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Review of yarn production

1.1 Historical basis

1.1.1 Historical background [1]

The long reach of history shows how prosperity varies as civilizations have waxed and waned. The course of prosperity has been bumpy and there are dangers in extrapolating the future based on the short-term past. Successive centuries have seen fundamental changes of varying types. Greenwood [2] outlines steps related to yarns and textiles in the first two millennia and points out the extraordinary fineness of the materials that have been made. He also discusses some of the developments that have improved the productivity of the manufacturing systems and reduced the costs over the centuries. The eighteenth century saw a financial revolution, the nineteenth saw the industrial revolution, and the twentieth saw the information revolution.

The history of humanity contains many references to textile materials because they were, and still are, part of the fabric of our lives. Consequently, the history of fibers is one of the traceable threads in the story of yarn production. A second thread concerns the extraordinary developments of the industrial revolution. There were gigantic steps in productivity of both people and machines. Another thread concerns the developing economic environment that has surrounded these changes. Thus, let us first make a brief survey of the history of some important fibers.

1.1.2 A brief history of silk

The origin of silk is found only in legend and fable; certainly it was used in the time of Emperor Huang Ti in China in the third millennium BC. Sanskrit literature refers to silk in India in the second century BC and the Old Testament also refers to it. When it percolated to the West, it was as valuable as gold on a weight-to-weight basis. Roman Emperor Justinian tried to monopolize the trade (unsuccessfully), smuggled silk worms to Constantinople (*c.* AD 550) and started sericulture there. Byzantine silks became world famous. The Moors established sericulture in Spain and so the production of silk spread. It reached northern Europe in the fifteenth century and the western hemisphere in the sixteenth, although it failed at first. However, the strong luster and ability to take brilliant dyes made silk very attractive. The peak of activity was after World War I and by 1919 the price had risen to US$21/lb; that is equivalent to over $1200/lb in the currency of 2003. Once fine man-made fibers entered the market, the price and the demand for silk dropped; but there is still an important market in some areas of the world.

Perhaps the early inventors of synthetic fibers were influenced by the knowledge of the manner in which silkworms, spiders, and other creatures extruded filaments. Doubtless, they were also impressed by the extraordinary properties of these naturally extruded fibers. Such inspiration was probably very important in determining the future of fiber production.

1.1.3 A brief history of bast fibers

Bast fibers are derived from the stems of various plants.

Cultivated flax [3] probably originated in the Mediterranean region; certainly it was used in prehistoric times. It was found in Stone Age dwellings in Switzerland, the ancient Egyptians used it, and references to it are sprinkled throughout historical writings. It has been used both for its fiber and for its seed. The fiber is used to make linen cloth, and the crushed seed yields linseed oil, long used for the preservation of leather and wood. Until the eighteenth century, linen manufacture was widespread in the domestic industry of European countries. The development of cotton processing and the great inventions of the industrial revolution dealt an almost fatal blow to this erstwhile prevailing industry.

Jute fiber was largely unknown in the West until the eighteenth century, but it was in common use in Bengal before then. There was resistance to its use because blending it with hemp or flax was regarded as adulteration. In the nineteenth century, the Dutch government replaced linen coffee bags with jute and this gave an impetus to use it in the West. Research was carried out in Dundee, Scotland, which became a recognized center of yarn production. Also, much of the production was in what are now Pakistan and India. (Strangely, after partition in 1947, India had the jute processing resources, and the bulk of the corresponding agricultural producing sector was in Pakistan: Jute played a prominent role in the development of trade relations between the two countries.) It was attractive because it was strong, bulky, and cheap. However, in more recent times, the increasing use of polypropylene for cotton-bale wrapping, carpet backing, sacking, and other products has decimated the jute industry.

Hemp fiber is thought to have originated north of the Himalayas and was well known in China in the second millennium BC. It was brought to the Americas in the sixteenth century and, by the twentieth century, was being grown throughout the world. The plant not only produces fibers but also narcotics. Some species of hemp produce little in the way of narcotics, but many countries make the growing of it illegal for social reasons.

1.1.4 A brief history of wool fibers

The use of wool for clothing dates back to antiquity. Outstanding properties of wrinkle resistance, moisture absorption, warmth, and tendency to felt, have given it a role, not only in apparel, but also in blankets, upholstery, and floor coverings. Babylonia is translated by some as meaning ‘the land of wool’. It is known that the

Phoenicians traded wool fabric during the first millennium BC [3]. The Ancient Romans established wool factories to supply their army; the fame of these factories was spread by the travels of Roman soldiers. In Britain, the wool flocks were scattered by the incoming Saxons and the wool trade there then went into decline. The Normans re-established the trade and it developed for a time, although there seems to have been little progress through the dark ages; it was not until after the seventeenth century that structural changes started to occur. After many struggles over restraints in trade, wool was very important in England in the eighteenth century. Spain too was a major producer but its government had enforced rigid restrictions on the export of fleeces at about that time [4].

In times of rapid technological change, many are left behind. Mechanization in the Low Countries and Britain in the nineteenth century permitted spinners in these regions to out-produce those who had not embraced the emerging technologies. There was then a vast opening-up of the supply of raw wool from the western and southern hemispheres. It was the combination of a plentiful supply of raw material and high productivities of people and machines that produced the displacement of the centers of production and sites of the markets changed also. Now, many of the industrial companies then formed have, in turn, been overtaken by new technology and economic changes. The development of synthetic fibers and new processes has created a new situation; the market in wool has declined somewhat even in the last decade. Despite this, the world consumes about 1.5 million tons of wool per year, and its value is greater than the weight might suggest. Australia abolished its price support in the 1980s and prices globally were determined more than before by market forces. In the decade centered on 1990, prices plummeted [5], but supply is now in better balance with demand and there is hope for expansion. China is now a large consumer.

A remarkable feature of wool is its ability to recover from deformation over a time, and this gives apparel made from the fibers attractive crease-shedding properties. Also, the rate at which the fiber takes up and disperses moisture is such that it gives clothes made from wool good comfort properties. These inherent properties give wool an attraction that is likely to guarantee it a place in the world market; the main question is how much of that market it will retain.

1.1.5 A brief history of cotton fibers

The use of cotton fibers has been traced back to as far as 3000 BC. Yarns were found in the ruins of Mohenjo-Daro, a city in the Indus valley [2]. Cotton has been known, cultivated, and worked in India since the earliest historical periods. A Hindu Rigveda hymn (*c* 1500 BC) mentions cotton, and Herodotus (*c* 450 BC) is said to have mentioned 'wild trees bearing fleeces as their fruit'. Ancient Egyptians were known to have grown and spun yarns in the seventh century AD. When the Spaniards arrived in America they found cotton being used to make cloth. Cotton was found in prehistoric pueblo ruins in Arizona, and cotton grave cloths from pre-Inca Peru are still in existence.

Cotton has remarkable durability in the marketplace; it filled a major role in the industrial revolution and it has formed an alliance with man-made fibers in more recent times. Therefore, it is perhaps best if further discussion of the history of cotton is left to unfold with some of those events.

1.1.6 A brief history of man-made fibers

Ideas about synthetic fiber processes were expressed by Robert Hook (1775) and René de Reaumur (1734); Louis Schwabe extruded glass fibers in 1842. Much of the early work was to develop a means of 'liquefying' cellulose to permit extrusion. In 1846, C F Schoenbein prepared nitrocellulose, and George Audemars patented a process for making a material related to rayon from nitrated wood in 1855. Sir Joseph Swan coagulated nitrocellulose solutions to produce fibers but he was interested mostly in producing filaments for electric light bulbs. The stage was therefore set for Count Hilare de Chardonnet to begin commercial production, in 1891, of filaments coagulated in heated air, from a nitrocellulose solution derived from mulberry leaves. Louis Henri Despeissis then developed a cuprammonium solvent for cellulose itself, from which filaments could be coagulated in sulfuric acid. Another important milestone was when C F Cross and E J Bevan patented (1892) a viscose rayon solution resulting from dissolving cellulose xanthate in dilute sodium hydroxide. In 1902, Max Mueller discovered a way to convert cellulose xanthate into regenerated cellulose and the production of viscose rayon yarn could then start at Marcus Hook in Pennsylvania, USA, in 1911. (It might be added that the pressures from environmental concerns at the end of the twentieth century have led to the closure of some plants making products of this nature.)

Synthetic polymers (which are large molecules, or 'macromolecules') were developed as a result of research into the properties of large molecules starting in 1926. This is an early example of the commercial exploitation of organized scientific research. Wallace H. Carothers and his associates found that they could draw out filaments from long-chain polymers. Such filaments were extruded and toothbrush bristles were made from them. Soon after that, polyamide filaments for knitted hosiery entered limited production, and in 1940 wider production began of the first truly commercial filament – nylon. Nylon is a polyamide and the idea of extruded macromolecules has since expanded to include many other chemical types. Polyester was developed in the 1950s and Brunnschweiler and Hearle have collated an interesting account of this development [6]. Even after the chemical and mechanical problems (with excessive discontinuities in extrusion) had been reasonably well worked out, there were still difficulties with developing appropriate fiber crimping and finishes. There were also difficulties with static electrification, dyeability, oily soiling, pilling, dye sublimation during ironing, hole melting, and other problems in fabrics. But, by 1952, production had begun and there was a boom that lasted for five years; then the pace of market development moderated as the producers of natural fibers formed their own marketing organizations. The excesses of a multitude of small, single-knit fabric producers also caused a condition of oversupply of knitted fabric. Since that time, however, there has been a continuous expansion of the markets for all fibers. In those markets, polyester has expanded to some 10 million tons/year, with acrylic fiber running at about one-third of this. It is noteworthy that in staple production, the ratio between polyester and natural fibers still holds at roughly equal proportions. The centers of production of man-made fibers have spread throughout the world.

Man-made fibers have been produced in filament and staple forms. In the early days, the cellulosic filaments were difficult to texture, and the shiny, slick surfaces were not in universal demand. Many were cut up into staple and blended with natural fibers. As synthetic filaments began to appear, means of texturing them followed closely and a successor to the silk throwing industry, aimed at the apparel industry, began to appear in advanced countries. Technical filaments rapidly penetrated the industrial market because of the strength of the materials, and heavy textured nylon yarns made a large penetration of the home furnishings market, especially in carpets. Also, blends of synthetic staple and natural staple fibers began to appear. Of these, polyester/cotton and polyester/wool blends have become significant raw materials for yarn makers.

1.1.7 Historical development of the economic environment

Religious persecution of the Huguenots in mainland Europe before the seventeenth century caused them to flee to England and they carried their knowledge of textile manufacturing with them. The village of Worstead in Norfolk gave its name to the worsted process at that time. The business skills of these and others led to the development of the idea that credit is as good as cash. The outcome of this was the founding of the first publicly financed companies, leading to an explosion of business ventures that swept the inventions into the industrial revolution. Others similarly exported their skills over succeeding decades and centuries with the result that technological and business environments spread through the world. Writers have referred to the industrial revolution as though it occurred in a flash. In reality, it was spread over the eighteenth and nineteenth centuries, during which time there were ups and downs in all the economies concerned. Similarly, the newly termed 'information revolution' will evolve over a considerable timespan.

The success of the industrial revolution stems from the opening of new markets. For example, in the initial phase, cotton fibers were very expensive in markets where cotton did not grow naturally. Cotton, at the beginning of the industrial revolution, cost the equivalent of roughly US$100/lb in 2003 currency. The alternatives used by many were wool and bast fibers; the yarns were coarse and the fabrics heavy. Only the rich could afford to pay more than the equivalent of, say, $100/lb for fine cotton yarns. Cotton in Europe at the beginning of the twentieth century, cost roughly the equivalent of $10/lb in modern currency. In 2003 it is less than $1/lb. Reductions in the cost of fiber did not happen accidentally. Expanding demand, improvement in agricultural techniques, mechanization of harvesting and ginning, and, ultimately, the rise of man-made fibers all put downward pressure on fiber prices.

The beginnings of the industrial revolution involved extraordinary inventiveness, availability of capital, and much human exploitation. Development of machinery did little to make the life of the mill worker easier at the turn of the century; much of the benefit went to the mill owners and traders. Many inventors were also excluded from benefit. The short-term result in the nineteenth century was that the cost of the goods produced was sharply reduced and there was a worldwide expansion of trade. In the early stages, goods were transferred from a rich economy (Group A) to others (Group B) and wealth in other forms flowed in the opposite direction as shown in Fig. 1.1. As

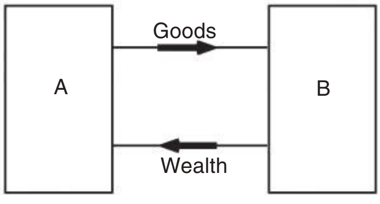

Fig. 1.1 Historical flow of wealth

the development continued, Group A expanded to include a range of nations and economies so that the simplistic model given here became less applicable, but the general idea is the same.

Long-term results of the worker exploitation in the Group A economies were the rise of socialism and the associated rise in wage costs during the twentieth century (Fig. 1.2). This widened the economic gap between Groups A and B; also, there was a marked decrease in fiber prices as the market expanded. These two factors played important parts in the economic changes throughout the world. Of course, there were short-term fluctuations in these costs; therefore Fig. 1.2 shows only trend lines.

It is not surprising to find that a growing number of the Group B economies desired to join the industrial nations and set up production units under their own control. This was especially so during the second half of the twentieth century. The element of widely differing wage levels became an important factor in the competition, and eventually in the net flow of textile goods. To combat the differences in wages, machinery was then developed to reduce the need for human intervention and improved to increase machine productivity as indicated in Fig. 1.3. The increases in productivity now seem to be leveling off and perhaps we should not expect the same massive changes in the present century that we have experienced in the last.

The enhancement of machine productivity was not the only contributor to the reduction in costs. At the beginning of the twentieth century, it was normal to have six or seven stages of processing between carding and spinning in the cotton industry. Nowadays, some mills work with as little as one stage between those processes. The reduction in the number of stages gives at least two benefits. First, it reduces the capital cost components. Secondly, it reduces the need for transfers of the textile product from one machine to the next. Formerly, these transfers were manual and

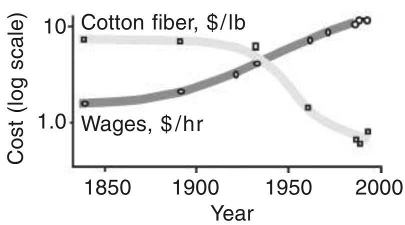

Fig. 1.2 Costs in 1994 US$ in an 'A' economy

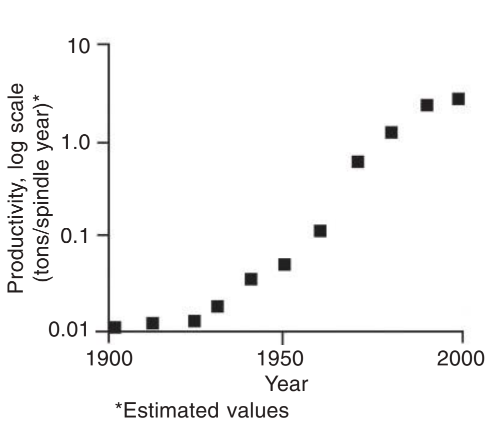

Fig. 1.3 Changes in machine productivity

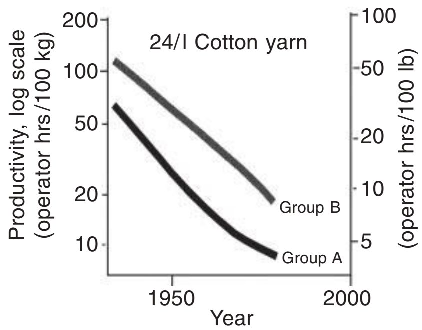

Fig. 1.4 Changes in operator productivity

thus accounted for much of the need for human resources. Modern automated transfer systems are now available, which change the balance between the cost categories of labor and capital. The transfers are still a significant cost component; reducing the number of them plays a part in the economies of the modern technology. Technical developments include automation, automatic handling, and reduction of the number of process stages as well as enhanced productivity of equipment. The rate of adoption has varied throughout the world and, for the present purpose, rates appropriate to the categories mentioned earlier are indicated in Fig. 1.4 to illustrate the point. The normalized variable quoted in the diagram in metric units (known colloquially as 'HOK') is a measure of the productivity of the workers in the factories.[1] If we multiply the wage rate by the HOK variable we get the labor cost per 100 kg of product. Labor cost per unit weight has changed less than might be expected over the last century after discounting inflation and allowing for changes in other cost components. This is despite the steep rise in wage rate shown earlier. The cost per unit weight has been low in the Group B economies and this has given them an advantage in the past.

However, as the HOK shrinks, so do the effects arising from the differences in wages; other cost factors then tend to predominate. As wealth flows to the lesser-developed countries, the standards of living improve and wage rates rise. As wealth flows from Group A economies, there is a trend for a particular industry to decline, sometimes to the detriment of the local standard of living. In other words, there is a tendency towards equalization of wages. Of course, there are more than two categories of economy in the world and the spectrum of wage rates is wide. Nevertheless, the trend still exists, with some nations moving up the scale and others moving down; it is a fluid situation with changes certain over the coming years. Losses in manufacturing jobs due to automation also have had, and will have, a marked effect. Automation not only affects costs of production but also affects the tastes and the ability of the remaining workers to buy textile goods. The markets tend to be more widely distributed and their character changes. The cost of fibers has changed, especially in the last half of the twentieth century, and there are a number of reasons for this. There was more attention given in the second half of the century to civilian matters than in the first.

1 HOK = operator hours per 100 kilograms of product and OHP = operator hours per 100 lb of product. The acronym 'HOK' appears to be illogical because it is derived from a language other than English.

Much of the first half was spent in war and depression, and the markets did not realize sustained expansion. The economic expansion after 1950 probably played a large part in reducing costs because of improved efficiencies of the organizations and equipment. Also, man-made fibers became a larger competitor to natural fibers.

A range of man-made fibers became commercially viable over a number of markets in the second half of the century. The sales were accompanied by technical service and research that developed more new markets and facilitated competition in many traditional ones. As time progressed, the production of man-made fibers spread throughout the world and is now ubiquitous. Producers of natural fibers have combined to form various organizations that emulate the research and service provided by the man-made fiber companies. But if the price of a fiber falls, as it did with wool, then the service from such organizations becomes more restricted. There have been cutbacks over a range of such organizations. In general, as fibers become more nearly perfect commodities, less is spent by fiber producers on research. Eventually, they are less able to give the same technical support to the textile producer as before. It is therefore likely that textile producers will have to look for other resources and this may have an impact on some companies' ability to compete.

1.2 Present day conditions

1.2.1 Costs and sales

In yarn production, labor costs are only part of the total cost. Livingston [7,8] states that US labor costs formed 14% of the total in 1992; the largest component was said to be that of fiber costs, which comprised approximately 50% of the total. However, the percentages vary from place to place in the world. Energy costs in yarn production vary with the product but, for example, can run at up to some 10% of the total. These costs rise with speed and count. It can be expected that power requirements will rise in Group B economies as more plants run at higher speeds and install air conditioning. Also, amortization costs rise with investments in equipment. Again, there is a trend for equalization of the costs between the various economies. Where the main flow of goods is global, shipping costs become increasingly important because they impose a premium of perhaps some 10% on the transoceanic shipper of the goods. An additional hindrance to trade is caused by tariffs and quotas. The fairly recent international actions expressed by GATT (General Agreement on Tariffs and Trade) and NAFTA (North American Free Trade Agreement), and others to follow, are likely to reduce these barriers and there are hopes for an enlarged market. There is emerging evidence that the move of parts of the textile industry from Group A to Group B regions has been hastened by the freer market. Some erstwhile Group B regions have, indeed, become Group A regions. Relative currency changes also affect the issue.

Sales are not determined by price alone. Quality of the product and service also affect the issue. Most textile products go through a chain of sales transactions before reaching their final destination. These intermediate transactions are between professionals, and technical quality becomes important. Of course, the requirements of the purchasing public have also to be considered. The point is that considerable investment has to be made in appropriate testing equipment, and care in testing becomes essential to satisfy buyers. Probably the most important aspect of service is delivery of goods at the specified times. To get the best advantage, quality and service have to be managed efficiently.

History leads to think that the most important factor for success is to recognize expanding markets and plan accordingly. Mechanical inventions may have a relatively small effect on the future competitive position. Other technologies, such as telecommunications and computing, are likely to have a greater effect. Nevertheless, the need to operate a mill in the most economic manner is still a paramount consideration, and high productivity machinery has to be used for major installations. In addition, there is a great need to make products of a quality that will satisfy the market; this involves quality control, which becomes ever more sophisticated. Cost and quality of the product have to be carefully balanced for each market to achieve a competitive position without which the enterprise will fail.

1.2.2 World market for yarns

According to Thomas *et al*. [9], the market for spun yarns will be dominated by cotton. At the time of writing, the share held by cotton is about two-thirds of the world market and this has been stable in recent years. Nevertheless, this is not to say that the market has remained unchanged; on the contrary, shifts in consumer demands and preferences, cost structures, and geographic migrations of the industry are powerful agencies for change.

Europe has suffered losses in production capabilities whereas Asian output has soared. American output has increased but the character has changed. There is consolidation amongst the companies that might be seen as evidence of the sorts of pressures that have affected Europe. However, Europe is still the world leader in the smaller market of long-staple spinning. The production of cotton is still very strong in the USA and this is one of the reasons why the industry there has maintained stability. Production of polymers and man-made fibers and filaments has dispersed through the world and, again, the production in Asia has made remarkable strides and is affecting Western markets.

1.3 Future of the means of textile production

One reason for the reduction in HOK over the years is that the productivity of the machines has increased. Greenwood [2] quotes HOK values ranging from 12 500 in Neolithic times, through 3120 in ‘pre-fourteenth century’, to 0.63 for open-end (OE) spinning in the 1970s. In staple spinning, the mule was superseded by the ring frame and then by newer technology. The move to rotor spinning and other new technology in the USA and in some other areas has been highly significant. The productivity of the fastest machines has escalated rapidly but it is difficult to imagine how the pace can continue. There are signs that the productivity curves are flattening and they seem to be approaching maximum values asymptotically.

Next let us turn to materials handling. At the beginning of the twentieth century, the whole process consisted of a myriad of steps, with human intervention at each one. Gradually the number of steps has been reduced and automatic handling has become common. Automatic handling takes several forms. It ranges from the pneumatic transfer of fiber, to the use of robots to carry packages between machines. It follows that these developments have also contributed to the reduction in labor. Again there are limits; as we approach the irreducible minimum number of stages and automate the transfer of textile material, there is little to be gained in possible labor cost reductions. However, there might well be other advantages. Thus, for this reason, the HOK curves shown earlier cannot be extrapolated too far. Nevertheless, these considerations imply that improvements in the technology of production will play a diminishing role in deciding the partition of the markets.

1.4 Modern production systems

1.4.1 Some comments on the mechanics of fiber structures

Some knowledge of the properties of the fiber, and of the yarn as well, is useful to understand the difference between various products. At this stage, suffice it to consider only the mechanical properties of stiffness and bulk. A coarse fiber (i.e. one having a high linear density) is stiffer than a fine one. Consequently, fabrics made from the coarser fibers often feel harsh and prickly. Thus one can understand the drive to use fine fibers that give a softer 'hand' to fabrics. However, if carried too far, the use of ultra fine fibers can lead to difficulties with the production of nep (a fiber fault caused by fiber knotting or tangling with itself to yield a tiny ball of fiber which may take up dye at a different rate). Next, consider fiber bulk, which is affected by fiber crimp or convolution. Crimp typifies the extent of zigzag, helical, or other non-linear shape of the fiber. The greater the crimp, the more volume it takes up and the more 'bulky' is the yarn. Figure 1.5 is intended to show the effect of texture in regard to bulk. Figure 1.5(a) indicates a series of parallel fibers, which could be easily compressed to form a strand of very little bulk. Figure 1.5(b) shows similar fibers which have been induced to curl into helical configurations, lying beside one another like a series of bedspring coils to occupy a much greater volume than before. A bulky yarn made up into fabric produces a material with good insulation properties. Fine, bulky fibers produce fabrics that feel warm and soft. Fine, non-bulky fibers produce silk-like fabrics. On the other hand, coarse fibers are often used to make carpets because the carpet tufts stand out from the backing and can be loaded at their ends in normal use without buckling too severely. A fine fiber would buckle and change the appearance in the loaded areas of the carpet. Thus, the use of coarse fibers helps to reduce the appearance of tread marks on the surface of the carpet.

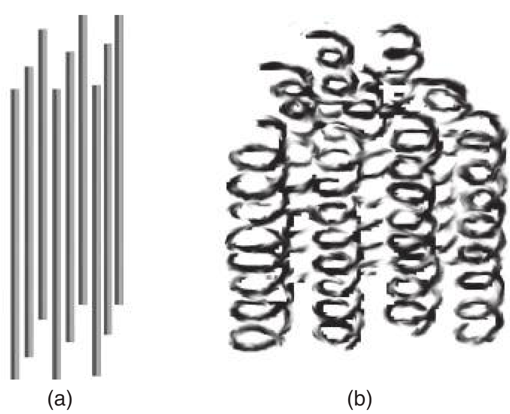

Fig. 1.5 Volume occupied by fibers

1.4.2 Filament production

Fiber production before the eighteenth century was an agricultural undertaking with the result that, except for silk, the fibers available were of a relatively short finite length (we call these staple fibers). Yarn production systems of antiquity were mostly staple yarn systems. In modern times the range of raw material has expanded and synthetic fibers have become available. These so-called man-made fibers are supplied in staple form and also as 'continuous' filament. Thus, in modern times, there is a range of yarn making technologies which did not exist earlier. This range continues to expand, perhaps at a declining rate, as economic factors other than machine productivity take precedence.

Extruded filament yarn manufacture is a short, mechanical process involving only one or two steps. Yarn is extruded and drawn to approximately the right 'size'; it then is often textured to give the final product. A schematic drawing of a simple melt extrusion system is shown in Fig. 1.6. It shows only a rudimentary polymer chip feed system. A practical system may have a complex liquid polymer feed and two or more draw zones in a single spinline. There are a variety of alternative systems within this broad category of filament production. Although the production of filament yarns appears deceptively simple, there are complexities. The processing conditions have to be very carefully monitored and controlled because heat, humidity, and mechanical stress affect the polymer in a way that affects the dyeability of the final product. Thus, it is imperative that those in charge understand the problems which can arise due to the chemistry and molecular structure of the polymers from which the fibers are made. This is in contrast to the *mechanical* complexities of staple processing.

Staple yarn manufacture is much more complex from a mechanical standpoint; it involves many stages of processing before the products are ready for shipping. There

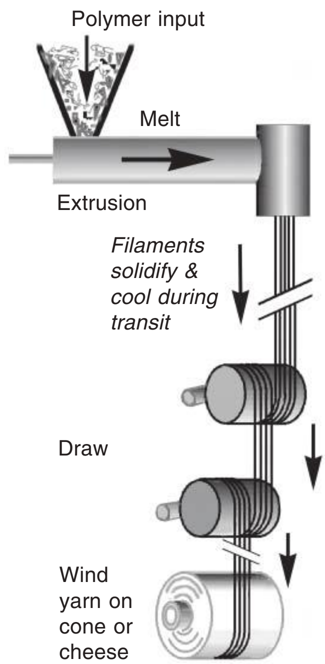

Fig. 1.6 Simple polymer chip feed system for the production of filament yarn (Note: practical systems are more complex)

are a variety of staple spinning systems available, but broadly they can be categorized as short- and long-staple systems. Short-staple spinning is the logical development of the cotton spinning of history, but the range of fibers has increased dramatically in this century. Long-staple spinning has a heritage of spinning wool and bast fibers; but in recent times, the range of long-staple fibers has also increased markedly. A comparison of various systems is given later in Table 1.1.

1.4.3 Textured yarn production

In yarn production, polymer is supplied either directly from the chemical reactor or as polymer chip. The polymer is fed to an extruder in which a rotating screw or auger transports the input material through the extruder barrel and pressurizes it; as the polymer passes through the barrel it is melted or maintained in the molten condition. The extruder changes the form of the molten polymer, from a relatively slowly moving mass to the high speed thin jets of polymer which form the yarn. It is metered and filtered before passing through the spinneret, which contains one tiny hole for each filament. The emerging filaments cool rapidly and solidify; they are also 'drawn' by taking them up at a faster rate than that of the supply. Drawing is a very important part of the process because it stabilizes the molecular structure and strengthens the yarn by improving the molecular orientation.

The main idea in most texturing systems is to heat set the filaments into some sort of crimped or convoluted form, such that each filament is held as separate from its neighbors as possible. In this way the yarn contains the many air pockets needed to produce insulation properties, permeability, and softness. Furthermore, the yarn now occupies a greater volume, which is also very important since the purpose of most textile materials is to cover some underlying strata; the greater the bulk, the better the cover. Also the yarn becomes more extensible and this, too, is an added attraction. It is possible to get various combinations of stretch and bulk. For filaments (such as rayon) that cannot be heat set, it is possible to tangle the fibers to lock them mechanically.

Table 1.1 Typical process schedules

	Nylon filament	**Nylon tow**	**Polyester staple**	**Cotton**	**Wool**
Fiber processes	Extrusion Drawing Winding	Extrusion Drawing Stretch-break	Extrusion Cutting Crimping Baling	Harvesting Ginning Baling	Shearing Sorting Scouring Baling
Mill processes	Texturing Winding	Drawing Drawing Roving Ring spinning Winding	Opening Carding Drawing Drawing Roving Ring spinning Winding	Opening Cleaning Carding Drawing Drawing Roving Ring spinning Winding	Opening Cleaning Scouring Carding Drawing Drawing Roving Ring spinning Winding
Typical yarns	Textured	Staple	Staple	Staple	Staple
Typical uses	Hosiery	Carpet	Apparel Household	Apparel Household	Apparel Carpet

An example of this is air-jet texturing. Sometimes it is desirable to combine air-jet with false-twist texturing. Air-jet texturing gives a product that is nearer to a staple yarn than is a false-twist textured yarn. It has much of the hand and appearance of the staple product. False-twist machines with built-in air-jets are now becoming common.

1.4.4 Tow and man-made staple fiber

Man-made staple fibers are made from tow, which is extruded in the same basic way as with filament yarns; however, the number of filaments involved is vastly larger. The linear density of the filaments in the tow depends on the end use. A large extruder supplies a number of spinnerets and several extruders are ganged together to produce a thick rope of filaments. These filaments must be fully drawn before they are cut into staple or shipped to the spinning mill. The major production of most tow makers is cut within the organization and the product is sold as staple fiber. However, some tow is sold to those mills which elect to stretch-break or cut their own staple. Usually, such mills make long-staple yarns. Where the fiber maker cuts the material, great care is needed to blend very large volumes of material to ensure uniformity of the product over long periods of time. Care also is taken when the fiber makers' processes are altered in any way because the slightest change can cause tremendous difficulties in the mills. The fibers are batched in so-called 'merges' so that changes can be equalized and controlled. This is not to say that there are never variations in fiber properties, but rather that they are sensitive to change and that great technical expertise is needed to control them.

For long-staple processes, where the mill chooses to convert the tow within the mill, different standards apply. There is no longer an opportunity to merge batches in gigantic blending operations. Each tow supplied to a mill must stand on its own merit and the tolerances on the filaments have to be even more strict than with general tow production because there is little opportunity for doubling; thus the cost is higher.

Another factor is that even the modern stretch-breaking machine used for converting tow to staple is limited in the linear density of tow that it can handle. The tows supplied to mills are often much lighter than those used internally by the fiber maker. A simple calculation illustrates the point. If the strength[2] (tenacity) is, say, 35 cN/tex and the tow has a linear density of 10^6 tex, the breaking strength of the tow is 0.35×10^6 Newtons (over 30 tons). Thus, the loads needed to break the fibers in a filament tow are very high and the stretch-breaking machine has to be very robust. Such machines are expensive. Even the lightest tows used today might have a quarter of a million filaments in the cross-section.

1.4.5 Staple yarn production

Staple fibers usually arrive at the mill in compacted bales containing about 500 lb of fiber. The bales are stored according to fiber classification; this makes blend component selection easier. Fiber supplies might come from brokers who deal in natural fibers, from synthetic fiber makers, or from both. In the latter case the product is often referred to as 'blended yarn' although, in reality, all staple yarn is blended. An example of a flowchart for cotton and melt spun staple fibers is sketched in Fig. 1.7

2 A tex is a measure of 'thickness' or linear density equivalent to 1 g/km

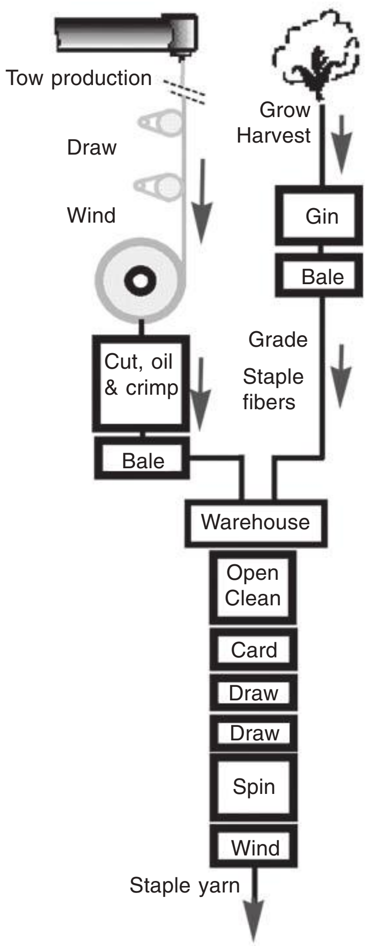

Fig. 1.7 Staple fiber processing

and any combination may be used according to the market being served. Somewhat similar routes apply to wool/man-made fiber blends but in this case there has to be a wet process stage somewhere to remove the wool grease. This is increasingly being done in the agricultural sector.

1.4.6 Short-staple yarn production

Short-staple yarns are produced from bales of short staples, which are delivered to the mill by the fiber suppliers. The yarn maker 'opens' the bales to produce a flow of more or less discrete fibers, which are then combined into a rope-like strand called 'sliver'. Yarn making requires that the fibers be well oriented and therefore must use processes which will straighten and parallelize the fibers. An important one of these is drawing, which is a process of elongating the strand to make the fibers slide over one another and hence help in orientation.

Drawn sliver has to be reduced in size and then twisted to make yarn. There are various processes of drawing (sometimes called drafting) and twisting. For some specialized uses, yarns can be twisted together to form ply yarns.

1.4.7 Long-staple yarn production

There are three major types of long-staple yarn production systems; these are called (a) worsted, (b) woolen, and (c) stretch-breaking. In practice, some worsted and woolen manufacturing plants also make their own staple by cutting or stretch-breaking tow. There is much more variation in plant layout for long-staple yarns than there is for short-staple ones.

The worsted system was devised for twisted yarns made from wool but it has been adapted for man-made fibers such as acrylic and its blends. In principle, it is similar to the short-staple systems just described except that a wet scouring operation precedes the mechanical processes, different types of card are used, and the machine elements are generally larger than for short staple. It is an important process.

Woolen processing, despite its name, can also involve the processing of a variety of long fibers ranging from wool to man-made fibers. The process (one of the original short-process lines) consists of a card set comprising several roller-top cards assembled in series on a single frame as well as spinning frames; and winders. The yarns are softer and weaker than worsted yarns.

Stretch-break systems use only man-made filament tows and usually start with a stretch-breaking machine, omitting the carding and preceding processes. It is a relatively short process line. In carpet yarn production, the system is in competition with bulked filament production, which has limited its growth as a system. Very occasionally, the stretch-broken material is fed to a card when there is a desire to blend it with a natural fiber. Process schedules for different products are given in Table 1.1.

1.4.8 Man-made carpet yarns

Carpet yarns are considerably heavier than apparel yarns and the poundage produced is very large. Carpets produced with man-made yarns have displaced those made of natural fibers in many markets. Nevertheless, the total market size has increased and traditional carpets still hold a significant portion of it. This is of sufficient importance to be mentioned at an early stage.

Several alternative manufacturing routes may be used, two of which are indicated in Fig. 1.8. On the left is the traditional route in which tow is cut, oiled, and crimped by the fiber maker before shipping bales of staple fiber to the yarn manufacturer (the crimp is intended to make the fibers mutually cohere to make further processing easier). On the right is a system in which the tow is shipped to the yarn maker and the cutting or stretch-breaking is carried out in the mill to convert the material to staple fibers in sliver form. The sliver is then bulked so that the yarn made from it has a soft hand with good cover. Alternatively, the fiber maker might bulk the yarn before shipping it directly to the carpet maker. The productivities of the equipment in manufacturing bulked filament yarns are very high and the economies of size favor the fiber maker over the small installations in the mills in this particular field.

1.4.9 Composite yarns

A variety of systems are now emerging that combine filament and staple processing. Some of these involve the wrapping of filaments round staple fiber bundles or low twist staple yarns; some include a filament core for strength and others use binders. These are referred to generally as composite yarns. Where low twist is used, the yarns

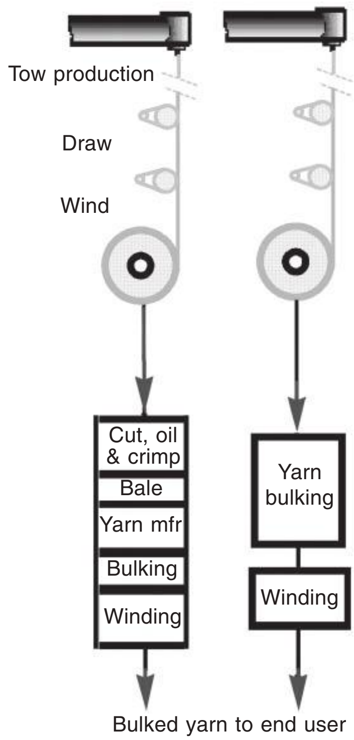

Fig. 1.8 Carpet yarn production

become softer in hand, but there is a danger that the filament will 'grin through'[3] the staple fiber covering. This might result in an unacceptable appearance of the fabric. Adequate cover of the filaments is generally required and this imposes limitations. Other changes in yarn structure may also alter the aesthetics of fabrics and hence much market research is needed for such new products.

The category of composite yarns also includes industrial yarns where the most important attribute is strength. Some man-made filaments are exceedingly strong and the technology of composite yarns becomes very important where there is a need for a sheath of fibers with different characteristics that surround a strong core. A common example is that of sewing thread, where a non-meltable sheath is desired.[4]

Some non-textile composite materials are made in which strong yarns are embedded in a matrix to reinforce it. For example, concrete can be reinforced by high tenacity yarns or fibers.

1.4.10 Review of processes

Since the cost of fibers is a large proportion of the final cost of yarn, it is important that the spinner understands something of the processes and products of the fiber-

3 Grin through is a term used for exposure of the filament surface in the fabric, which may cause changes in light reflection and areas of differing dye pick-up.

4 In sewing, a thread passing through a needle at very high sewing speeds might be caused to melt in places by the high temperatures in the needle eye. For example, nylon thread might melt on the surface; but if it has a cotton sheath it will be protected because cotton does not melt.

producing industries. Not only do the *average* attributes of the fibers influence the efficiency of mill processing and the quality of the yarn, but the defect levels and variability within the fiber supply are also highly relevant. Thus quality control is important. Consequently, this book may be regarded as containing three sections. Chapter 1, which is a general overview, may be regarded as the first section. Chapter 2 is written in three segments to emphasize the materials employed and may be regarded as the second section. The subsequent chapters deal in detail with the wide range of processes used to convert fiber to yarn; these chapters may be regarded as the third section of the book.

The subject matter covers a wide array of processes with many interlinked ideas. There is an interplay of topics in the complex web of production processes and there are some common principles that cut across the boundaries of the various process sequences. For example, two important ones are drawing (or drafting) and twisting. Drawing occurs in both filament and staple yarn processes. So does twisting. Consequently, the next section begins with a discussion of these common principles, which should lay a basis for the chapters that follow.

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