POLYPROPYLENE
FIBERS AND FILMS

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The major problem with regard to widespread use of polypropylene is limited dyeability, a characteristic which stems from the inherent inertness of the polypropylene structure to permeants. However, in view of the major research effort devoted to this problem, it is reasonable to expect that an answer is forthcoming.

In summary, the relatively low polymer cost and outstanding properties of polypropylene fibers rank this material as one of the important fibers of the future.

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stem from the numerous combinations of molecular weight, length variations of isotactic structural sections, and portions of atactic regions which comprise the polymers. This characteristic permits the preparation of polypropylenes with a wide range of mechanical properties from the same starting monomer, depending upon the steric structure imparted to the polymer. Thus a material can be tailored specifically, within relatively wide limits of physical properties, to best satisfy the needs of a particular application.

Many olefins have asymmetrical monomeric units and, as such, could not crystallize because of their structural nonuniformity. Table 1 denotes the polymerization mechanism required to crystallize various olefinic monomers.

Stereospecific polymerizations, by imparting a regular structure to the macromolecules, permit the use of simple and inexpensive monomers, factors of great importance in the overall cost of the finished fibers. The cost factor of a new fiber in such a highly competitive industry as textiles is naturally of paramount importance. Table 2 shows comparative monomer cost data based on the production of monomers in the United States.

II. Fiber Manufacture Operations

Three basic methods of preparation of synthetic fibers are used commercially: (1) wet spinning, (2) dry spinning, and (3) melt spinning. In each process a viscous fluid is extruded through a multiholed die or spinneret, forming a fine-diameter fiber. Polypropylene fibers are prepared via the melt spinning technique, which essentially is comprised of two manufacturing stages: (1) extrusion of a fiber and (2) the subsequent thermal and mechanical stretching of the fiber. A diagram of a typical equipment line arrangement is shown in Figure 3. The various process equipment used in the preparation of polypropylene fibers is described below.

A. EXTRUSION

The melting of the resin, sometimes termed as "plasticating," is accomplished with a conventional thermoplastic extruder equipped with a polyethylene-type metering screw having a minimum 4:1 compression ratio and a metering zone no less than four flights in length. An extruder barrel with a length-to-diameter ratio of 24:1 is preferred since polypropylene requires higher extrusion temperatures than most other thermoplastic resins.

A wire cloth screen pack in the head of the extruder is positioned to prevent foreign particles from impregnating the extruded fibers. Since highly oriented fibers, such as polypropylene, are sensitive to contamination breakage, this screening is expedient. A pressure control valve is generally in-

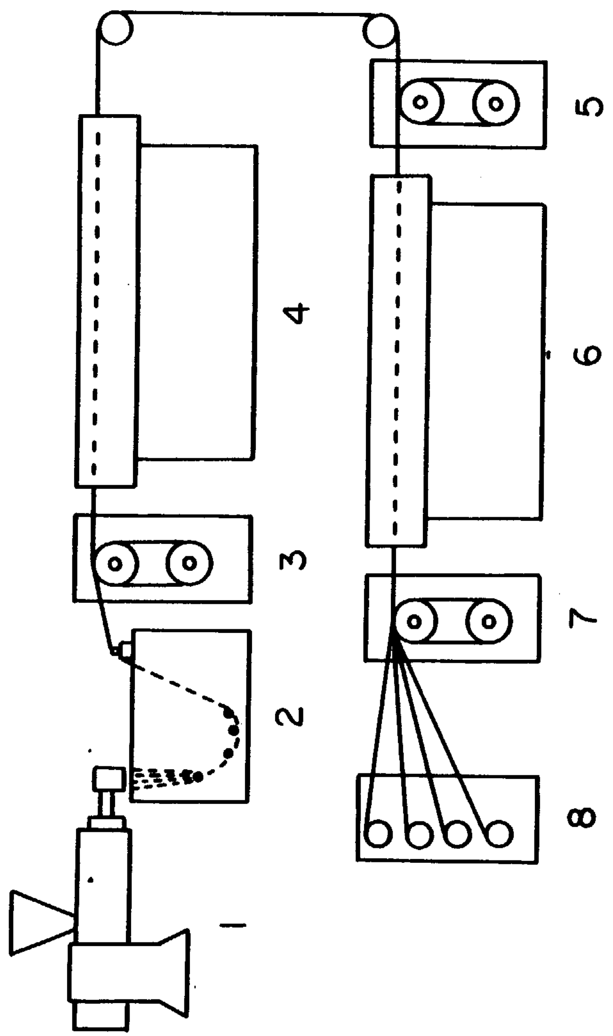

Figure 3. Typical Line Diagram for the Extrusion of Polypropylene Monofilaments [28]: (1) Extruder. (2) Quench Tank. (3) Pull-Out Rolls. (4) Draw Oven. (5) Draw Rolls. (6) Relax Oven. (7) Relax Rolls. (8) Wind-Up.

stalled after the screen pack (immediately upstream of the die) to compensate for variations in polymer throughputs at a given screw speed, which may result from varying polymer melt viscosity or barrel temperature profiles. This pressure control is best obtained at the 90° bend of the polymer flow stream inherent in monofilament die heads; the die head is essentially the transition section of the extrusion line which conveys the extruded melt to the die.

The die containing the capillaries through which the molten polymer is forced into fibers is mounted to the downstream side of the die head. The melt temperature and pressure are monitored at the entrance to the die by thermocouples and pressure gauges, or, preferably, pressure transducers. The extrusion die is the most important single part of the monofilament operation and requires careful design, machining, and maintenance. Filament irregularities which can be attributed to deficiencies at the die include (1) end-to-end fiber diameter variation, (2) surface flaws, (3) flow pulsation and attendant diameter variations in the fiber produced, and (4) excessive fiber waviness in the quench bath.

B. DRAW-DOWN, QUENCHING, AND DRYING

Between the die exit and the pull-out rolls (first Godet station), the extruded fibers are predrawn, water-quenched, separated into an orderly arrangement, and dried of adhering surface moisture.

The predraw, or draw-down, is a decrease in fiber diameter which occurs as the molten polymer emerges from the die; the diameter of this unoriented fiber is approximately 50% of the die hole diameter. The operational variables controlling the uniformity of draw-down are polymer throughput and filament velocity just prior to the quench bath. Upon solidification of the fiber in the quench bath, draw-down is complete.

Fast quenching retards crystal growth and results in an amorphous fiber composed of a large number of small crystallites; this type of fiber excels in toughness and flexibility.

Quenching at higher bath temperatures promotes crystal growth, resulting in a more crystalline fiber which exhibits superior strength and rigidity.

The quenched fibers are drawn around an adjustable guide assembly located in the quench bath and over another set of guide bars positioned at the exit of the bath, which serves to maintain an orderly arrangement of the fibers. An air jet is directed at the "tow" to surface-dry the fibers, upon their exit from the bath. Removal of this moisture is of prime importance as uneven heating will result in the fiber orientation section.

C. ORIENTATION, RELAXATION, AND WIND-UP

The fibers then pass into the orientation, or draw, stages, which impart thermal and mechanical treatments to the fibers. Initially the temperature of the fibers is raised by an orientation oven in preparation of the all-important stretching of the fibers. This step is the most single important operation in the manufacture of fibers relative to the properties exhibited by the fibers. The stretching of the fibers is effected by high-speed draw rolls driven by powerful motors; the ratio of the speed of the pull rolls and the draw rolls is the draw ratio. The higher the draw ratio, the more orientation imparted to the fibers.

In order to minimize shrinkage, by relieving residual stresses, the fibers are then permitted to relax and become heat-set by passing through another oven. The heat-set temperature must be higher than the end use of the fibers in order to be effective in preventing shrinkage. The last set of rolls which pulls the fibers through the relax oven is driven at a speed slightly lower than that of the draw rolls. The individual fibers in the tow are then wound upon a spindle in the wind-up station. This wind-up unit is generally synchronized with the speed of the other rolls to maintain uniform winding.

III. Influence of Fiber Processing Conditions on the Structural and Physical Properties of Polypropylene Filaments

The properties of polypropylene fiber are dependent upon the structural characteristics of the macromolecules comprising the polymer; in turn, these macromolecules are significantly affected by (1) polymer properties prior to extrusion, and (2) processing conditions of fiber formation.

The pertinent structural characteristics of a polymer include molecular weight, average molecular weight (distribution), crystalline structure, crystallinity, orientation, and terminal end groups. The significant manufacturing conditions are extrusion temperature, draw ratios, annealing time and temperature, and quenching time and temperature. Whereas the crystallinity and orientation are affected by quenching, drawing, and annealing conditions, the extrusion conditions affect the crystallinity, orientation, and molecular-weight distribution.

A. GENERAL CONSIDERATIONS OF CRYSTALLINITY, ORIENTATION, AND MOLECULAR WEIGHT OF FIBERS

One of the most important polymer characteristics with respect to determining the chemical and physical properties of fibers is crystallinity. All fibers consist of macromolecules