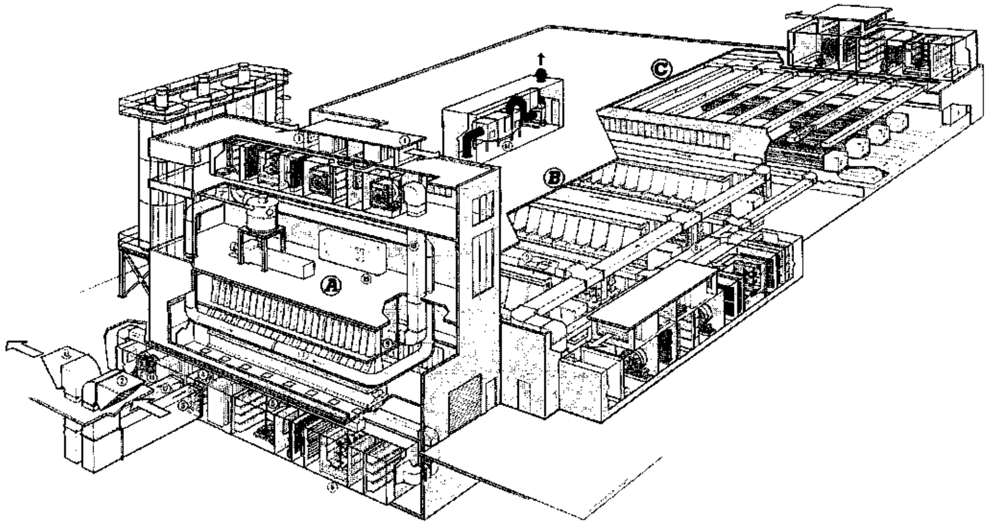

Figure 6.11 Schematic presentation of air conditioning plants for production and further processing of man-made fibers. A: for spinning, particularly the quench; B: for POY package winding; C: for drawtexturizing; D: for twisting and coning [21]

Table 6.2 Approximate Data for Sizing Air Conditioning Plants

Room	Material	Process	Temperatures (max) inlet °C	Temperatures (max) outlet °C	Quantity m^3/h	Supply pressure mm WC
Polymerization	—	Polym, drying	21...27	35	15·V	10
Spinning	—	melt spinning	23	35	(20...30)·V	10...20
Quench	PA	melt spinning	14 (20)	T_g-10	35·G	> 30
		staple, BCF	14 (20)	T_g-10	40·G	> 60
	PET	textile filaments	20...23	40 (45)	22·G	> 50
		staple	20...23	30	22·G	> 60
		staple (radial)	20...23	30	12·G	< 350
	PP	staple	20 (14)	30	40·G	> 40 (100)
Winding		LOY	20	25	30·V	15
		POY	20	25	(50...100)·V	15
Draw twisting Draw texturing Coning			23	30	25·V	15

V = relevant room volume (m^3); G = spinning throughput (kg/h)

6.3 Heating Systems and Heat Transfer Media

Temperatures up to ca. 150 °C are typical for solution polymers, up to 320 or 350 °C are typical for melt- or dry spinning, and special polymers often require up to 450 °C. Glass and minerals require temperatures up to 1400 °C and carbon fibers temperatures of 1800 to 3000 °C. Table 6.3 gives an overview of the appropriate heating methods and media.

The most commonly used liquid heat transfer media are water, Marlotherm and Diphyl (Dowtherm), particularly when heat transport is also involved. For vapor heating, steam and Diphyl (Dowtherm) vapor are most commonly used; here the condensate should be drained away from the surfaces to be heated. Table 6.4 lists some properties of Diphyl [25] and Marlotherm [24], while Fig. 6.12 gives pressure and typical heat transfer coefficients for commonly-used heat transfer media.

With a central heating plant, it can be advantageous to use secondary heat exchangers before each user and to regulate these separately using a supply from a central high temperature heating system.

6.3.1 Heating Plants

Figure 6.13 shows an example of a Diphyl (Dowtherm) vaporizer. Here the electrical heating tubes are embedded in a protective outer tube, which is welded to the vessel flange, making it possible to exchange single heating elements without interrupting production.

Table 6.3 Heating Media and—Methods

Application temperature range °C	Corresponding pressure range bar	Specification	Recommended application	Achievable temperature constancy ± °C	Source
7...160	1...8	Water (for gentle heat transfer)	Dissolving tanks, vacuum driers, chem. apparatus	1	
100...240		Steam	Chem. apparatus, drying drums	1	
140...240		Induction heater with steam jacket	Drawrolls, godets	1	
120...300		Liquid: mineral heat transfer oils	Heating by forced circulation, also for higher temperature ranges, cooling	2...4	
	1	Marlotherm® S		2...2.5	[24]
	1	Diphyl		2	[25]
	0.02...2.5	Dowtherm S			[35]
180...370	0.15...7.6	Vapor: Diphyl	Chem. apparatus, spinning beams	1	[25]
180...390		Dilotherm OMO (vapor)	Chem. apparatus, spinning beams	1	[26]
70...400		Santotherm (liquid), with accompanying heating	Chem. apparatus	2.5	[27]
50...400		Syltherm 800 (liquid, pressurized) for 150 250 300 350 400 °C p 0.3 2.6 5.1 8.8 13.8 bar	Chem. apparatus	2.5	[28]
60...400	—	Induction heater with inductor cooling	Drawrolls, godets	3...7	
60...400	—	Electric Mecanit heating bands	Extruder cylinders, simple small apparatus	4...7	
200...500	—	Electric ceramic heating bands	See above	5...10	
200...600	—	Electric resistance heaters, molded into Ms or Gg	High temperature extruders and – spinning beams	3 = 1%	
400...700	—	Radiation heaters	High temperature godets (multi-zone)	1% (> 4)	[33]
200...500	—	Molten salt (with accompanying heating)	Up to 400 °C in ST35-8	2...3	[29]
			Up to 600 °C in 1.4541		[31]
200...700	—	Liquid metals (with accompanying heating)			
50...1200	—	Gases, particularly combustion gases			
70...1400		Direct electrical current flow (e.g., PtRh)	Glass- and mineral melts	3...1% (> 4)	
Up to 1800		Direct electrical current flow: metal carbide rods			
Up to 3000		Direct electrical current flow: graphite in protective gas		2...1% (> 4)	

Table 6.4 Properties of Diphyl [25] (Dowtherm) and Marlotherm S [24]

Temperature °C	Diphyl					Marlotherm S	
	Vapor pressure bar	Density liquid kg/m³	Density vapor kg/m³	Heat content liquid	Heat content vapor	Density liquid kg/m³	Specific heat kJ/kg K
0						1043	1.51
60		1029	0.0045	66.4	423.4	1001	1.71
120	0.0169	979	0.0812	173.9	511.6	959	1.92
180	0.146	927	0.6301	290.5	608.2	918	2.13
240	0.725	873	2.881	415.5	710.6	876	2.34
300	2.48	818	9.339	549.3	817.7	834	2.55
360	6.54	759	24.23	692.2	925.9	782	2.76

Diphyl = Eutektic mixture of Diphenyl and Diphenyloxide

	Diphyl	Marlotherm S		Diphyl
Max. film temperature °C	410	370	Specific heat at 20 °C	1.55 kJ/kg K
Boiling point at 1 bar °C	256...258	≈390	Average molecular weight	166
Freezing point °C	12.3	≈−35		
Flame point °C	115	≈190		
Ignition temperature °C	615	>500		

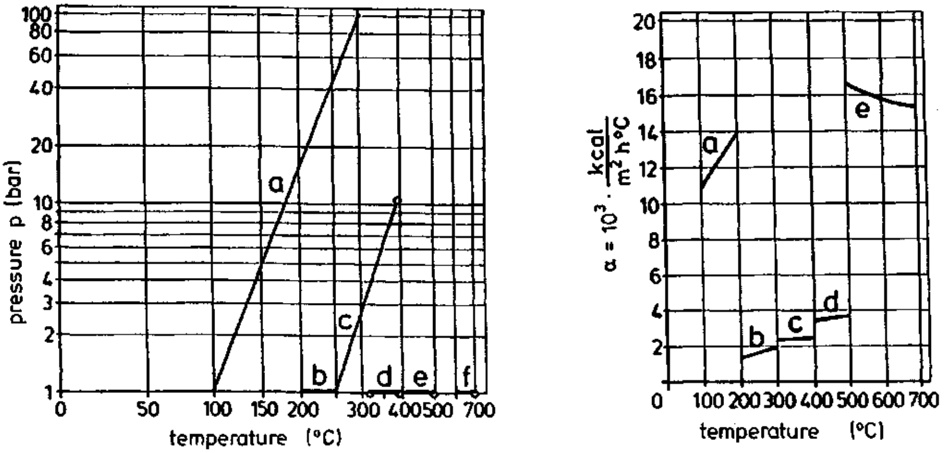

Figure 6.12 Heat transfer coefficients of various heat transfer media in a 2″ pipe at a fluid velocity of 2.5 m/s (turbulent flow) (right) and vapor pressure of various heat transfer media as a function of temperature (left)

a) Water
b) Thermal oils, etc. (Dowtherm, Diphyl)
c) b, pressurized
d) Thermal oils, nonpressurized (Marlotherm, etc.)
e) Molten salts
f) Liquid metals up to 1200 °C; hot gases

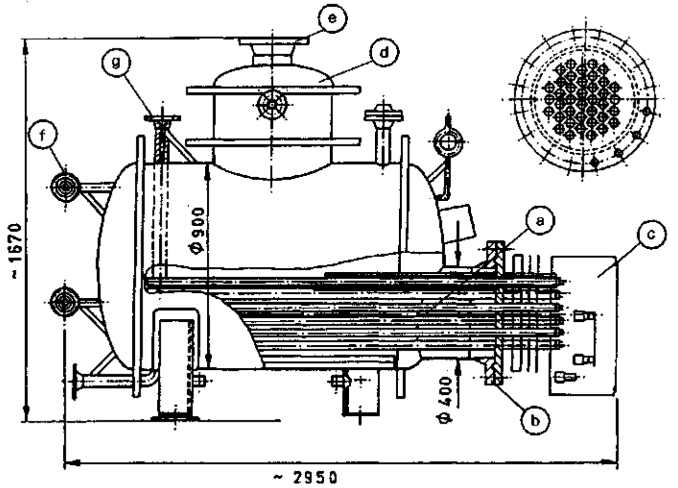

Figure 6.13
Electric Dowtherm (Diphyl) vaporizer, 81 kW, 2.5 bar, 320 °C (Klöpper-Therm GmbH [34])
a) Electric heating elements
b) Heating element flange
c) Electrical connection
d) Dowtherm vapor dome
e) Vapor exit to plant
f) Liquid level indicator
g) Condensate return line

The vapor rises through the dome (d) and the connecting flange (e) to the machine or user to be heated, after which the condensate returns through (g). A liquid level gage is incorporated between the flanges (f). In order to avoid thermal damage to both the heating elements and the Diphyl, a heat flux of ca. 4 W/cm^2 should not be exceeded; better still would be a design flux of 2.5 W/cm^2. In heat exchangers for secondary circuits, the above protective tubes can be replaced by a tube bundle bearing the primary flow.

The principle of an electrical through-pass heater for thermal oil is shown in Fig. 6.14. The heat transfer fluid flows in the narrow gap between the outer, protective tube and the heating rod. In another version having many small protective heating tubes (Fig. 6.15), crescent-shaped plates fixed at right angles to the tubes ensure that the flow occurs predominantly across the tubes or bundles (Fig. 6.15).

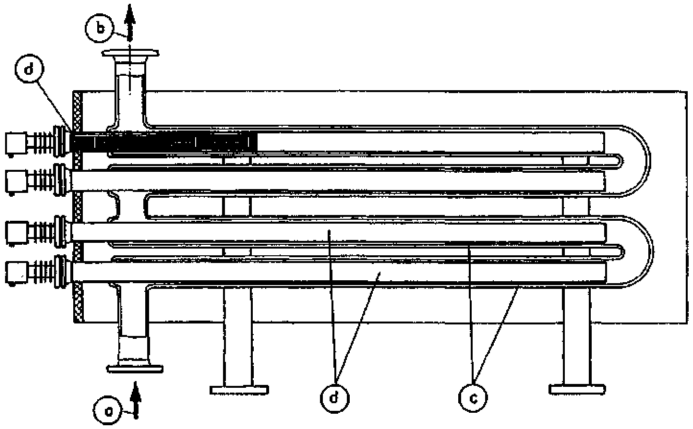

Figure 6.14 Electric heat exchanger for thermal oil, 50...200 kW, 1.0 bar + pump circulation pressure, 220...320 °C
a) Cold liquid entry to exchanger
b) Heated liquid exit (to machine)
c) Heat exchange tubes, with
d) Electrical heating tubes of large diameter

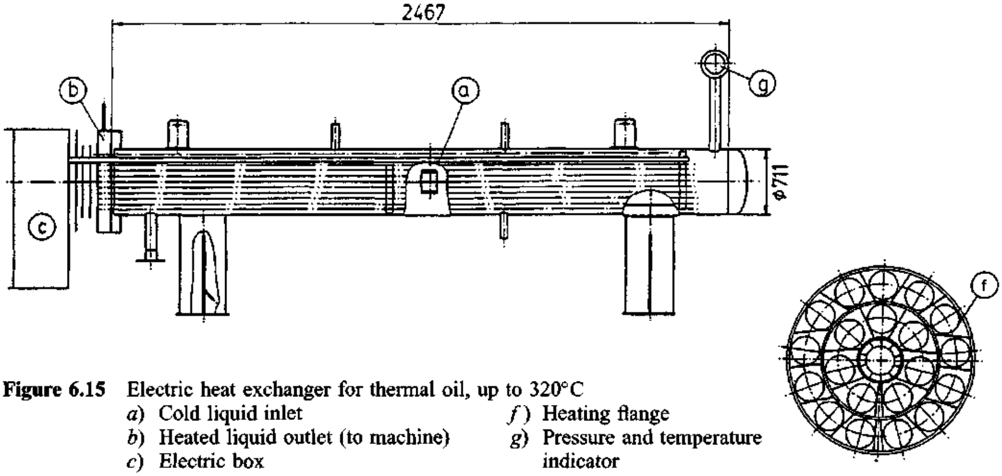

Figure 6.15 Electric heat exchanger for thermal oil, up to 320°C
a) Cold liquid inlet
b) Heated liquid outlet (to machine)
c) Electric box
f) Heating flange
g) Pressure and temperature indicator

All heating equipment must be optimally insulated. In liquid heating, the system must include an expansion vessel, while in vapor heating, a loss condenser must be attached above the user. The calculation and construction should be done according to German AD-Instructions and the VDI Wärmeatlas [94], and it should be manufactured and operated according to German TÜV conditions and procedures (different norms and standards apply in other countries). See Fig. 4.4 for German requirements.

Dowtherm vaporizers are located at least one storey below the user, while the loss condenser must be at least one storey above the user. If the safety thermometer in the loss condenser indicates a fall in temperature, the plant must be vented or the Dowtherm changed on account of degradation products therein.

6.4 Protective Gas [40]

The most widely-used protective gas is nitrogen having <5 ppm O_2 and a dew point of under $-40\,°C$. This is used, e.g., at a pressure of 20...50 mm w.g. for blanketing molten polymer surfaces. Under a pressure of 8...15 bar, such nitrogen is also used to extrude polymer from autoclaves. For dry-spinning of PAN, among others, $<2\%$ O_2 suffices. Also used are CO_2 (rarely) and, for high temperature processes (carbonization, graphitizing, etc.), nitrogen or argon having <1 ppm O_2.

The following methods can be used for provision:

- high pressure flasks, filled at a pressure of 200 bar, then reduced down to the required pressure—only for small consumers
- purchase of liquid nitrogen (very rarely)
- stoichiometric burning of hydrogen or hydrocarbons with air
- low temperature cooling of air,

the latter two possibly together with catalytic cleaning. Combustion plants for production of N_2 are available in sizes of 25...300, possibly up to 1000 Nm^3/h for 97...99.5% purity N_2 [36–38]. The N_2 production costs (1988) are DM 0.4/Nm^3 for smaller plants and DM 0.20/Nm^3 for larger plants.

The cleaning plants for gas operate catalytically and have a water separator and a gas drier. To ensure removal of residual oxygen, an excess of H_2 must be added.

Table 6.5 gives guide values for nitrogen usage; these, however, can vary widely according to the experience of the plant personnel.

Table 6.5 Guide Values for Nitrogen Usage

For	Purity, pressure	Quantity Nm^3/h
Polycondensation plants, autoclaves		
PA Flushing	<5 ppm O_2/40 mm wg	0.2...1
Extruding, normal viscosity	/8...10 bar	10 Nm^3/m^3 × batch
Extruding, high viscosity	/15 bar	15 Nm^3/m^3 × batch
PET	− 40°C dew point, as above <5 ppm O_2	
PA6 VK tube	as for flushing	0.4
Chip silos for melt spinning		
PA, PET	<20 ppm O_2/40 mm wg	0.1/m gasket +0.2/silo
PP, PE	—	—
Vacuum drier, flushing	< −35°C dew point <20 ppm O_2/1.5 bar	2 Nm^3/m^3 × batch
PAN (and other) dry spinning	<2% O_2/100 mm wg	1 Nm^3/tube open +0.1/tube
Polysulfone, wet (air gap) spinning	<0.1% O_2	0.1/spin pack set
Carbonization oven	<1 ppm O_2	
Graphitization oven	<1 ppm O_2	

6.5 Compressed Air

Compressed air usage, particularly in POY- and FOY-spinning, can be considerable; automation tends to increase usage strongly. When winding at 4000 m/min, 8 bar over-pressure suffices for both winding and general use. In 6000 m/min spin-drawing, this increases to 16 bar, which is also required for some nonwoven processes. A 10 bar over-pressure air compressor suffices for 8 bar plant operation. At 9 bar, the compressor automatically cuts in and fills a surge vessel of size $V_{\text{vessel}}[\text{m}^3] = [\text{Nm}^3/\text{h usage}]/8(P_{\min}{}^{-1})$.

Figure 6.16 shows the requirements for a POY or FDY winding position: the compressor (a) delivers, e.g., 12 bar to the general surge tank (reservoir) (b), which directly supplies the hand aspirator and machine-based aspirator (c), as well as the yarn cutter (d). A second buffer tank (reservoir) (f) is supplied via a non-return valve (e), which separates the second tank from the first tank. After drying (g) and as fine filtration (h), the separator rolls (j), if fitted, and the winder (i) are supplied from this second tank with both operating-and control air, the latter after pressure reduction (k). Larger spinning machines require 2 to 3 such stations, which must be separated, since excessive aspiration in one system could otherwise cause the other systems to trip out.

Using the average consumption values in Table 6.6, the compressed air demand of an 8-ends per position, 8 position POY machine can be calculated: $16 \times 2\,(\text{A1}) + 16 \times 1.7\,(\text{A1})\,\text{Nm}^3/\text{min} \times 10\,\text{min} + 1 \times 4 \times 60\,(\text{D2}) \times 1\,\text{h} = 32\,\text{Nm}^3/\text{h}\,(\text{A1}) + 432\,\text{Nm}^3/\text{h}\,(\text{D2})$. Two separate systems would be required, so that switching on the yarn aspirators (D2) would not trip out the winders (A1). The systems would also require two buffer tanks of ca. 0.8 m^3 for (A1) and 7 m^3 for (D2), with a flow-limiting non-return valve from (D2) to (A1) to cater for continual short-term demand variations.

A compressor station for a man-made fiber spinning and winding plant comprises (screw) compressors, a compressed air buffer tank per air circuit, the corresponding compressed air (cold) drier, the fine filter and pressure control or reduction [41, 42]. Good noise reduction and location in a separate room are necessary, as the noise level can sometimes exceed 85 dB. The required motor power is ca. 0.65 $\text{kW/bar} \times \text{m}^3/\text{min}$. See [40] for fittings and detail.

The ca. 10 bar compressed air for general factory use has not been discussed here. Care must be taken to dimension the compressed air pipelines sufficiently large to cater for the sudden, high air demand of the aspirator guns. The compressed air supply pipes are usually laid out in the form of a ring main connecting all users.

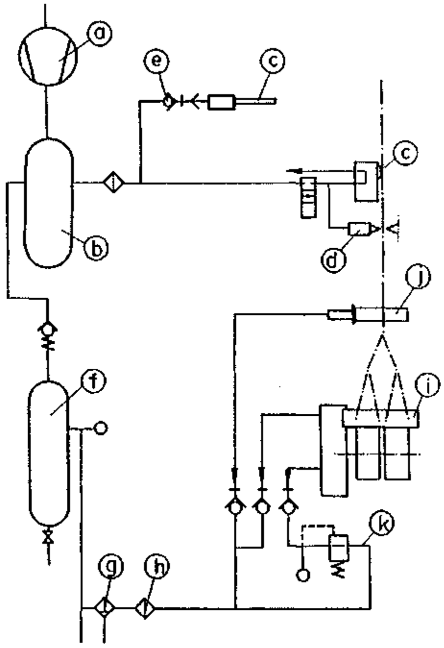

Figure 6.16
Compressed air supply for a winding machine—mains and distribution
a) Compressor (8–10 bar)
b) Surge tank (air reservoir)
c) Hand yarn aspirator gun or machine-based aspirator
d) Yarn cutter
e) Non-return valve
f) Buffer tank
g) Water trap
h) Fine filter
i) Winder
j) Yarn separator roll (air bearing)
k) Switching-reduction valve

Table 6.6 Guide Values for Compressed Air Usage

Component	Specification Usage $Nm^3/h \times$ item	Specification Pressure bar	Duration (for calculation)	Air
Separator roll, air bearing	2...4	5...7	cont.	A1
High speed winder				
up to 4000 m/min	2	7	cont.	A1
up to 6000 m/min	3	7	cont.	A1
Control air	<0.1	3	cont.	B1
BCF texturizing jet	40	7	cont.	C2
Yarn aspirator and cutter, machine mounted	100	7	5 min/h	D2
Hand yarn aspirator				
up to 4500 m/min	240	7	5 min/h	D2
up to 6000 m/min	480	16	5 min/h	E2
Non-woven jets				
Docan	30	16	cont.	E2
	+120	7		D2
Melt blowing		4		D1

A–E: separate systems; 1: dry, oil-free, dirt < 0.1 μm; 2: oil-free, dirt < 1 μm

6.6 Cleaning of Polymer-Soiled Parts

The parts transporting polymer, melt or solution become contaminated through depolymerization, cross-linking, carbonization, gel formation, etc., during operation, and must then be removed and cleaned. The cleaning must result in shiny metal faces, free from the smallest contamination. The running time before cleaning can be determined in the case of filters, e.g., by observing the pressure increase before the filter (Fig. 6.17), and for spinnerets by noting the time between insertion and "dripping", and taking about 2/3 of these averages as the running time before cleaning. If, e.g., the filter (b) in Fig. 6.17 reaches its predetermined limit of 100 bar after 40 days, it should be changed after 26 to (max.) 30 days. In the case of spinnerets, attention must also be paid to the behavior of the metal/sand filter and possible carbonization on the spinneret face. Table 4.25 gives achievable filter lifetimes and throughputs, which also limit the spinnerets lifetime. In the case of spin pumps, one can reckon on an exchange time of 3 to 6 months; smooth polymer distribution pipes can run for more than one year before cleaning is necessary.

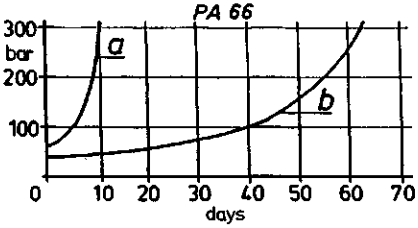

Figure 6.17
Pack lifetime of PA66 spin packs (a) without prefilter, (b) with prefilter [92]

An overview of the many cleaning methods and processes is given in [43]; only some of these are suitable for man-made fiber production equipment. A large cleaning plant always has several of these processes available.

Most cleaning processes consist of a pre-cleaning, a second high quality cleaning, a post-cleaning, neutralization, ultrasonic bath cleaning and a final drying in dust-free air.

Cleaning of parts by hand using a tool and blowlamp should be the exception, as parts can be damaged and the process is labor-intensive.

6.6.1 Burning-Out Ovens

The parts to be cleaned are placed in a circulating air oven running at ca. 500 °C for 12...24 h. After removal and cooling, the parts are cleaned of ash and combustion residues with a brush and are then ultrasonically cleaned. This process is very time- and labor-intensive, and also depends on the skill of the operatives.

6.6.2 Molten Salt Bath Ovens

The main cleaning can be carried out in a crucible containing molten sodium nitrite at 350 °C, and lasts for 4...6 h. Better still is the use of Kolene® [44], which, depending on type, can perform the main cleaning as a melt between 350 and 450 °C within 10 to 60 min, giving a good result. Figure 6.18 shows a salt bath cleaning system, comprising a crucible (b) for the molten salt, two cleaning baths (c, d) and a neutralization and rinsing bath (e). The workers must be protected against melt-spitting and explosive popping caused by traces of water. All polymer is burnt, and releases a considerable amount of soot and combustion gas, which—like the contaminated salt—must be disposed of. Salt consumption is ca. 3 kg/kg polymer at 350 °C, reducing to ca. 1 kg/kg polymer at 450 °C. The process is exothermic: if the cleaning load is sufficient, the salt only needs to be melted. The nominal power requirement is 0.4...0.3 kW/l salt bath.

This is the most effective cleaning process when, in addition to polymer, pigment and additive residues clinging to metal surfaces need to be removed.

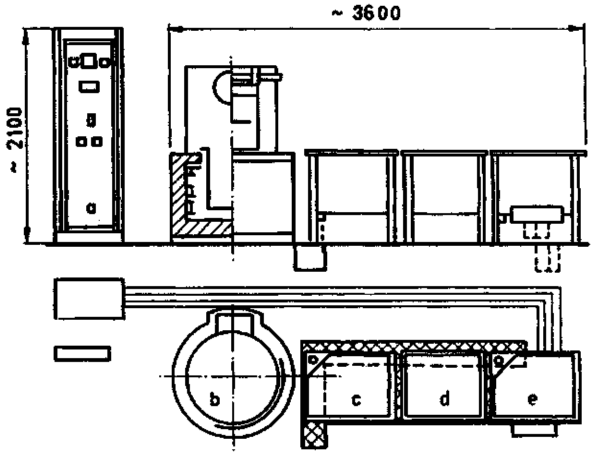

Figure 6.18
Kolene®—10 salt bath system for cleaning small parts in man-made fiber production [44]

6.6.3 Aluminum Oxide Fluidized Bed Process

This system, known as the Procedyne® process [45], abrades and burns off polymer from metal parts suspended in a fluidized bed of Al_2O_3 powder at 500...550 °C air temperature (Fig. 6.19) [45]. The cleaning of external surfaces is very good, but the particle size of the Al_2O_3 prevents the cleaning of filters, internal cavities and spinneret capillary bores of less than 0.2 mm size. The abrasion process, however, results in the rounding of the once-sharp spinneret capillary exit holes.

All of the above three cleaning processes generate soot and smoky exhaust gas, which must be treated in an after-burner. Figure 6.20 shows such a system, which can be larger than the cleaning system itself.

6.6.4 Hydrolytic (Pre-) Cleaning

Polyester-contaminated parts, in particular, can be pre-cleaned by hanging them in a vessel (2) as in Fig. 6.21 which is heated to 400...500 °C and filled with superheated steam. The polyester is hydrolyzed to low viscosity and drips from the contaminated parts into a collector pan (3). The steam requirement is only 10...20 kg/h × m^3 oven volume, the installed power is about 30...35 kW/m^3 and the pre-cleaning time is 3...4 h.

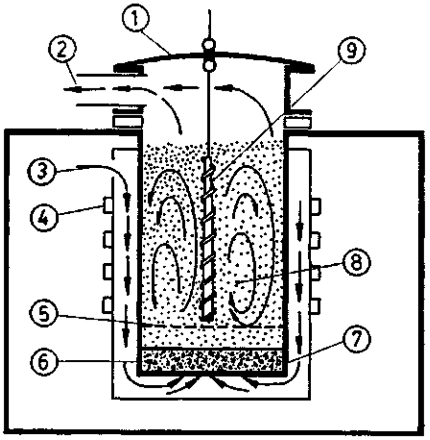

Figure 6.19
Principle of the "Procedyne" fluid bed cleaning system [93]

1) Lid
2) Gas exhaust
3) Fluidizing gas inlet
4) Band heaters
5) Protective sieve
6) Diffusion plate
7) Retort
8) Fluidized bed (Al_2O_3)
9) Metal parts to be cleaned

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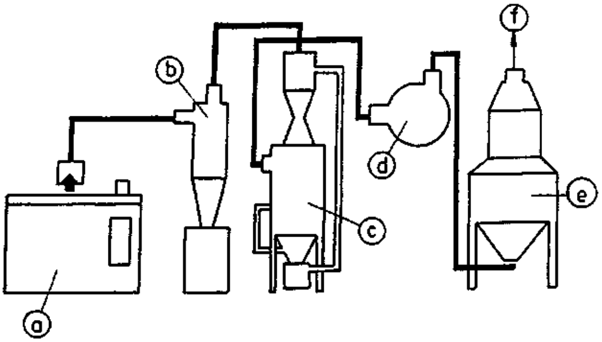


Figure 6.20
Necessary post-cleaning of exhaust gas from "Procedyne" (or similar) cleaning plant [45]

a) Procedyne cleaning plant
b) Cyclone dust remover
c) Washer
d) Fan
e) After-burner
f) Exhaust gas

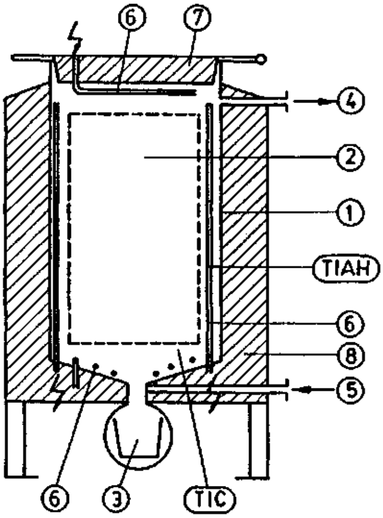


Figure 6.21
Hydrolysis pre-cleaning oven (Messrs. Fourné Maschinenbau [50])

1) Hydrolysis vessel
2) Parts to be cleaned
3) Collection pan
4) Hydrolysis exhaust gas
5) Steam entry
6) Electrical heating (up to 500 °C)
7) Lid, electrically heated
8) Insulated housing

6.6.5 Solvent Cleaning

Polyester- and polyamide contaminated parts can be cleaned in ethylene glycol (EG) at ≥ 280 °C in a vessel pressurized to ≥ 15 bar; this makes sense only when, e.g., EG recovery is available in the PET polycondensation plant. More advantageous—whether with or without pre-cleaning by saponification—is boiling in triethylene glycol (TEG) at atmospheric pressure at 280...285 °C for 4...6 h. Figure 6.22 illustrates the principle of such a cleaning plant [50]. After the initial cleaning in soiled TEG, a second cleaning is done in purified TEG (Fig. 6.23). An initial post-cleaning with a 150 bar/150 °C water jet (=automobile motor cleaner) can be useful. Further post-cleaning is done in 15% aqueous HNO_3 and/or only in 20...30% aqueous alkali, followed by neutralization and ultrasonic cleaning.

This process is particularly useful for cleaning multi-layer- and candle filters, sealed filter housings, shattered stainless steel filter powder and spinnerets having fine capillaries. Carbonized residues present on the metal parts always require the above-mentioned post-cleaning in aqueous HNO_3.

Metallic catalyst residues (e.g., Sb_2 from antimony trioxide) can be removed from surfaces by an appropriate bath composition [50].

TEG cleaning vessels of volume greater than 300 l should have a pumped circulation system, since otherwise the heating up and cooling down cycles would take too long.

PET-contaminated autoclaves and spinning beam polymer distribution pipes, amongst others, can be cleaned by pumping boiling TEG from the cleaning plant through them. A filter must be built in before the pump.

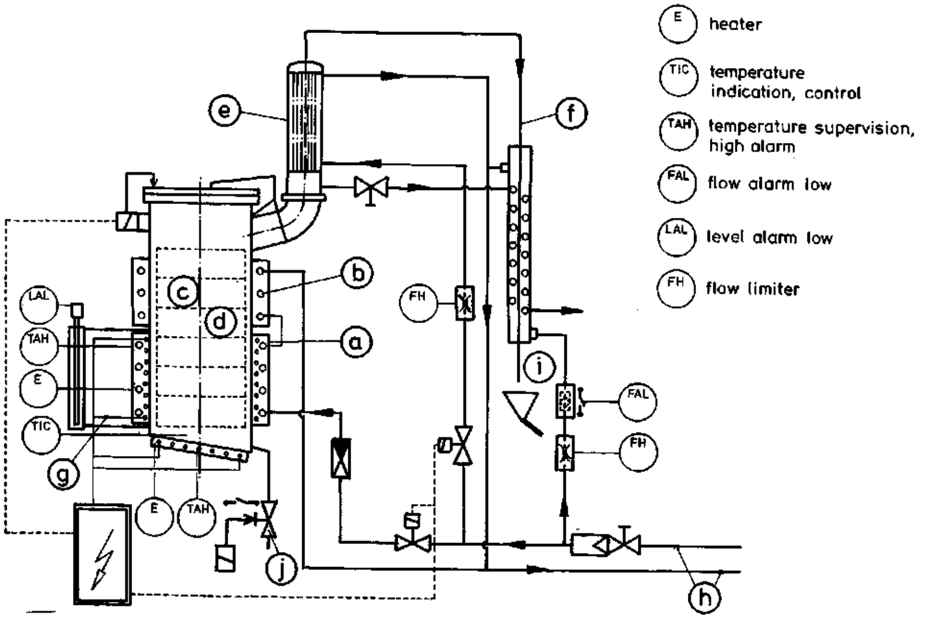


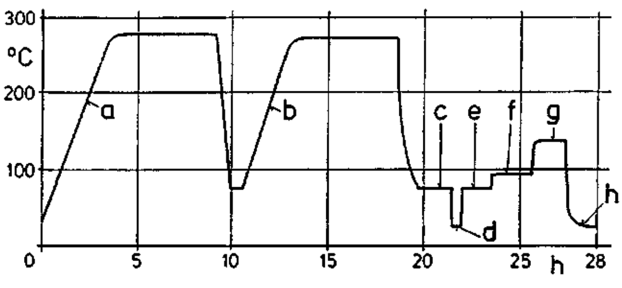
Figure 6.22
Triethylene glycol (TEG) cleaning bath, atmospheric (Fourné Maschinenbau [50])

a)	Heating and cooling cuffs	*f*)	Condensation of volatiles
b)	Cooling cuffs	*g*)	Cooling water inlet
c)	Boiling vessel	*h*)	Cooling water and condensate return
d)	Parts to be cleaned	*i*)	Volatiles condensate
e)	Reflux condenser	*j*)	Valve

During the cleaning of PET-contaminated parts by TEG, there occurs an absorption of end groups by TEG, as well as the splitting of PET chains, which leads to a lowering of the TEG boiling point [43] to below 270 °C, at which point no further cleaning action occurs. After 18 h of boiling PET/TEG, the mixture consists of TEG and about 0.28% H_2O + 5.11% EG + 0.8% DEG, and has a boiling point of ca. 255 °C. Before starting a new cleaning cycle, the low boiling point fraction is boiled off by not supplying cooling water to the reflux condenser until its temperature exceeds 275 °C; the distilled products are collected separately.

The contaminated TEG is either returned to the manufacturer [52] for recovery or is distilled from the cleaning vessel using a special hood. The bottoms, which constitute 3...4 kg TEG/kg polymer, must be disposed of.

Figure 6.23
TEG cleaning cycle
- *a*) 1. Cleaning with partly soiled TEG
- *b*) 2. Cleaning with clean TEG
- *c*) Cleaning in water + (20...25)% HNO_3 or water + caustic cleaner
- *d*) Washing with water
- *e*) Ultrasonic cleaning in water bath containing 5% soda or tenside, etc.
- *f*) Drying in dust-free hot air
- *g*) Dust free compressed air blowing
- *h*) Vacuum sucking



6.6.6 Vacuum Pyrolysis [47–50]

If the burning-out process described in 6.6.1 were to take place in a vacuum of ca. 100 mbar, the polymer molecules would be broken down into their basic components and aspirated by the vacuum. The exhaust gases would mainly consist of oxygen- and hydrogen bond compounds of the other atoms, and—as such—not be seriously detrimental to the environment. Figure 6.25 shows the CSB value in mg O_2/l water of the vacuum pump, the water conductivity (mS) and the pH value of the water as a function of time during the vacuum pyrolysis of PA6 contaminated parts. It is even more beneficial to allow most of the polymer to either melt off or be hydrolyzed from the parts to be cleaned. In this way, 90. . .95% of the polymer can be removed before the remaining polymer clinging to the parts is pyrolyzed.

As shown in Fig. 6.24, such a vacuum pyrolysis cleaning system comprises an air-tight vacuum vessel (a) and a heating system, which may either consist of internal radiant heating rods (g), which, when the interior temperature has been raised to 500 °C, only result in a vessel jacket surface temperature of ca. 150 °C, or a heating jacket. By means of a spray condenser fitted with a filter (d), the water jet vacuum pump (e) draws the required vacuum. The parts to be cleaned are placed on a metal trolley, which is pushed into the oven. During the melting phase, polymer melt drains into the cold collector pan (c), from which it can be disposed of. The valves (h, i, j) are used to bleed in air or steam and to ventilate the vessel at the end of the cleaning process. As part of the safety system, a bursting disk (k) and a non-return valve (l) are incorporated. A similar pyrolysis cleaning process can be run using nitrogen at atmospheric pressure.

Figure 6.25 shows the process as a function of time for a meltable polymer. After introducing the soiled parts and closing the vessel, the vacuum is fully applied and the temperature is increased to 70. . .90 °C above the polymer melting point, then held there for about 1 h. The temperature is then increased and controlled at, e.g., 450 °C for PE and PP, 480 °C for PA6 or 500. . .525 °C for PET and PA 66 and held constant for ca. 3 h. It has been shown useful to open valve (i) in Fig. 6.24 about 1. . .2 h before the end of the process to allow in sufficient air to oxidize the last traces of polymer and carbon still clinging to the parts to be cleaned.

Non-melting polymers such as PAN and PAR are directly heated to the second stage. Polyaramid (PAR), e.g., is taken directly to 525. . .535 °C under full vacuum, also with an oxidation stage in the last 1. . .2 h.

Exhaust gases which do not dissolve in water can result in an odor problem. Such gases can be removed by an active carbon filter.

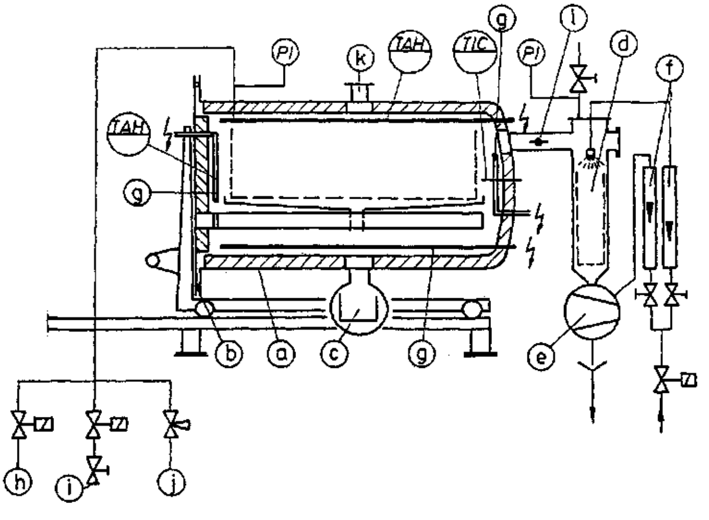


Figure 6.24
Vacuum (pyrolysis) burning out oven (Fourné Maschinenbau [50])

a)	Burning out vessel
b)	Cover with parts carriage, movable
c)	Collection vessel, with pan
d)	Spray condenser
e)	Water jet vacuum pump
f)	Water flow regulator
g)	Heating elements
h,i,j)	Valves
k)	Bursting disk
l)	Non-return valve

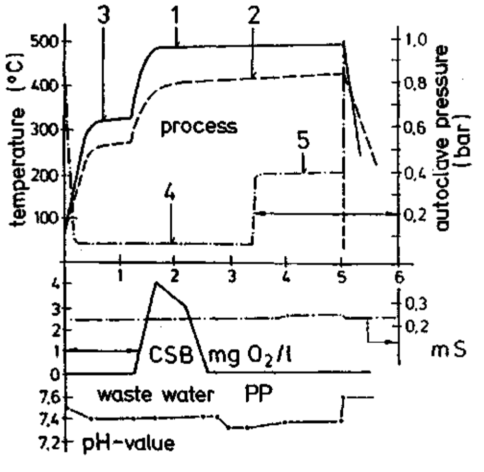


Figure 6.25
Vacuum pyrolysis cleaning: process diagram and soiling of waste water

This system also cleans the interiors of parts, so that—after some experience—spin packs do not have to be disassembled before cleaning. The finest spinneret capillaries and filters suitable for treatment at these temperatures can be well-cleaned by this method.

6.6.7 Final Cleaning and Comments

After cleaning filters and machine parts by any of the above methods, a final aqueous ultrasonic cleaning is necessary, often with 5% soda or detergent added to the water bath. Here all commercially-available ultrasonic baths operating at 25...40 kHz and heatable to 60...70 °C are suitable. Ultrasonic cleaning requires between a few and 10 min, with the parts turned during this time.

Finally, dust-free drying must be done, either using compressed air or, better, a hot air oven, followed by a check on cleanliness or functioning. For testing filter candles, a bubble point tester is available; this is used to check the air throughput and the formation of bubbles [50]. Before the cleaned parts are re-used on the production machines, they are heated to 20...30 °C above their working temperature in order to insert them without problems. In large spinning machines, special pre-heating ovens are located nearby. This pre-heating should not last more than 8...16 h to avoid oxidation of the metal faces.

High pressure steam—or water jet spray lances able to achieve 150 °C water/steam temperature and up to 150 bar jet pressure (as in automobile engine cleaners) are a valuable tool for removing adhering inorganic residues from the parts cleaned by any of the above methods. Such pressure lances can also be used to clean multi-layer filters using a "shock therapy": hot at high pressure, then cold at high pressure, repeated many times and possibly from both sides to dislodge TiO_2.

According to a new process (Du Pont), polymer can be removed from soiled faces using water lances operating at ca. 300...700 bar, either cold or up to ca. 200 °C, distanced 2...15 cm from the part to be cleaned.

6.6.8 Cleaning Plants [50]

Generally, a cleaning line must incorporate a number of consecutive processes, particularly when there is a high demand on the cleanliness of the parts, e.g., when using filter candles for fine titer yarns or making film of thickness < 10 μm. Figure 6.26 shows a layout of such a cleaning line, comprising a hydrolysis

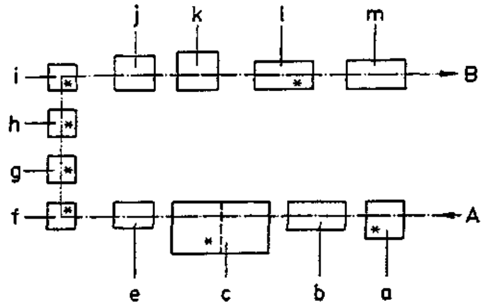


Figure 6.26
Lay-out plan for a combined vacuum pyrolysis- and TEG cleaning plant, including auxiliary equipment [50]
A) Entry of soiled parts, disassembly
B) Delivery of cleaned parts
a) Disassembly
b) Vacuum pyrolysis
c) 2 TEG cleaning baths
e) Intermediate storage
f) Acid post-cleaning
g) Alkaline post-cleaning
h) Neutralization
i) Boiling out (water)
j) Ultrasonic bath
k) Washing, blow drying
l) Drying (clean air)
m) Inspection, re-assembly

oven, dismantling table, 2-vessel solvent cleaning line, steam jet cleaning (as used for automobile engine cleaning), various washing and post-cleaning baths, ultrasonic cleaning, circulating air drier (dust-free), bubble point tester and assembly bay. In many cases, a distillation plant is also required for recovery of soiled TEG. If vacuum pyrolysis is used, the washing and post-cleaning baths can be omitted.

For the cleaning of apparatus or equipment which cannot be disassembled, a solvent cleaning system of sufficient volume having a recirculation pump for pumping around nearly-boiling solvent is required. The plant to be cleaned is connected to the pressure side of the pump, and the solvent vessel receives the returning solvent, which is returned to the pump inlet. The pump must be protected by a quick-change basket filter.

6.7 Spin Finishes and Spin Finish Systems

Without the correct spin finish, no yarn package could be wound, no staple fiber produced and no yarn would reach or pass through further processing. The incorrect or non-optimal spin finish can easily increase yarn break rates by one or more factors of ten. Should the yarn break rate exceed 1 (or possibly 2) breaks per tonne of yarn (excluding voluntary doffing breaks), spin finish specialists should be called in. Slubs, single filament breaks, etc., should be counted in with yarn breaks. Overthrown ends at winding can be caused by spin finish, but not necessarily so.

Spin finish application can be classified according to

continuous filaments → spinning take-up/winding
staple fibers → further processing

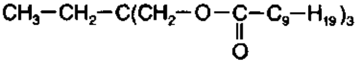
A good spin finish must satisfy the following conditions:

- good and stable solubility or -dispersability
- good filament to filament cohesion
- non-sticky
- no migration from the yarn surface
- can be easily washed off
- effective at minimal oil on yarn levels
- biologically biodegradable and non-toxic

There are, additionally, various further requirements which depend on further processing, such as good heat stability, particular fiber to metal or fiber to fiber friction, and—on the one hand—good fiber cohesion and good sliver cohesion, and—on the other hand—good fiber opening after cutting, etc.

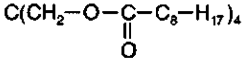
6.7.1 Spin Finish [53]

Paraffinic mineral oil derivatives [51] having temperature resistance up to 200 or 240 °C mostly form the basis of spin finishes, constituting up to 50% by weight. Sterically-hindered esters of fatty acids, e.g., derivatives of trimethylolpropane or pentaerythritol; decyl- or pelargonic acid esters of these alcohols:



$$CH_3-CH_2-C(CH_2-O-\underset{\underset{O}{\|}}{C}-C_9-H_{19})_3$$

Trimethylol propane tridecylate



$$C(CH_2-O-\underset{\underset{O}{\|}}{C}-C_8-H_{17})_4$$

Penta erythritoltetrapelargonate

are an alternative to mineral oil derivatives.

The mineral oil lubricants also bestow good fiber cohesion; if ester oils are used instead, fiber cohesion must be obtained through the use of an additive.

Non-ionic emulsifiers must not affect the fiber material nor must they attack machine parts, such as cots and rolls on texturizing machines, etc. Emulsifiers are predominantly oxylates of aliphatic alcohols.

Antistatic agents are also required; they are mostly derivatives of phosphorus pentoxide (P_4O_{10}). These waxy mixtures of phosphoric acid mono- and di-esters are reacted, e.g., with bases to yield oil-soluble salts. Long chain amino oxides [52] of type $C_nH_{2n+1}-(CH_3)_2N-O$, with $n = 2 \ldots 22$, are also well-known. One can also use derivatives of $POCl_3$ as antistatic agents, i.e., a considerable number of phosphoric acid nitrile esters. For further simple formulations, see [53–56].

6.7.2 Frictional Behavior

The frictional behavior of a fiber dressed with spin finish containing a lubricant on frictional behavior is discussed in [51, 57, 58] (Fig. 6.27). Boundary layer friction (range I) occurs between a gliding speed of 10^{-4} and 0.1 m/min. In this region, there is intermittent contact between fiber and surface (e.g., a godet, etc.). Between 0.1 and 5 m/min, there occurs a mixture of contact -and fluid friction (range II), with friction decreasing both with increasing speed and increasing fluid friction participation. Above 5 m/min, pure hydrodynamic friction (range III) occur with friction increasing both with speed and with viscosity of the finish film. Increasing the pressure between the yarn finish film and the frictional body, as well as a limited increase in the roughness of the frictional body, leads to a reduction in friction [57]. Thus, e.g., bright hard-chrome has a higher friction than matt chrome, and polished Al_2O_3 a higher friction than matt Al_2O_3.

The friction coefficient of spin finish–dressed yarn depends mainly on the viscosity of the spin finish (Table 6.7), and the friction coefficient of dressed yarn can exceed that of dry yarn. The temperature dependence of the friction coefficient μ is inconsistent. Figure 6.28 shows three examples; the reduction of friction with increasing temperature is the expected result.

The dependence of the friction coefficient of various fibers and yarn guide materials is given in Fig. 7.7. Unfortunately, no details are given for these commercially available spin finishes.

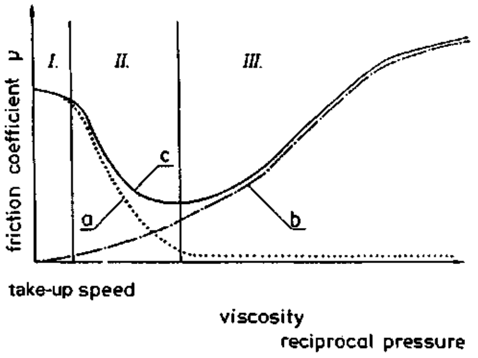


Figure 6.27
Frictional behavior of yarns
a) boundary layer friction
b) hydrodynamic friction
c) mixed friction (a + b)

Table 6.7 Effect of Topography and Fiber Structure on Hydrodynamic Friction, Measured at 164 m/min, 1.02 cN Inlet Tension and a Wrap Angle of 70° over a Ceramic Pin at 20°C and 65% Relative Humidity

Fiber	Titer dtex/f	Luster	Twist m^{-1}	Frictional coefficient (2% oil on yarn)			
				without finish	with finish, of viscosity (mPa·s) 10	30	150
Polyamide	78/34	semi-dull	50 Z	0.27	0.29	0.32	0.49
Viscose	84/30	dull	50 Z	0.32	0.26	0.24	0.33
Orlon® = PAN	84/30	semi-dull	8 Z	0.40	0.30	0.39	0.56
Acetate	84/24	dull	O	0.60	0.23	0.27	0.47
Dacron® = PET	78/34	semi-dull	O	0.6	0.36	0.43	0.61

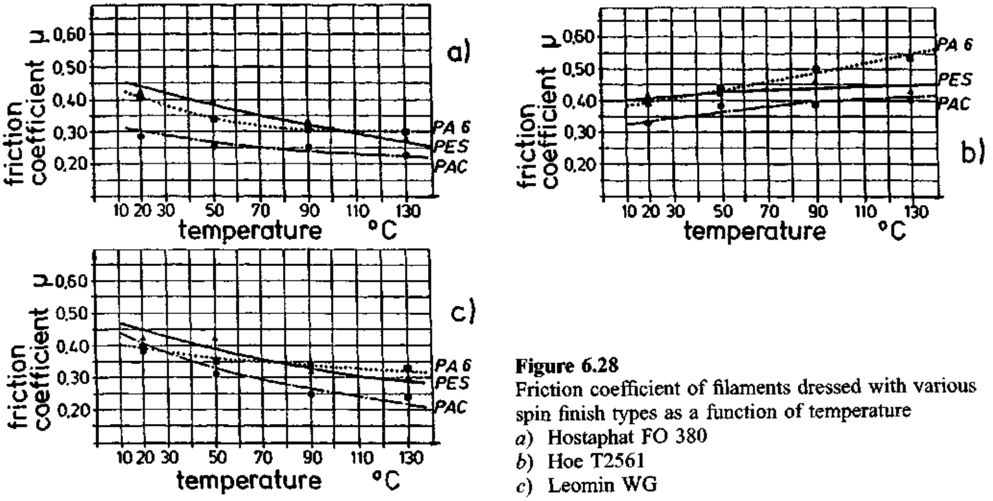


Figure 6.28
Friction coefficient of filaments dressed with various spin finish types as a function of temperature
a) Hostaphat FO 380
b) Hoe T2561
c) Leomin WG

6.7.3 Filament Cohesion

The available results describing the cohesion between the filaments of a multifilament yarn or tow can be summarized by the formula:

$$Ps = \eta L\left(\frac{W}{\delta}\right)^3 \cdot k + 2L\sigma\left(1 + \frac{W}{\delta}\right),$$

where:

Ps = force to separate filaments
η = spin finish viscosity
L = contact length
W = relative speed of separation
δ = distance between the filaments
σ = surface tension of the spin finish
k = constant depending on the separating medium

It follows that a "flowable" spin finish, which increases filament to filament cohesion, will also increase the yarn adhesion to other surfaces, a result which is not often desirable.

6.7.4 Antistatic

"Antistatic behavior" means the prevention of the build-up of static charge. Spin finishes, however, only reduce the acquired static charge after application. In spinning, this is particularly important, as the freshly-spun yarn acquires its static charge before spin finish application. Ionic substances are good antistatic agents, whereas non-ionic substances are only weakly antistatic, but have the advantage of being less moisture sensitive: they require an environmental relative humidity of only 40%. Increasing the concentration of antistatic agent and/or the spin finish pick-up increases the antistatic effect, but also increases the hydrodynamic friction.

6.7.5 Emulsifiers

These almost exclusively non-ionic products are added for the application of the spin finish. Here it is to be noted:

- the adhesion properties of the emulsifier must fit those of the lubricant, and not make the latter "rough" or "dull"
- it must not affect the yarn (e.g., must not swell the yarn)
- it must be ecologically harmless

Based on these and other criteria, the dominant materials in use, particularly for primary spin finishes, are the oxethylates of aliphatic alcohols, with a minimum polyethylene glycol content.

6.7.6 Spin Finish Application in Practice

Spin finish oils are diluted with distilled water in the ratio of 1 : 20 to 1 : 5 to form solutions, dispersions or emulsions. Often the user establishes the final (optimal) concentration of commercially-available spin finish (or pre-products) to be used based on local plant conditions, which are often the decisive factor. After drying or heat treatment, the finish concentration can increase to ca. 1 : 3 or 1 : 1.

The diluted spin finish is applied either by means of sintered corundum kiss rolls (see Section 4.4) or ceramic spin finish applicators (Fig. 6.29). These applicators are supplied with finish by gear-toothed metering pumps; the application can be single or double. In staple fiber production (two stages), the plied cable is once more treated with spin finish to increase its moisture content to 10...20% in order to facilitate tow laying in the cans, and the canned cable is again treated with spin finish in a dip bath (with excess stripping) on entry to the fiber drawing line.

An example is given from PET staple fiber spinning: a 10 g/l aqueous finish solution/dispersion is applied to the spinning cable using 1 or 2 spin finish rolls to obtain a 0.05...0.06% finish pick-up. After plying and before deposition in the cans, the same finish is applied to raise the tow moisture content to ca. 20%. After drawing the tows from the cans and plying on the drawline, the tow is dipped in a finish bath at 35...45 °C to raise the moisture content, the excess being scraped off. Often heated spin finish is applied to the tow below the 5th drum of the delivery system. Thereafter, in the second draw bath, a finish suitable for further processing is applied at a 0.1...0.12% oil on yarn level. The effective finish usage is between 18...24 kg active finish per ton of fiber.

Catalogs of the various spin finish manufacturers give a wide range of products suitable for various yarn and fiber types [60–64], all of which are suitable. The application level needs to be optimized for local conditions; here the manufacturers' specialists can be utilized.

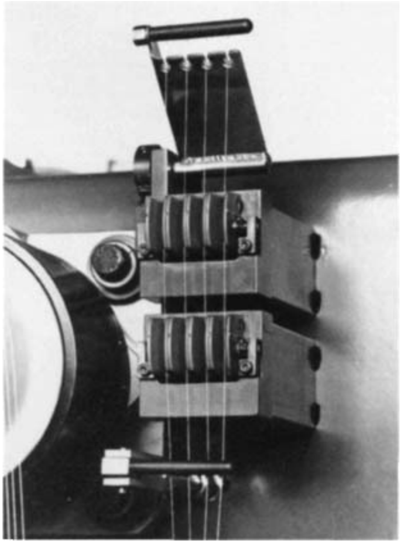


Figure 6.29
Double metered spin finish application, 4-fold spinning [77]

6.7.7 Spin Finish Preparation

Spin finish oil is slowly added to distilled (or, if necessary, fully desalinated) water in a plastic, glass or stainless steel vessel at a temperature >50 °C and stirred intensively until completely dissolved or dispersed. In the spin finish preparation plant shown in Fig. 6.30, the tanks (1) are for storage and (2, 3) for dosing pure water and spin finish oil. These are mixed with rapid stirring in the heated vessel. After filtration (7), the prepared finish is held in the storage vessel (8), where it is stirred rapidly to prevent separation or sedimentation. The preparation finish is filtered once more (10) and is then pumped to the spinning machine storage tanks.

Figure 6.31 shows a possible configuration of such a spinning machine spin finish storage tank. The storage tank contains about 3...5 h supply of finish. The inlet to the tank has a basket filter of <5 μm fineness (b), and the tank liquid level is controlled by a float valve. A level control switch (g) activates the delivery pump (11 in Fig. 6.30). The tank is provided with an overflow (f) and an outlet supplied with a 3-way valve (d), from where the finish flows through individual shut-off valves (e) to the individual spin finish pumps.

To prevent the spin finish applicators from dripping when the spin finish pump is not running, the heights in Fig. 6.32 between spin finish level, pump and applicator should be maintained.

When using rolls or slit application, the excess spin finish can be returned to the machine tank. In the case of pin applicators, however, the throughput is so low that the excess finish oxidizes. For this reason, the finish overflow is led away in separate piping to waste containers.

6.7.8 Uniformity of Spin Finish Application

There is much contradictory opinion concerning the uniformity of spin finish application. One can, however, reckon on ±40% variation when using rolls or slits, and ±7...10% variation when using metered spin finish and applicator pins, both variations being measured shortly after application. Soon after the yarn has been wound onto the spun package, finish migration occurs, reducing the variability. Improvements of more than ca. 30% of the above values are not, however, to be expected.

In the micro-length range, the non-uniformity is significantly worse, as can be seen in Fig. 6.33 for a PET 22f1 filament. There are many places where almost no finish is present. In the case of 150 dtex f30 PET, the "no finish" areas disappear with time, as they do when excess finish is applied, but there is no improvement over a 50 mm range (=1 stripe distance) [90]. These results can be confirmed by measurement on PA 6 yarns of various titers using diverse, simple liquids (glycerol, ethylene glycol, etc).

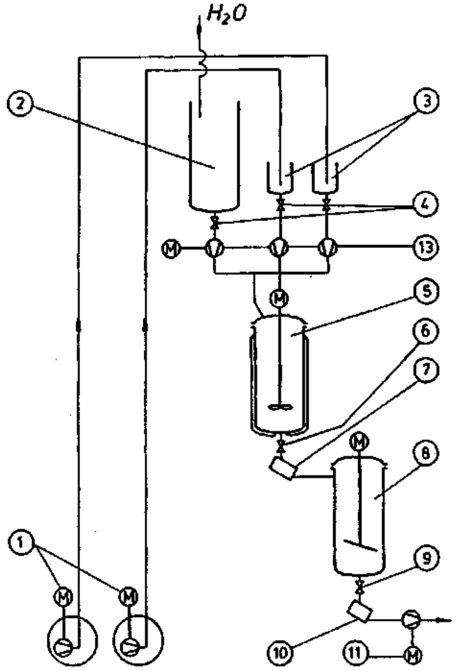


Figure 6.30
Spin finish preparation plant
1) Supply tanks for spin finish components, with delivery and dosing pumps
2) Weighing tank for distilled water
3) Weighing tanks for spin finish components
4,6,9) Valves
5) Mixing tank
7,10) Filters
8) Storage tank for spin finish emulsion
11) Pumps for transporting spin finish to machine storage tanks
13) Dosing pumps

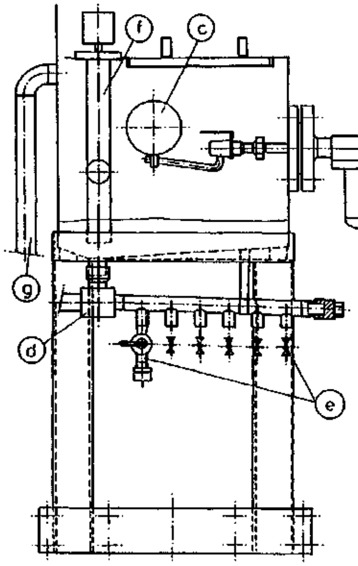


Figure 6.31
Spinning machine spin finish tank [50]
a) Inlet from position 8, Fig. 6.30
b) 5 μm fine filter
c) Float valve
d) Delivery manifold for outlets
e) Outlets to individual spin finish pumps
f) Level switch for pump, position 11, Fig. 6.30
g) Overflow to position 14, Fig. 6.30

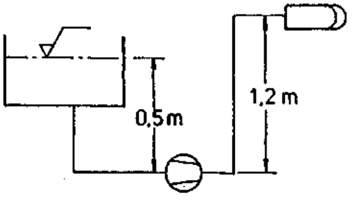


Figure 6.32
Optimal height relationship between machine spin finish tank, spin finish metering pumps and spin finish applicators [76, 77]

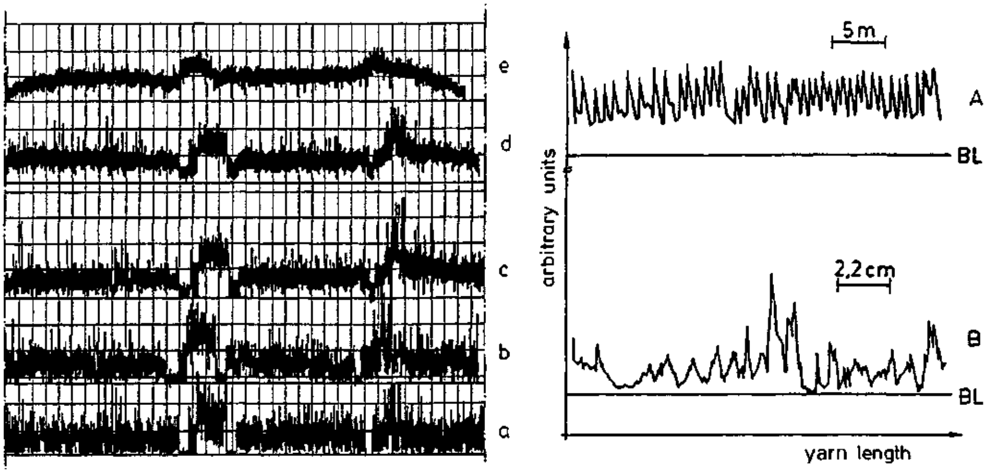


Figure 6.33 Spin finish distribution on spun yarn [90]
A) on PET (Diolen®), 22 dtex f1, drawn without extra finish application, fresh
B) Yarn from A, 4 h later, 0.73% oil on yarn, at 200 m/min
BL: baseline—no spin finish on yarn
a–e) on PET (Diolen), 150 dtex f30 semi-dull, 40% spin finish in benzine, 1% oil on yarn
a) freshly spun, b) after 1 h, c) after 6 h, d) after 1 day, e) after 4 days

Here it seems that water absorption by the freshly-spun, cooled down fiber before finish application plays a role, since the fresh fiber is presumably coated with a layer of water molecules onto which the spin finish is attached.

Other important factors affecting finish uniformity are: unsteady threadlines, resulting in the yarn striking the finish film, collapse of the finish film and spraying (and the sideways forces on the yarn arising therefrom). These factors have, to date, not been thoroughly investigated.

6.8 Delustering and Spin Dyeing

To eliminate the often undesirable shine of man-made fibers, the polymer is delustered before spinning, mostly using anatase titanium dioxide (TiO_2). Some polymers cannot be dyed in a dyebath. In this case, the melt is mixed with a dyestuff (max. 2...4%); this is termed spin dyeing [66]. Addition of these additives to the monomer is no longer carried out, as this contaminates downstream plant and results in delays when the additive is changed. Today these additives are added as far downstream as possible, yet, however, good distribution of additive must still be achieved (Fig. 6.34) [67]. Determination of additives after addition often results in values too high by 0.1...0.2%, as inorganic additives and the ash of non-volatile catalysts and stabilizers are often included [68].

6.8.1 Delustering

Anatase TiO_2 is almost exclusively used for delustering. It has a refractive index of 2.55, a pH value of 7.5...8, an average particle size of 0.26 μm, a Mohr Hardness of 5...6 and a reflectivity of $R_y = 97$ [67]. Additionally, Al_2O_3, SiO_2 or Mn-modified titanium dioxide are (rarely) offered to make the additive more suitable. Only elastane (spandex) is delustered using rutile TiO_2.

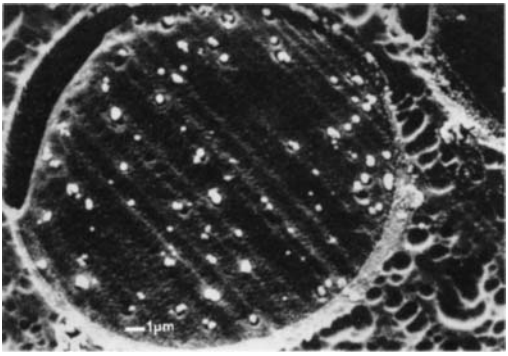


Figure 6.34
Filament cross-section showing good TiO_2 pigment distribution [67]

When TiO_2 is added at the start of polycondensation, the TiO_2 is first intensively slurried with a polymer solvent and milled, then diluted, filtered and dosed. The earlier process of washing and sedimentation is not necessary today. Table 6.8 gives recipes for TiO_2 preparation; TiO_2 loadings can be found in Table 6.9.

Table 6.8 TiO_2 Preparation

For	Mix/mill in	Concentration %	Temperature °C
PET	Glycol	55	
PA 6	Caprolactam	50...60	85
PA 66	Water, distilled	50...60	
PAN	5% PAN in DMF	30	

One can also add TiO_2, mixed with a little polyglycol, to the granulate in a given weight ratio, and mix it thoroughly. The last positon for doing this is in the silo of the extruder, such silo being fitted with a mixing agitator. Better, however, is the addition of TiO_2 in the form of a masterbatch [69–71, etc.] to a side-stream extruder [50].

Table 6.9 Polymer Delustrant Level

Description	Symbol	TiO_2 concentration %
Clear	C	0...0.03
Bright	B	0.03...0.05
Semi-dull	SD	0.25...0.35
Dull	D	0.45...1
Fully dull	FD	>1 (≤ 3)

Such masterbatches can contain up to ca. 50% TiO_2 in the case of PA and up to ca. 40% TiO_2 in the case of PET. A dosing pump meters the molten masterbatch into the main (raw white) extruder, e.g., into the last third of the compression zone, after which it is well dispersed by, e.g., the extruder mixing head and a static mixer on exiting the extruder. Downstream filtration must be sufficiently coarse to allow the additives to pass.

6.8.2 Dyestuffs for Spin Dyeing

Dyestuffs for spin dyeing are either pigments or dyestuffs soluble in the melt or the spinning dope (solution). They must be sufficiently thermostable and, in view of their particle size (ca. 0.1 ... 1 μm), lend themselves to fine and uniform dispersion in the melt. A very high degree of fastness is achievable. All major dyestuff producers ([69–71], among others) manufacture such dyestuffs for spin dyeing, marketing them in various forms, mainly as masterbatch, powder or polymer/powder blends.

The demand for spun-dyed, however, is relatively small, since textile producers prefer to color goods as far down the textile chain as possible. Spin dyeing is employed mainly for the non-dyeable polymers such as PP and PE, and for articles such as hydraulic engineering materials, dolls' hair, wigs, military uniforms and sailcloth, etc., where fastness is important. It has not been possible to date to achieve, via spin dyeing methods (e.g., using Hostasol® [70]), fluorescent dyeings of comparable quality to those achieved by aqueous dyeing methods. This is also true for the (light blue) dyeing of X-ray films. Table 6.10 shows a selection of dyestuffs for spin dyeing supplied by various manufacturers for different fibers. Using these dyestuffs, practically any color can be obtained, as can be seen from color cards, customer color sample cards, etc. Details can be obtained from these manufacturers.

Table 6.10 Spin-Dyeing Pigments and Dyestuffs

Manufacturer	For PA	For PP	For PET	For PAN
BASF [69]	Palamid	Luprofil Lufilen		
Hoechst [70]	Renol AN	PV fast Remafin	PV fast Polysynthren Hostasol Renol AT	PV fast Remastral
Sandoz [71]	Sandofil Sandorin	Sandorin Graphtol Sanduror Sanylene	Sandorin Graphtol Estofil	Sandorin Graphtol

6.8.3 Addition of Pigments/Dyestuffs

According to the type and form of the dyestuff, the polymer and the machine, one of the methods of addition given below is used. Important considerations are production security, good and uniform dispersion and minimum cleaning at a color change. It is also beneficial to spin long color programs, working from lighter to darker shades. After spinning the darkest color, the spinning machine must be cleaned.

The competitive processes are:

- the chip surface coating process: The dyestuff is tumbled together with the granulate, to which an adhesive agent (e.g., polyglycol) may be added, and the dyestuff coats the chip surface. Only light pastel shades are achievable using this method. There is a danger that extruder vibrations could shake off part of the adhering dyestuff, which could collect in the extruder throat and later result in non-uniform coloration.
- the thermodiffusion process: The dyestuff is added at 120...185 °C during vacuum drying, diffusing into the surface of the granulate. This method cannot be used with pigment dyestuffs. The dyestuff must be thermally stable for at least 10...15 minutes at spinning temperature plus ca. 20 °C. This method, too, is only suitable for small lots and light shades. Suitable, inexpensive dyestuffs are available for this method.

- Continuous mixing of powdered dyestuff or colored chip in the extruder throat. The dyestuffs must have sufficient time-temperature stability. Two methods of addition can be used here:
  - the volumetric addition of powder or masterbatch [72]: This method is suitable for many practical applications. The constancy of color addition is not 100%. In the case of large single shade (monocolor) BCF carpets, this leads to non-uniform coloration.
  - gravimetric addition, e.g., according to the electronically-controlled "loss in weight" system [73] shown in Fig. 6.35b. The color uniformity achievable is very good because the dosage of powder or masterbatch is electronically coupled to the throughput of the extruder.
- Continuous dosing of masterbatch melt from a side-stream extruder via a controlled drive, toothed-gear metering pump (Fig. 6.35a) into the main extruder, either into the compression zone or into the start of the metering zone; here the main extruder should be fitted with a mixing head (Section 4.6.4.1). Masterbatch can also be dosed through an injection valve (Section 4.6.5) after the sidestream extruder into the manifold after the finisher of the continuous polymerizer or into the main extruder, as well as before the main stream polymer gear pump; in each case, a dynamic and/or static mixer should be fitted before the consumer. Figure 5.28 explains this process: the main melt stream is divided into four parts, each of which is dosed with a possibly different additive by a side stream extruder via an injection valve.

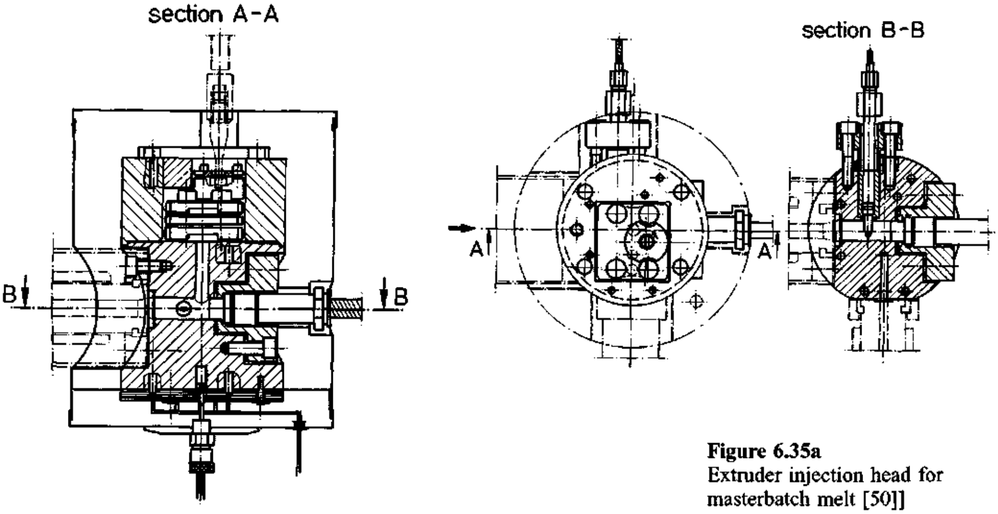


Figure 6.35a
Extruder injection head for masterbatch melt [50]]

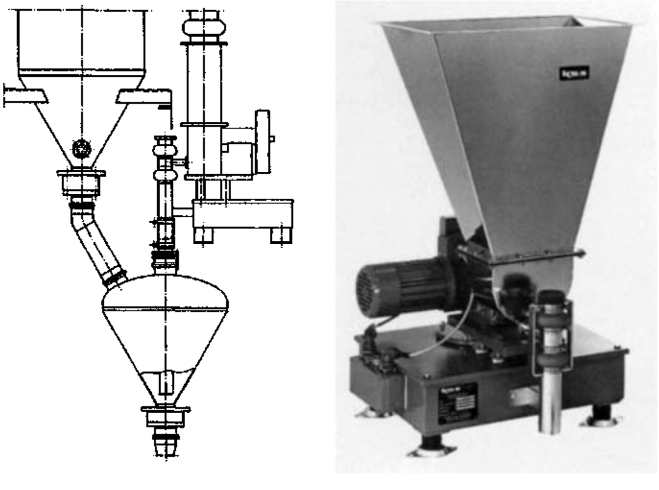


Figure 6.35b
Dyestuff or masterbatch electronically-controlled dosing unit having a "loss in weight" system, for location at the extruder throat [73]

As here the addition is done at the latest possible position, this process has the greatest flexibility and causes the least problems with contamination. It is, however, the most capital intensive.

If G is the throughput in kg/h and c the concentration of the final product, then:

$$G_o = G\left(1 - \frac{c}{c_m}\right) \quad \text{and} \quad G_m = G \cdot \frac{c}{c_m},$$

where the indices o and m refer to the main extruder and masterbatch respectively.

As an example, if $G = 100$ kg/h, masterbatch concentration $c_m = 30\%$ and 2% dyestuff concentration (c) is required in the main stream, then:

$G_o = 100 \times (1 - 0.02/0.3) = 93.333$ kg/h, and $G_m = 6.667$ kg/h. The difficulty with this process lies in the exact control and coupling of the dosage rate to the main polymer flow, particularly when a spinning pump is activated or de-activated, thereby causing a change in the main stream flow.

6.8.4 Additives

In addition to delustering and spin-dyeing, there is a large number of additives which are used to modify particular polymer properties to achieve certain desired effects. These additives can be introduced before polymerization (bP) or into the granulate as masterbatch (M) or powder (P), or can be first applied to the spun yarn in a manner similar to spin finish application. Prior to 1964 [15], 0.3% "Flexamine" was added to caprolactam to improve its thermal stability [88]; the resulting "golden caprolan" [87] showed an improvement in flex fatigue temperature of from ca. 93 °C to ca. 160 °C.

A detailed listing of polymer additives and their effect on polymer properties is given in [89]. Table 6.11 lists fiber-specific additives; the table is by no means complete. These additives can be dosed according to one of the methods already described for dyestuffs. For addition before polymerization, the additive must be a fluid or a melt-spinnable substance of sufficient thermal stabilty. It then forms a comonomer, going either into the main chain or joining as a side group. Some properties can, understandably, be adversely affected, in particular tenacity and elastic modulus; in the case of anti-pilling fibers, this can be desirable. Application of additive-based emulsion to the finished fiber is not water-resistant enough, and is not therefore used. If standard granulate is used in production, the most widely used method is masterbatch injection into the melt.

6.9 Testing of Spinning Pumps

New spinning pumps, as well as pumps which have gone through a number of cleaning cycles, must be checked for the following deviations:

$$\frac{Q_n - \bar{Q}}{\bar{Q}} = \text{throughput deviation} \leq 0.005$$

$$\frac{Q_{p1} - Q_{p2}}{Q_{p1}} = \text{pressure dependence} \leq 0.01$$

(Q_n = individual throughput; $\bar{Q}$ = average batch throughput; p1 and p2 are pump back pressures, usually 20 and 60 bar respectively). Testing is done using oil; silicone oil TK017/35 is recommended. Such a test stand for one to four spinning pumps, each of 1 to 4 pump streams, is shown in Fig. 6.36. Each pump has a quick clamping device, and they are driven by a common drive of ca. 6 kW. If the deviations found are greater than those given above, the pumps should either be reworked or sorted [76, 77].

Similar test stands are available for checking spin finish pumps having up to 12 parallel streams [77]. The temperature of the test oil must be checked during testing, as it can warm up through compression.

Table 6.11 Additives and Reasons for Application

Purpose	Additive	Advantages (+) and disadvantages (−)	Typical concentration	For	Addition point	Manufacturer
Heat stabilization	Anti-oxidants – Cu salts (possibly with halogen or phosphorus bonds)	Strong coloration (−) Water extractables (−)	50 ppm Cu ≈ 1000 ppm halide	PA	bP	Bayer, Ciba Geigy, Cyanamid . . ., Hoechst, ICI
	"Flexamine"	Strong (golden brown) coloration (−) Increases long-term thermal stability to ca. 160°C (+)		PA6 tire cord	bP	Naugatuk Chemicals, Conn., USA
	– Cu acetate + iodide (e.g., KF)		30 ppm Cu Ac. + 1000 ppm KF	PET	bP	
	– Phenol with thiothan		0.02…0.1%	PP		
	– Phenolic AO + phosphite or phosphonite		0.02…0.1%	HM PE		
	– HNO_3, preferably organic phosphite or phosphate	Melt stabilization (+)	0.05…0.1%	PET	bP	
Light stabilizer (against photo-oxid-action)	Sterically-hindered amine possibly with Ni (e.g., HALS) – Also pigment effect		0.25…0.5%	PP		BASF, Bayer, Ciba Geigy, Hoechst Du Pont
	– AOIX + Ph 1	Attacked outer layers protect core	0.5 + (0…0.5)%	PA		
				PET, PA	bP	
Dyestuff enhancer	– Incorporation of acid groups (e.g., sulfo isophthallic acid)	Cationic dyeing Reduction of glass temp (−)		PET, PA	bP	
	– N-dicarboxylic acids			PET	bP	Du Pont, Hoechst, ICI
	– 5 sulfoisophthallic acid			PET	bP	
	– By increasing or reducing amino end groups	For differential dyeing		PA	Poly	
	– Organic metal complexes (particularly Ni complexes	For selected dispersion dyes		PP	bP	
	– Polyvinyl pyridine, polyamide or amine	For acid-, metal complex- and dispersion dyes				
Transparency agent	"Estorin"	PA becomes almost invisible in (sea) water (+)	0.2%	PA	M	Stockhausen
Optical brightener	"Leukopur EGM"	Whitens and brightens fabric (+)	0.01…0.1%	PET	M	Sandoz, Ciba Geigy
	"Uvitex MES"					
	– Organic metal complexes (particularly Ni complexes)	For selected dispersion dyes		PP	bP	
	– Polyvinyl pyridine, polyamide or -amine	For acid-, metal complex- and dispersion dyes		PP	bP	
Flame retardant	2,2-bis (4,4′hydroxy ethoxy-3,5 dibromophenyl) propane,	Flame retarder (+)	≈ 12%	Co PET	bP	Du Pont (Dacron 775)
	polyphosphate	Flame retarder (+)	5…7%	Co PET	bP	Toyobo
High shrinkage fibers	Neopentyl glycol	Boiling water shrinkage 20% Hot air shrinkage 40%		Co PET	bP	Hoechst
Anti-pilling		Reduction in tenacity (−) Brittleness (−) Flex resistance		Co PET	bP	Du Pont (Dacron 64) Hoechst (Trevira 350, etc.) Akzo (Diolen 21, etc.)
				(Co) PAN	bP	Hoechst (Dolan 44)

Abbreviations: HALS: hindered amine light stabilizer; AO: anti-oxidant; Y: applied to yarn; f: liquid; M: masterbatch; P: powder in granulate; bP: before polymerization

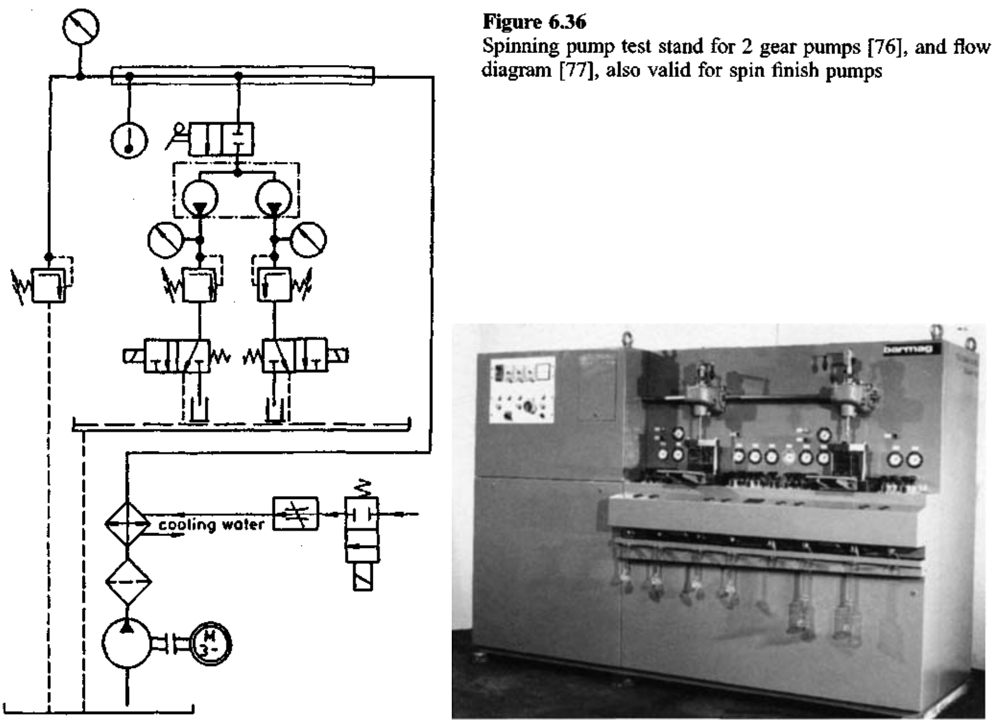


Figure 6.36
Spinning pump test stand for 2 gear pumps [76], and flow diagram [77], also valid for spin finish pumps

6.10 Testing of Spinnerets

Present day demands for high precision necessitate the checking of new and cleaned spinneret capillaries for uniformity, lack of damage and cleanliness. Many producers use a system involving one set in production, one set in reserve and one set undergoing cleaning, and replace the spinnerets once a year. Many yarn producers have established that Al_2O_3 fluidized bed cleaning causes more damage to the spinnerets than vacuum pyrolysis, which, in turn, causes more damage to spinnerets than solvent cleaning. There are three different test methods for checking capillaries:

- using a binocular microscope ($\geq 60 \times$ magnification) to view the face of the spinneret, each capillary is checked, since the edge of the hole exit is particularly important. This method is ponderous, time-consuming and depends on the person doing the examination, but is the least capital intensive for small firms.
- the second method is basically an automated version of the first method, with the capillaries magnified 30 to 1500 times on a monitor [78]. Spinneret scanning carriages are available for up to 240 mm diameter round spinnerets and for rectangular spinnerets up to 500 × 200 mm.
- the oil throughput of every capillary is measured; this corresponds to practical usage. Here a fixed oil flow rate is forced through each capillary, the pressure required is measured and stored in a computer. The equipment is fully automated [79]. Figure 6.37 shows a process diagram and Fig. 6.38 a typical evaluation diagram. With experience, it is possible to recognize the type of damage from these diagrams or to draw conclusions about recurrent damage patterns from the frequency distribution.

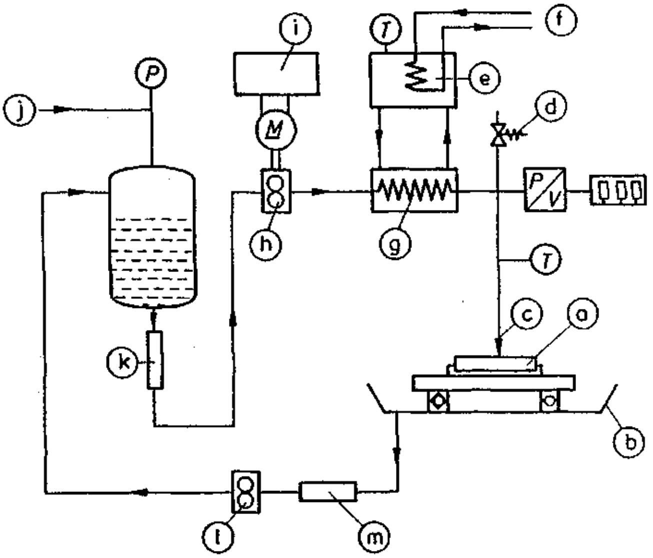


Figure 6.37
Spinning pump testing using oil flow test: functional diagram [79]

- *a*) Pressure plate
- *b*) Oil tube
- *c*) Pressure oil
- *d*) Oil supply
- *e*) Oil temperature uniformisation
- *f*) Heating/cooling stream
- *g*) Heat exchanger
- *h*) Oil pressure pump
- *i*) Motor controller for h)
- *j*) Oil supply
- *k*) Oil filter to h)

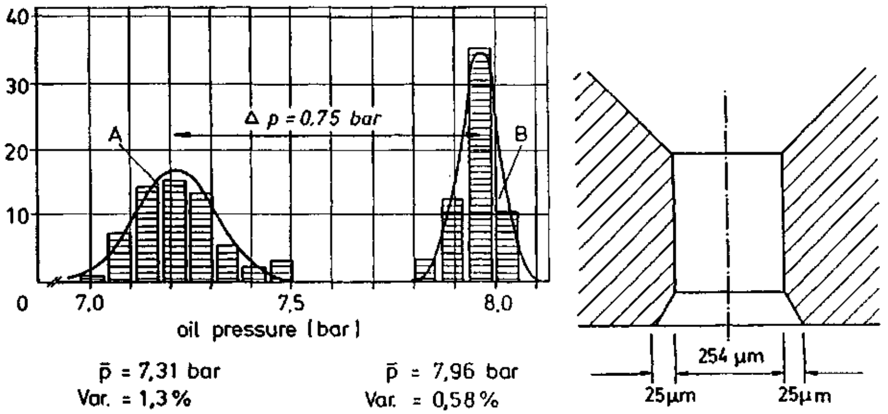


Figure 6.38 Evaluation of a spinneret oil flow test [79]: $\Delta p = 0.75$ bar: pressure reduction from 7.96 ± 0.58% to 7.21 bar ± 1.3% after wear, and max. allowable erosion of the capillary outlet

6.11 Yarn Containers (Spinning Tubes, etc.)

These yarn containers, drawtwist tubes and yarn beams, amongst others, accompany the yarn up to weaving or knitting, and are then replaced by appropriate beams, mostly flangeless wooden spindles. Although containers are partly standardized in some countries, a multiplicity of dimensions has arisen from agreement between yarn producers and end users. Only a few examples are given:

- spinning tubes for speeds up to ca. 2000 m/min are wound using phenol-impregnated hard paper [84], are hardened, grooved (up to 12 grooves/cm) on the surface, mainly lacquered with a colorless lacquer and dynamically balanced for speeds > 1000 m/min. Although these tubes are scored by knives used to cut off yarn residues, their usability is not impaired by this common practice. A frequently used size was 150 ± 0.2 mm inside diameter/162 ± 0.2 mm outside diameter and a length of 200 ± 0.5 mm. A hand cut notch at the end of the tube facilitated yarn string up. Such tubes are suitable for strokes of 100...260 mm.

Spinning tubes made from such phenolic paper, when used above 1500...3000 m/min, are very noisy during acceleration before yarn capture, and can explode under the centrifugal forces.

- for speeds up to 6000 or 8000 m/min, the spinning tubes are made from special paper; they are diagonally wound and then formed under pressure, and have a yarn-catching groove or slit at one end (Fig. 6.39) [85, 86]. Frequently-used dimensions are: 75 ± 0.2 mm inside diameter/87.3 ± 0.3 mm outside diameter, 90 ± 0.2/105 ± 0.4 mm, or 120 ± 0.2, 140 or 143 ± 0.2 mm inside diameter, with a wall thickness of 6...8 mm (the underlined size is the 1990 preference for up to 6000 m/min). The tube length is determined by the package pitch ± 0.2 mm. As a consequence of the high demands made by the chuck, acceleration, etc., these tubes can only be used once, in both POY and FOY spinning. For reasons of further processing, only one tube per yarn package is allowable.

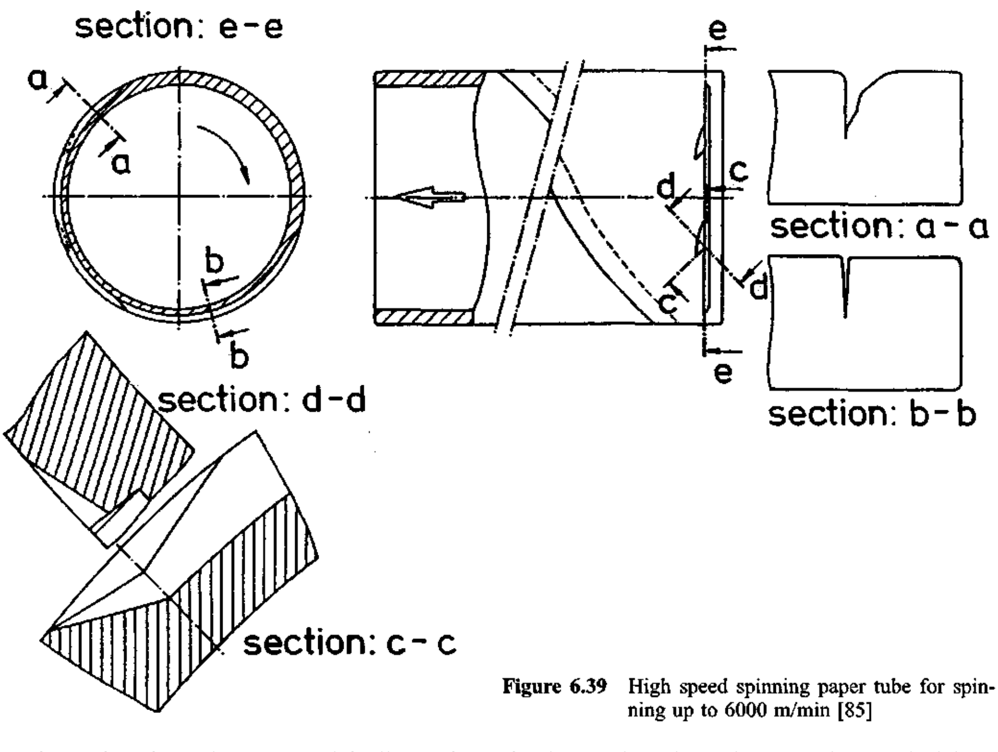


Figure 6.39 High speed spinning paper tube for spinning up to 6000 m/min [85]

- drawtwist tubes: These were originally cut from aluminum tubes, drawn into a slightly conical form and then shrink-wrapped with a plastic tube cover. Today one-trip drawtwist containers, made from molded parts and paper tubes similar to spinning tubes, are preferred. Typical dimensions are: 330 to 475 mm length and 46 to 75 mm outside diameter, depending on the ring diameter of the drawtwister. The internal triangular or square-sided support must fit the spindle positively (Fig. 6.40, [95]). Spindle speeds of up to 16 000 revs/min are typical.
- tubes for twisting and texturizing are cylindrically-wound paper tubes. If these tubes are involved in steam setting, the walls are made thin so that they can collapse during yarn shrinkage, and the tubes are coated with aluminum foil so as not to desorb dyestuff.
- conical tubes are often used in twisting and texturizing for direct sale to customers. The preferred cone angles are 3°30′ or 5°57′, the larger (seating) diameter is typically 46...90 mm and lengths are 175...300 mm (Fig. 6.41); the preferred package shape is the pineapple cone (Fig. 3.48b).

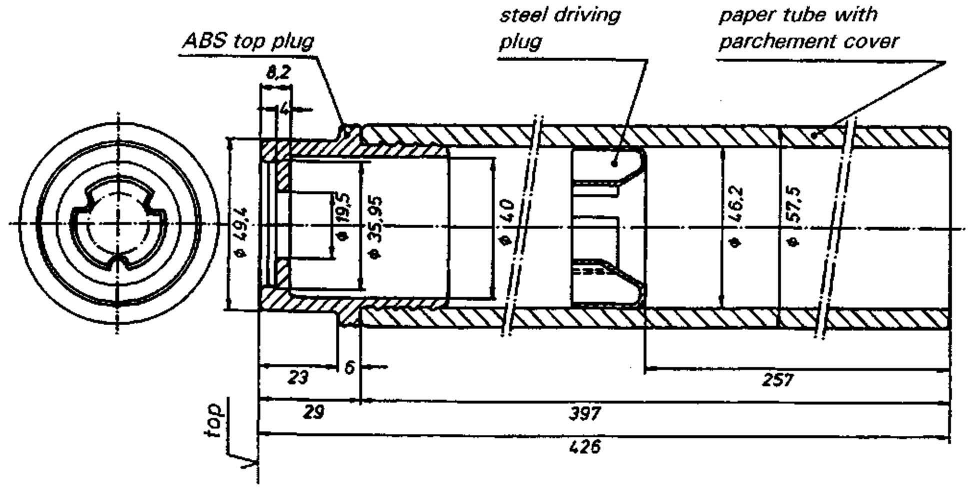
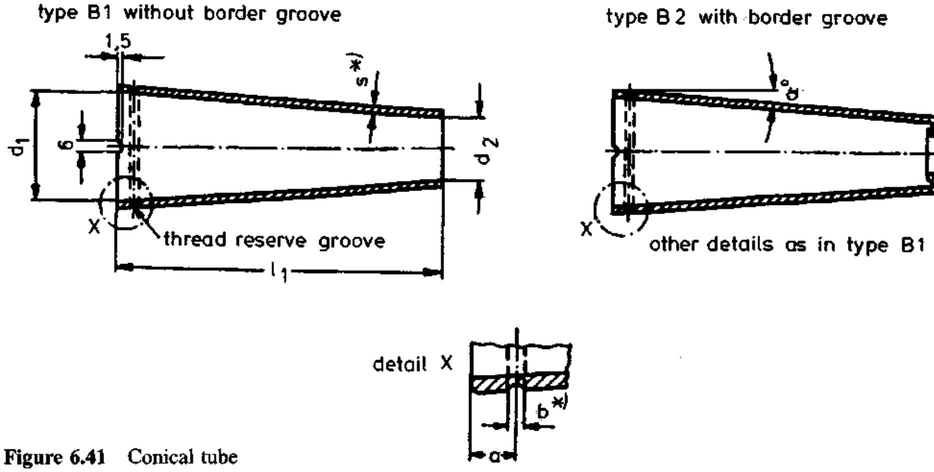


Figure 6.40 One-way drawtwist tube (for cops) [85]

- flanged bobbins (Fig. 3.48c). Despite the existence of standards, there are many forms, and the user should select a standard from the manufacturer's catalog, since the molds for these usually-sprayed bobbins are expensive. Dimensions to be noted are: seat (larger) diameter and/or support form, inner (winding) diameter and flange outer diameter, distance between the flanges and possibly winding- and shrinkage tensions. Flanged tubes are seldom used, and then only for thick monofilaments and hollow yarns in parallel winding. Single flanged bobbins are often used on heavy duty ring twisting machines.
- sectional beams and warping beams are used at knitting and especially at weaving, beginning with the warp-draw line (Section 4.11). Despite standards, there is again a plethora of beam sizes; practically every knitting- or weaving machine requires its own dimensions. The flange to flange distances are mostly adjustable. Beam loads, measurements and weights can be very large: a sectional warping beam can weigh 200 to 300 kg, a warping beam having an inner length of 1600 mm × 800 mm flange diameter can weigh more than 1t. The latter requires special transport and storage devices.


type B1 without border groove

type B 2 with border groove

Figure 6.41 Conical tube

They are manufactured mainly from steel or aluminum alloys, and have insertable drive spindles, mostly square shafts of 25...40 mm width.

- Identification: The large volume and multiplicity of yarn types flowing through a production plant makes identification essential. To this end, printing machines have been developed which print the yarn identification on the edge of the paper tube. Figure 6.42 shows such an identification printer and two examples of tubes identified on their edges [85].

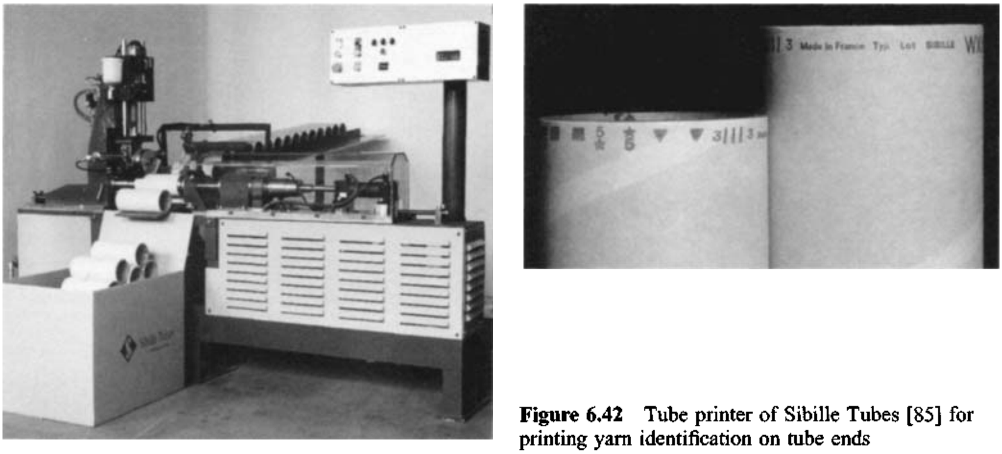


Figure 6.42 Tube printer of Sibille Tubes [85] for printing yarn identification on tube ends

6.12 Maintenance

Under "maintenance" one understands all technical, organizational and economic measures undertaken to delay the wear and tear and/or maintenance of the functional and working potential of the plant, including the security of technical working aids [81], subdivided according to Fig. 6.43. If one estimates, e.g., the out-of-production costs of a 200t/24 h PET polycondensation plant, including the associated staple fiber lines, at ca. DM 40.000/h, then the costs of a breakdown lasting many hours, including cleaning and re-starting, become evident.

These plants therefore require

- continuous cleaning, maintenance and checking, as well as
- preventive maintenance,

this work being done during the breaks in the production program, e.g., at a pack change, package doff or staple can change. Individual machines and equipment must therefore be constructed to be maintenance- and repair-friendly, capable of being run continuously without breakdown for, e.g., 8400 h per year. In the case of machines having many wear-prone parts, e.g., stuffer box crimpers and staple cutters, a second (standby) machine or machine component should be installed in the production line, enabling the tow to be diverted to the standby while the original is repaired. It must be possible to change spin packs in 1 min. max. and spinning pumps in 5 min. max. High speed winders should have a minimum number of plugs, connectors and fastening bolts, so that they can be quickly exchanged using a winder exchange trolley. A requirement here is sufficiently trained personnel and an adequate supply of spare parts.

Many parts, such as spin packs and pumps, filter sieves and quench air rectifiers, yarn guides, spin finish applicators, etc., must be preventively changed according to a fixed schedule. Table 6.12 gives recommended schedules for cleaning, checking and replacement of parts. Each producer should adapt Table 6.12 to his own production conditions, and observe and modify the schedule accordingly. Any large

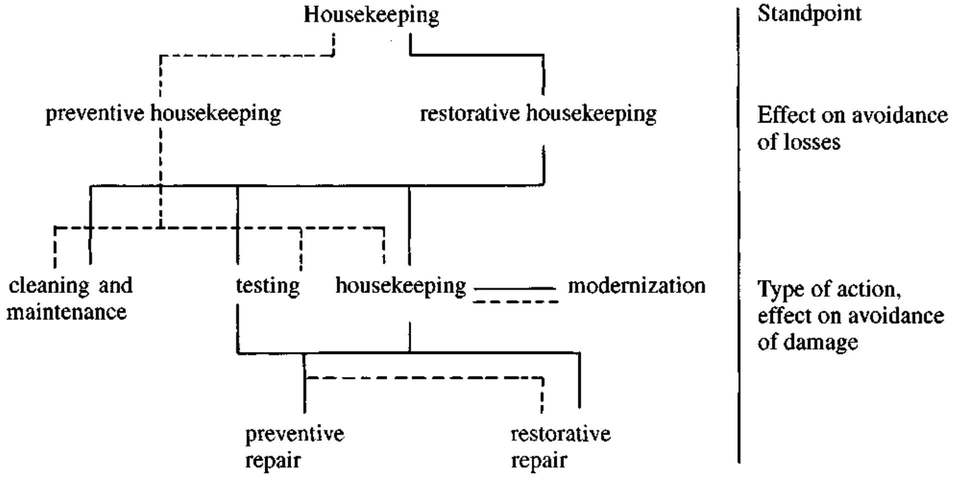


Figure 6.43 Structure of maintenance and housekeeping [82]: effect of housekeeping on reduction and avoidance of sudden damage and losses

Table 6.12a Running Time for Process Parts (Before Cleaning)

Part	Contamination	Running time days	Recommended cleaning procedure
Intermediate product filter in PET polycondensation	Dirt, metal from reduction of Sb_2O_3	40...60	RL (TEG) RL (H_2O + 30% HNO_3)
Large area product filter (between extruder and spinning beam)	Dirt, metal parts, gel, etc.	7...20	for PET and PA: RL (TEG)
Spin pumps	As above, coking	90...150	VHT, Proc., RL
Spinning pumps packs	As above, coking	7...20	VHT, RL, burning out oven
Spinnerets	As above, plus carbonized residues on the bottom face	7...20	For $D \leq 0.2$ mm, VHT, RL
Stainless steel (shattered metal) powder	As above, plus gel	7...20	RL (TEG + HNO_3) or other solvents
Polymer distribution pipes	As above	150...350	VHT or RL with appropriate solvent
Polymer autoclaves	As above	As required	Circulate or boil using appropriate solvents

Abbreviations: RL: cleaning bath; VHT: vacuum pyrolysis at high temperature; Proc.: Procedyne

deviation from these (and own) schedules should be investigated, and the problem corrected. There are always incidents requiring repair or complete exchange of parts. Here the downtime must be minimized. Many parts can be changed without stoppage, e.g., heating bands, heating rods and temperature-measuring elements, among others. In the case of polymer manifolds, it is often sufficient to allow these to cool down to a temperature which does not destabilize the melt, instead of cooling them down completely.

Even in an environment where the infrastructure for maintenance and repair work is favorable (e.g., in Central Europe or the USA), one must still reckon on 10...20% maintenance personnel, based on the numbers used in direct production. For the chemical section of the plant, these personnel would include equipment constructors, pipe fitters and argon arc welders having the necessary training and certification.

Table 6.12b Approximate Lifetime of Machine Parts

Part	Clean after	Renew/exchange after
Extruder screw, -cylinder	1 year	2...3 years
Static mixer	2...6 weeks	—
Spin	3...6 months	Test and possibly exchange
Spin packs and -filters	1...8 weeks	Replace filters
Spinnerets	1...8 weeks	6...12 months when using Al_2O_3 cleaning, ca. 24 months using vacuum pyrolysis, salt bath or TEG cleaning
Quench air rectifier, front mesh	2...4 weeks	According to test results
Stationary yarn guides, oil applicators	Check daily	2...6 weeks
Traverse guides		1...4 weeks
High speed bearings in winders, godets		2...6 months at ≥ 5500 m/min 1 year at ca. 3500 m/min 3 months at ≈ 5500 m/min
Pt100 in heated godets		1...4 weeks at 8000 m/min
Stuffer box components (staple)	Daily	<1 week
Yarn cutting knives (staple cutter)		3...8 h using knife steel 8...30 h using hardened steel
Hot plates for drawing	0.5 weeks	1...2 months when hard-chromed (or metallized) 4...6 months when hard-coated
Aspirator mouth piece		6...8 weeks

For the plant as a whole, the requirements are for machine fitters, machine constructors and precision mechanics, as well as the necessary electricians and electronic technicians, etc.

The workshop must be so equipped that all necessary jobs can be done there, i.e., next to argon arc welding there should be lathes, milling machines, drilling machines, etc., including possibly a horizontal boring machine, and the required personnel must be available. There should also be an electrical workshop having the necessary measuring instruments, including transportable balancing machines, stroboscopes, temperature- and speed measuring equipment, oscilloscopes, etc. According to plant size, a small to medium sized precision workshop is also required for making apparatus and other machine parts.

Furthermore, call out personnel must be available at all times during plant operation, even if they have to be telephoned, as is typical for small plants. Every production stoppage can prove to be very expensive.

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