# Review on the Manufacturing Processes of Polyester-PET and Nylon-6 Filament Yarn

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**Abstract**
Man-made fibers are integral to the lives we lead today. In contrast to natural fibers, the structure and composition of man-made fibers such as polyester, polyamide, acrylic, viscose, polypropylene and the like can be humanly shaped. This lends man-made fibers special properties and renders them valuable for many different purposes. The applications of these fibers in the textile sector have become so vital due to their availability, durability, appearance, high strength, stretch, elasticity, heat resistance, low absorbency, better dimensional stability and value for money, for example. In these years, man-made fibers account for 70-75% of all fibers produced worldwide and have brought about an almost revolutionary development in all parts of the textile industries. This paper deals with an overview of the manufacturing processes of polyester- PET and nylon-6 filament yarn carried out in the industries in order to produce these filaments. The spin-able matter is pressed through the extremely small openings of a spinneret. Upon leaving the spinneret, the filaments produced are either gathered to a filament yarn and reeled or joined to form tows. As it is an energy consuming process, various process parameters such as temperature and pressure need to be taken care of.
Keywords: Polyester, Nylon, Chips, Dryer, Extrusion, Melt spinning.

## Introduction

In textile arena, a fiber can be defined as one of the delicate, hair portions of the tissues of a plant, animal or any other substances that are very small in diameter in relation to its length. These fibers can be classified into various types such as natural, man-made and mineral fibers. Man-made fibers can be defined as fibers manufactured by industrial processes, whether from natural polymers transformed upon the act of chemical reagents or through polymers attained by chemical synthesis. The physical and chemical properties make these fibers particularly attractive for the production of clothing. The market research firm states that 50-54 % of global fiber production flowed into the clothing industry in the year 2011. Man-made fibers are used to produce athletic clothing, tights, undergarments, breathable summer clothing and clothing that protect against heat, cold and dampness. Another reason for the increase production of man-made fibers in the clothing industry is that they feel much like natural fibers and are comfortable to wear which is achieved by special finishing processes like texturing. Polyester is a fiber composed of linear macromolecules having a chain at least 85% by mass of a diol and terephthalic acid. This polyester commonly known as polyethylene terephthalate (PET) has become the world's major man-made fiber. Some plants take polyester- PET chips and melt them at around 280 $^0$C and then extrude the melt into continuous filaments to be wound onto packages while other plants produce the polymer by CP and form it into fibers without producing chips. If fully oriented yarns (FOY) are being produced the fibres are drawn on the spinning machine. If the yarn is to be textured, partially oriented yarns (POY) are spun. Secondly, a polyamide fiber can be defined as a fiber composed of linear macromolecules having in the chain recurring amide linkages at least 86% of which are joined to aliphatic units. There are many polyamide fibers made out of which one Nylon-6 is made by polymerizing Caprolactum. In order to produce, nylon- 6 is produced in a similar way that of polyester. The molten polymer is pumped through spinneret holes at a temperature of approximately 300 $^0$C depending on the process parameters to form filaments that are cooled and solidified by the process of quenching. Both the filament fibers are the workhorse for many, many applications because of their excellent properties at low and reasonable price. Apparel accounts for a large share of usage of polyester and nylon fiber or as blends. Use in tyre cord fabrics, technical fabrics, stockings, hosiery, carpets, ropes are also expanding rapidly. The interest in man-made fiber is rapidly springing up in terms of research and applications. While they have mainly been used in technical clothing and home textiles, the broad range of fibers now available are increasingly used to develop high-tech textiles for various purposes as stated above. In contrast to fibers like cotton, jute, linen that compete for land with, among other things, food corps; the materials used in the manufacture of man-made fibers are easily available in almost limitless quantities and are low cost. The triumphal march of these fibers is unstoppable. With the production of polyester and nylon, new opportunities are opened up for everyone, affecting the quality as well as the enjoyment of life. Today, the world of clothing as well as in research and development would be impossible without man-made fibers.

## Chip Storage and Feeding Area

The chips of polyester-PET and Nylon-6 are stored in godowns under standard conditions for further manufacturing processes. The chips can be of various types such as cationic super bright, HIV super bright, semi dull, semi bright and the like manufactured by different companies varying in weight. These chips are then transported to the feeding area with the help of AGV (Automated Guided Vehicle). The purpose is to let the chips enter the hoppers for further processing. The feeding area consists of chip hopper, chip silo and other small storage tanks connected by automated valves. The bags are lifted up from the ground base with the help of electric hoist and enter the hopper through which it enters the silo and then to the small hopper connected with conveying pipes which forces the chips to the wet chip hopper (in case of polyester-PET chips) with the help of blowers. It should be noted that in case for conveying nylon chips, nitrogen gas is used as atmospheric air causes oxidation. The pressure required for conveying PET chips ranges from 0.5- 2 kg/cm$^2$ and in case of nylon-6 chips, it ranges from 1-2.5 kg/cm$^2$. Table 1 shows the properties of chips.

Table 1. Properties of the chips

| TEST PARAMETERS | POLYESTER-PET CHIPS | NYLON- 6 CHIPS |
|---|---|---|
| Relative viscosity (dl/gm) | 0.6322 | 2.552.58 |
| Amino end (Meg/kg) | - | 22.31 |
| Carboxylic end (Meg/kg) | 30 | 81.66 |
| Ash (%wt) | 0.30 | 0.20-0.21 |
| Moisture (%wt) | 0.20 | 0.045 |
| Chips per gram (Nos.) | 30 | 78-79 |
| Melting point ($^0$C) | 260 | 220 |
| UV test | Uniform | Uniform |

**Dryer**

It can be defined as a process which helps in removal of moisture from the polyester-PET chips to 0.004% because moisture can cause degradation in linear chain of the molecules which results in decreasing viscosity. The chips enter the fluid/crystallization bed which removes the moisture and increase the crystallize orientation of the molecules by the process of fluidization. Fluidization is a process in which the chips are converted from a static solid-like state to a dynamic fluid-like state. The chips are then forwarded to the column dryer which removes the remaining moisture present in the chips reducing it to 0.004%. It consists of different levels namely low, medium and high. Generally, the level is kept at medium level for smooth and productive functioning. The air temperature of the fluid bed and column dryer ranges from 170 $^o$C to 185 $^o$C which is sufficient to remove the moisture from the polyester chips. The column dryer consists of an outlet for dry chips which are transferred to the extruder. The dryer unit also consists of cyclone attached with a dust bag which removes the micro particles such as dust, sand and other impurities. The air which is circulated in the dryer is filtered and heated by the heaters provided at required temperature. The Air Pressure Regulator (APR) is considered as one of the most important mechanism of this process. It allows the atmospheric air free from moisture to enter the dryer system. It consists of a blower which sucks the air and passes it through chilled tubes maintained at a temperature of 5-7 $^o$C which results in the condensation of water vapor present in the air. Then, it passes through two towers; one is operational tower and second is regeneration tower. Both contains silica cylinders or cubes and act simultaneously. The working hours of each tower are 6-8 hours and its function is to remove the extra moisture from the atmospheric air. It should be noted that dew point has to be noted down when the air is passed to the main dryer system. It should be maintained at min -40 $^o$C which denotes zero % moisture in the air. Figure 1 shows the process diagram of the dryer process. Generally, the production of each dryer comes out to be approximately 750 kg/hr taking into account that the capacity of a dryer is 5 tones.

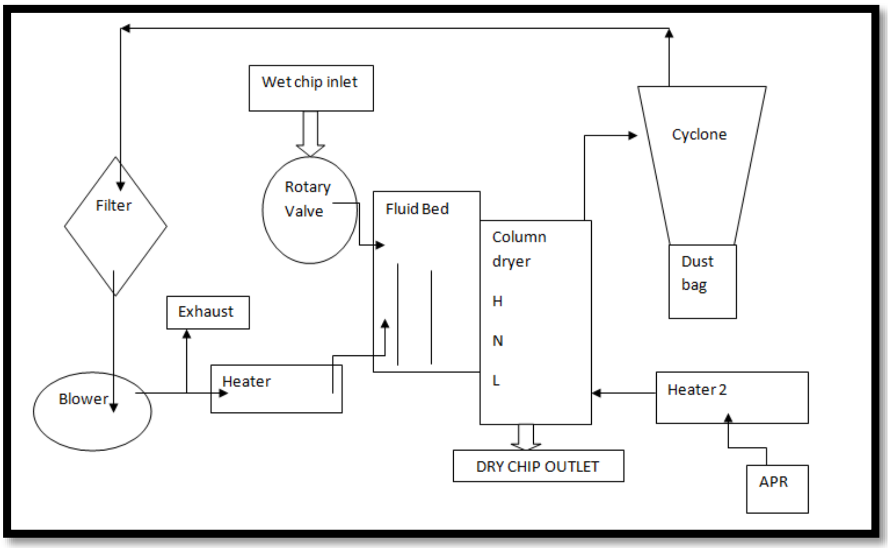


Figure 1. Process flow diagram of the dryer

## Extruder

Extrusion is a high-volume manufacturing technique in which the polymeric chips is melted and formed into a constant profile. This process starts by feeding the dry chips from a hopper into the barrel of the extruder. The chips are steadily melted by the motorized energy generated by the screws and by heaters set along the barrel. It then enters through the feed throat and makes contact with the screw. The rotating screw forces the polyester and nylon polymeric chips forward into the heated barrel. The preferred extrusion temperature is rarely equal to the set temperature of the barrel due to viscous heating and other process parameters. In most processes, a heating profile is set for the barrel in which three or more independent PID-controlled heater zones gradually boost the temperature of the barrel from the rear to the front. This allows the chips to melt gradually as they are pushed through the barrel and lowers the hazard of overheating which may cause degradation in the chips. It should be noted that three to five possible zones exist in a thermoplastic screw. Since terminology is not standardized in the industry, different names may refer to these zones. Often screw length is referred to its diameter as L: D ratio. An L: D ratio of 25:1 is widespread but some extruders go up to 32: 1 for more productive mixing. Each zone is outfitted with one or more thermocouples or RTDs in the barrel barrier for temperature control. The temperature profile is very significant to the excellence and characteristics of the final polymeric melt. Most of the screws have three zones namely feed zone which feeds the chips into the extruder; melting zone which melts the polymeric chips and lastly the metering zone which melts the last particles and mixes to an unvarying temperature and composition. Table 2 describes the process parameters related to the extrusion whereas Figure 2 shows the process flow diagram.

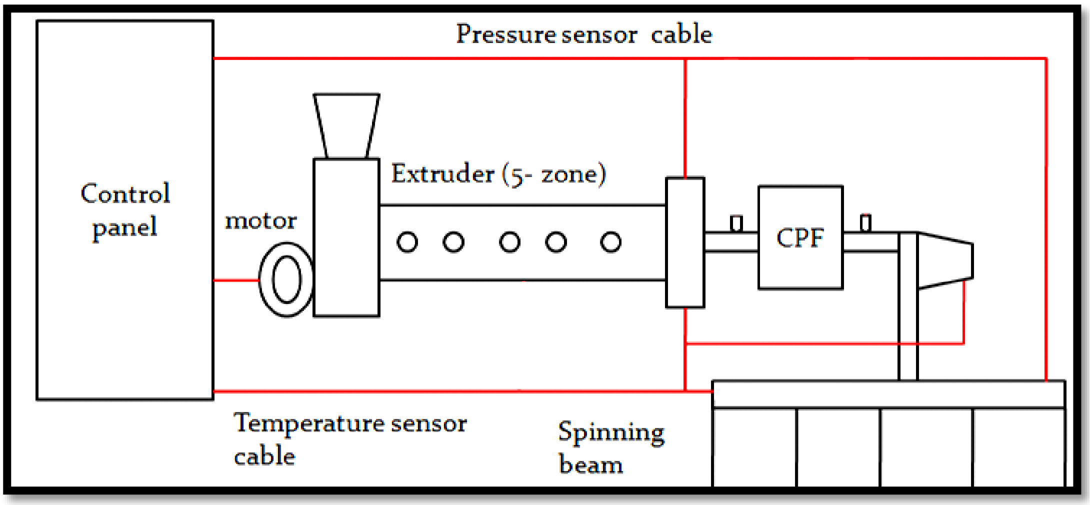


Figure 2. Process flow diagram of the standard extruder.

Table 2. Process parameters of the process

| PROCESS PARAMETERS | POLYESTER- PET | NYLON- 6 |
|---|---|---|
| Zones Temperature ($^0$C) | 276-280 | 252-256 |
| Dowtherm Temperature ($^0$C) | 285-287 | 255-257 |
| Melt Temperature ($^0$C) | 280-282 | 244-247 |
| Pack Pressure (bar) | 100 | 122 |
| CPF Requirement | Yes | No |
| Screw speed (rpm) and motor current (A) | Depends on the screw dimensions | Depends on the screw dimensions |

**Spinning beam**

Melt spinning is the utmost convenient and economic method for synthetic fiber manufacturing at industrial scales. The simplified explanation of melt spinning is that the polyester- PET and nylon- 6 chips are melted and then extruded through the spinnerets. The metering pump controls the flow of molten liquid to the spin head where it is filtered before extrusion to ensure any un- melted are removed so that they don't form nub which would cause weak points. The quench air cools the fibers as they emerge. The quenching works on the principle that the extruded filament from the spin pack is allowed to pass through an air quench chamber. It has a mild flow of cooling air maintained at a temperature of around 20 °C with a moderate relative humidity %. The cooling air when comes in contact with the spun filaments takes away the heat and facilitates their solidification. This involves cooling of the polymeric fiber past melt crystallization temperature and ultimately to its glass transition temperature. As soon as the glass transition temperature is reached, the spinning is considered to be complete. This is because, below glass transition temperature, polyester and nylon filament yarn is in glassy state and cannot extend any further. The filament speed at which the polymer reaches glass transition temperature is also the spinning speed of the process. The uniformity of airflow is tremendously important in regulatory the deviation of filament diameter in a spun fibre. It has been projected that a sudden but small change of 1% in quench air velocity may bring about an alteration of about 0.3% in cross sectional area of the filament. Also, it should be noted that in order to spin the cooled filament yarns, a spin finish or lubricant must be applied as the manmade fibers are not conductive and hence static can be problematic. Generally, the spinning area and the take-up area are separated by a floor and the two have different atmospheric pressure from each other; the former being slightly at higher pressure. This allows part of the cooling air to flow along with the delicate filament yarns. The polyester and nylon filaments are given a spin finish (lubricant) at the end of the spinning line by either kiss-roll or spray. The intention is to provide lubrication, antistatic properties, cohesion and the like. Spin finish is generally produced by emulsifying alkyl chain molecules with the aid of surfactants in aqueous medium. A balance of the two ingredients is significant to attain an optimum of all properties needed in a spin finish. Table 3 shows the constituents of a spin finish oil with the approximate proportions required. Lastly, the convergency is a critical element which influences the strength of the resultant filament yarn. Filament yarns of polyester and nylon can be extruded from the spinnerets in different cross sectional shapes such as round, trilobal, pentagonal, octagonal, etc. Figure 3 shows a schematic process flow diagram of the process.

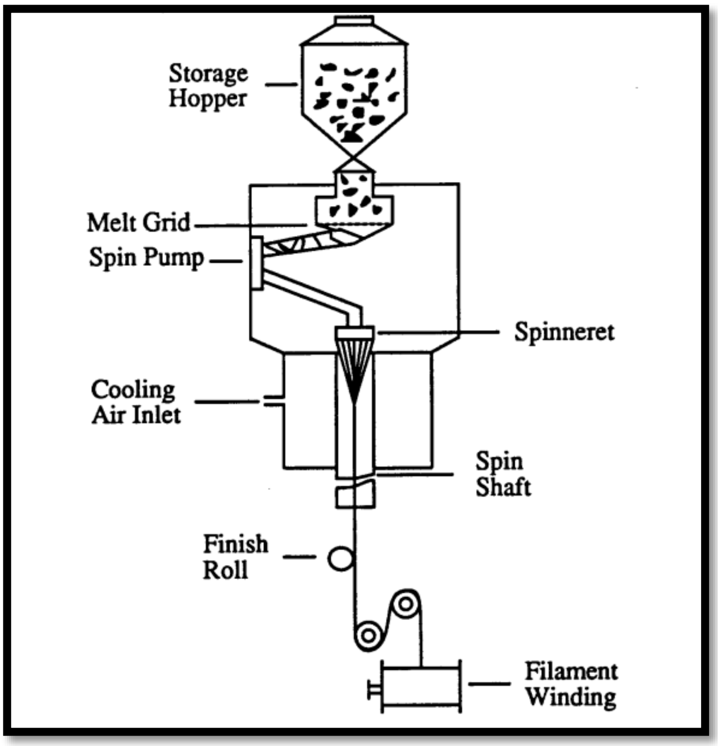


Figure 3. Schematic process flow diagram of a spinning line

Table 3. Constituents of a spin finish oil

| PARTICULARS | PROPORTIONS |
|---|---|
| Emulsions | 8-15 % |
| DM water | 84-92 L |
| Pure oil | 8-16 L |
| Anti-Bactericide (KHH/KBB) | 50-52 mL |

**Take Up (Winding)**

The next and last important device is the take up winder. Usually, the yarn is not wound directly onto the winder rather it is passed through take up godets. This breaks the vertical path of the spinning and allows the winder to be adjusted at ease in the available space. The spinning speed is determined by the speed of the first rotating surface the filament comes in contact after the spinning beam. The winders may be friction driven where the bobbin is driver by the friction roller so that the surface speeds of the winder remains invariable throughout the formation of the yarn packages. Nowadays, godets and friction roller are not used in high speed spinning industries as the yarn when comes in contact with such surfaces can be abraded and thus resulting in poor class and production. Therefore, new winders are used that have bobbins which are directly driven by motors. In order to compensate for the increasing speed as the diameter of the bobbin package changes, an auto feedback mechanism is installed where the speed of the winder is regulated to preserve constant tension in the spinning line. The type of polyester- PET and nylon-6 filament produced during melt spinning are decided by the spinning speed. Low oriented yarn is formed at speeds below 1700 m/min whereas Medium oriented yarn is spun between 1700-2700 m/min. Partially oriented yarn is spun at speeds between 2700 m/min to 4000 m/min where the yarn is more oriented with a little crystallinity which gives better firmness and therefore POY is preferred as commercial intermediate for textured or drawn yarns. It should be noted that High oriented yarn is spun at 4000-6500 m/min and fully oriented yarn is spun at speeds in excess of 6500 m/min. For nylon -6 filament yarns, the POY speeds are approximately 4000-4200 m/min. Nylon-6 usually spun at lower speeds undergo post spinning crystallization on conditioning. Therefore, it is complex to obtain amorphous nylon-6 yarn at any speed due to this phenomenon. At speeds near to 4200 m/min, nylon-6 partially oriented yarn is stable and essentially consists of crystals which are deformable during texturising. High speed spinning of polyester- PET at speeds greater than 6000 m/min produces highly oriented and crystalline yarn which may be categorized as fully drawn yarn (FDY). These may be used directly without further drawing, though their properties are poorer to fully drawn yarn obtained by two step process of spinning and drawing. Very high spinning speeds are required to amplify the drag force on the spinning filament which in turn increases the stress level in the filament so that polymer chains get oriented and stabilized by stress induced crystallization.

## Conclusion

The melt spinning technique for making man-made products has been forecast in recent years as one of the fastest growing in the manmade industry. With the current expansion and notice, it cannot be questioned that melt spinning is well on the way to becoming one of the major technologies. Other post spinning processes such as texturing is basically a variation of the drawing and heat-setting processes to impart curvilinear shape to an otherwise straight filament. This gives physical bulk to the filaments. The process of fibre formation is complete only when both spinning and post spinning operations are carried out. The quality control and assurance of polyester and nylon filament yarn is also one of the important step during the manufacturing process. A laboratory has to be set up and furnished with a range of test equipment. There are a number of points in the production cycle where testing may be carried out to improve the product or to prevent sub-standard merchandise progressing further in the cycle. Some important reasons consist of checking the raw material, monitoring production, assessing the final product, investigation of faulty materials, product development and research. Technical developments are also on the horizon that will increase the scope and utility. The application of these filament yarns will no doubt offer new textile materials unobtainable by other competitive technologies. The considerable work to modify the manufacturing processes in the production of manmade fibers such as polyester, nylon and the like is also going to have a great impact. The large market share underscores the advantages of man-made fibres in processing and usage. The textile market is no longer thinkable without man-made fibres and therefore a bright and strong future can be forecasted in this textile sector.

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