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Spinning of Poly(ethylene Terephthalate) Fibers from a Melt Pool without a Spinneret

F. C. WAMPLER, D. R. GREGORY, and W. D. KENNEDY,
Research Laboratories, Tennessee Eastman Company, Division of Eastman Kodak Company, Kingsport, Tennessee 37662

Synopsis

Monofilament fibers were spun continuously from the free surface of a pool of molten poly(ethylene terephthalate) without the aid of a spinneret. For take-up velocities in the range of 12 to 400 ft/min, the denier of the filaments produced was an inverse power function of take-up velocity, and the birefringence was an inverse power function of the filament diameter. Production rate and product uniformity were strongly dependent on take-up velocity and surface temperature of the melt pool.

INTRODUCTION

In the melt spinning of fiber, formation of individual filaments is usually accomplished by forcing the molten polymer through capillaries in a spinneret plate. Filaments can be produced, however, by pulling them from the surface of a melt pool; this method has been used for determining the qualitative "spinnability" of various polymeric systems.[1-3] It is doubtful, however, if this method has been used for large-scale production of melt-spun fibers.

We decided to determine the feasibility of spinning filaments from a molten pool of poly(ethylene terephthalate) (PET) without the aid of a spinneret. Subsequent to our experimental efforts, we learned of similar efforts by several Russian workers.[3-5] Investigations by Zak[3] and Podosenov[4] had shown that, by using the thermostating diaphragms which enclose most of the free melt surface, it was possible to have a stable continuous process of spinning and withdrawal of a continuous thread. Perepelkin et al. successfully spun polypropylene and polystyrene fibers using this method and established the temperature and velocity limitations for these two polymers.[5] They also produced bicomponent fibers of the core-sheath type and a hollow fiber.[5]

EXPERIMENTAL

Single filaments of PET were spun in our work from two different types of apparatus (Figs. 1 and 2).

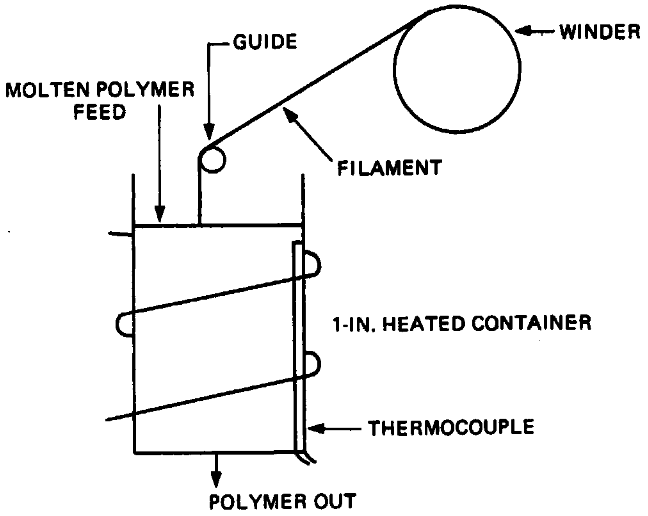

Fig. 1. Apparatus I for melt spinning poly(ethylene terephthalate).

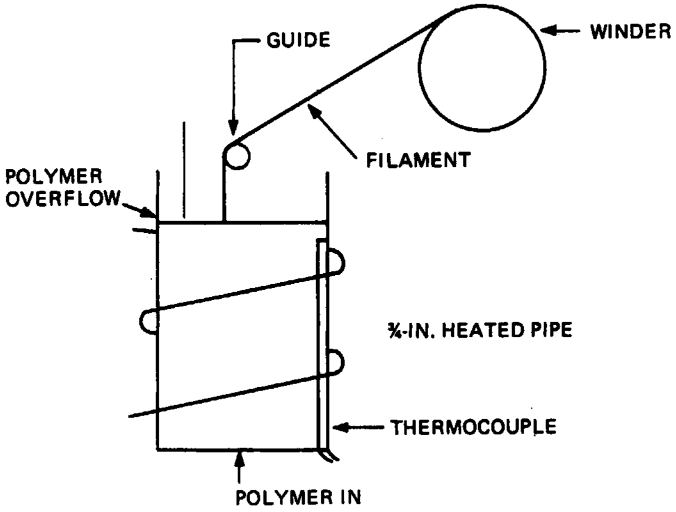

Fig. 2. Apparatus II for melt spinning poly(ethylene terephthalate).

The first type (Fig. 1) was constructed so that polymer from a laboratory extruder entered the top of a heated container and left through an adjustable opening in the bottom. The spinning process consisted of continuously withdrawing a monofilament from the melt pool over a guide located approximately 4 to 8 in. above the melt surface and winding it onto a winder. Take-up velocities were varied from 12 to 400 ft/min. Melt pool temperatures at the point of monofilament withdrawal were between 295°C and the solidification temperature of PET. Quenching conditions were uncontrolled at ambient conditions.

The second type of apparatus (Fig. 2) was constructed so that molten polymer from the extruder was forced up through the bottom of a heated container and out the top. A monofilament was spun from the free surface of the melt in the same manner described for the first type of apparatus.

The monofilaments produced in this investigation were tested for denier uniformity and birefringence uniformity.

RESULTS AND DISCUSSION

Continuous spinning of PET monofilament from the free surface of a melt pool was accomplished. There was an optimum spinning temperature between 295°C and the solidification temperature of the PET polymer. Above 295°C, the monofilament would not spin even at low take-up velocities. At temperatures near the solidification point, fracture of the spinning monofilament occurred.

Denier of the monofilament decreased from 589 to 6.1 when the take-up velocity was increased from 12 to 400 ft/min. These data are presented in Table I. As shown in Figure 3, a log–log relationship existed between the two variables. From a practical point of view, this phenomenon is not desirable because of the limiting effect on production rates for a particular denier item. Perhaps this difficulty cannot be overcome by adjusting melt temperatures because of the apparently narrow temperature range at which spinning can take place.

TABLE I
Effect of Spinning Speed on Denier[a]

Take-up speed, ft/min	Denier[b]	Per cent coefficient of variation, %
12.0	589	17.6
25.5	182	25.1
27.5	227	29.2
32.0	35.7	61.8
150	36.7	28.9
400	6.1	11.4

[a] Spinning temperature and quench conditions were essentially uncontrolled at the point of monofilament departure from the surface of the melt pool.

[b] Denier is taken as the average of three 90-cm samples.

The effect of take-up velocity on birefringence for variable flow rate and variable fiber diameter is shown in Figure 4. Figures 5 and 6, from an article by Ziabicki and Kedzierska,[6] show the effect of take-up velocity on birefringence for conditions of constant fiber diameter with variable flow and for constant flow with variable diameter, respectively. In general, the shape of the curve in Figure 4 is the same as those by Ziabicki and Kedzierska.[6]

The relationships between fiber diameter and birefringence for variable take-up velocities are plotted in Figures 7 and 8. Note from Figure 7 that

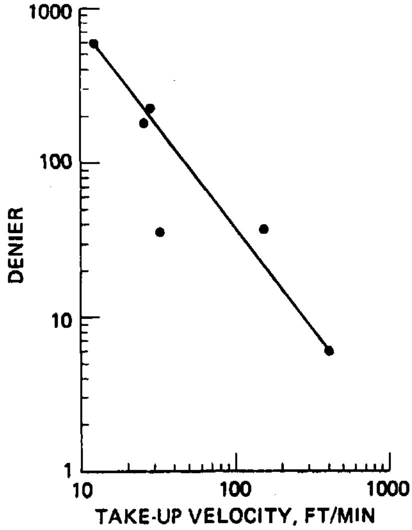

Fig. 3. Effect of take-up velocity on fiber denier.

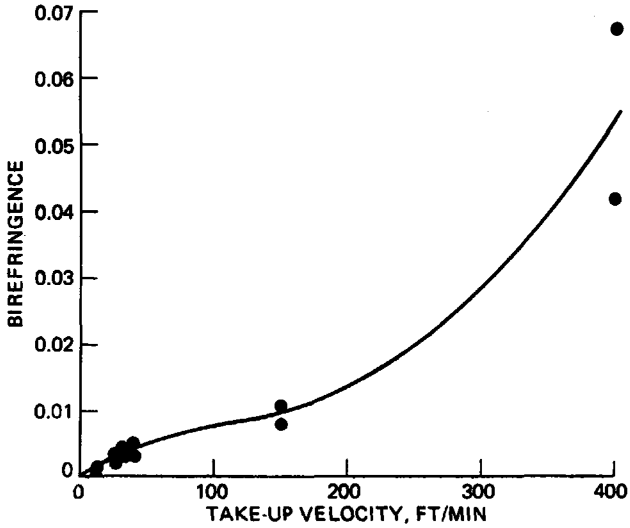

Fig. 4. Effect of take-up velocity on birefringence.

changes in fiber diameter from 300 to 140 μ had little effect on birefringence in the fiber, but changes in fiber diameter from 140 to 25 μ resulted in a large increase in birefringence. Since birefringence is a measure of molecular orientation in the fiber, it was concluded that the large fibers (140 to 300 μ in diameter) were spun at a high local temperature because of the large diameter; whereas the smaller fibers (25- to 140-μ range) cooled more rapidly and thus were spun at a lower local temperature, yielding a high degree of orientation. This result indicates that a delayed quench would yield lower degrees of orientation in as-spun polyester yarns. Fibers produced at take-up velocities of 400 ft/min tended to curl; this indicated a possible nonuniform radial orientation or quenching of the fiber as it passed across the guide pin.

Measurements of long-term (90-cm lengths) denier uniformity and short-term diameter uniformity are given in Table I. The per cent coefficient of

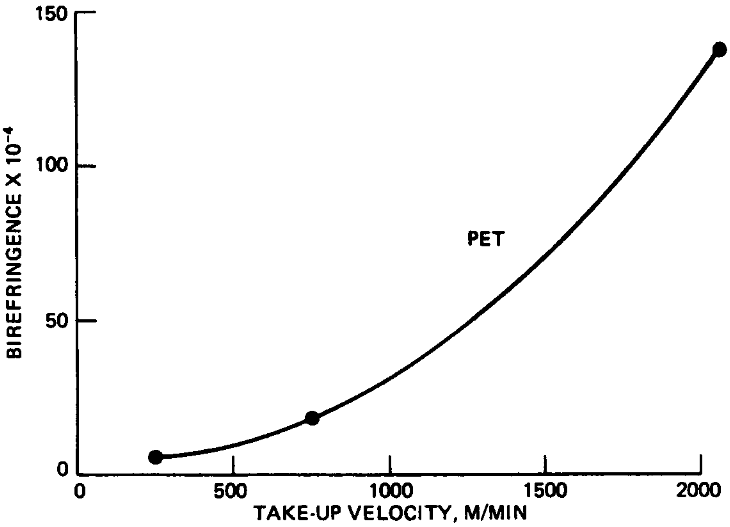

Fig. 5. Effect of take-up velocity on fiber birefringence at constant fiber diameter and variable flow.

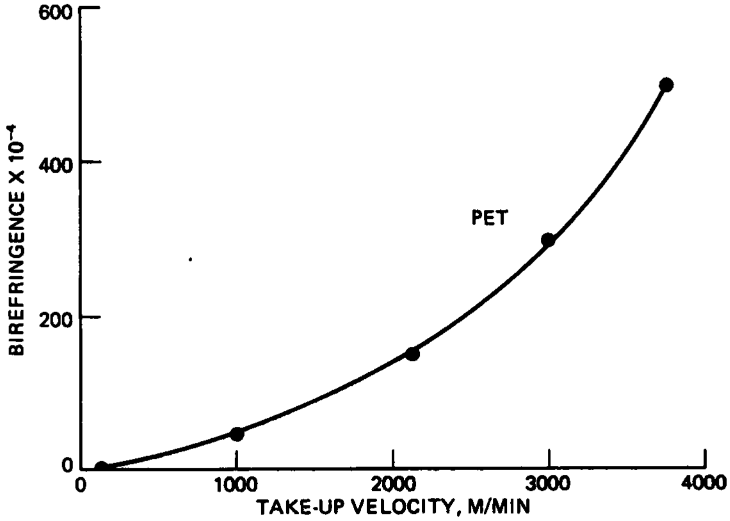

Fig. 6. Effect of take-up velocity on fiber birefringence at constant flow and variable fiber diameter.

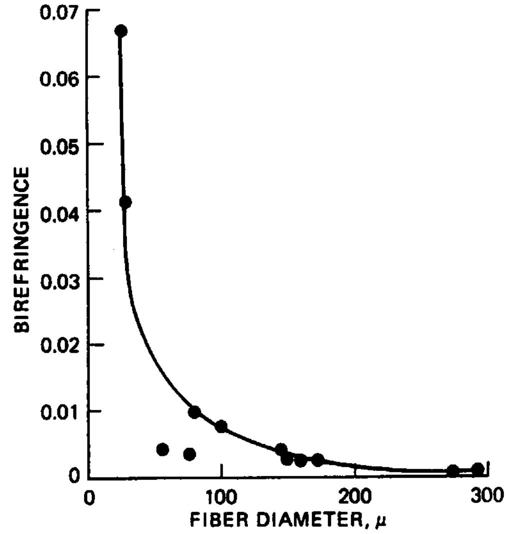

Fig. 7. Effect of fiber diameter on birefringence.

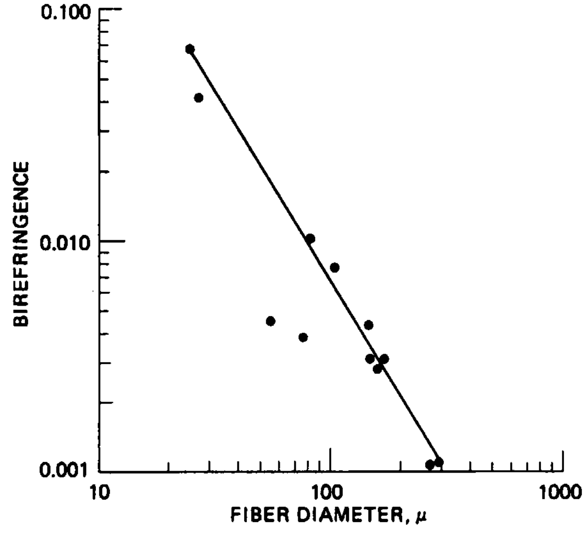

Fig. 8. Effect of fiber diameter on birefringence.

variation of the denier measurements ranged from 11% to 62%. Variation in the temperature of the melt pool surface was the probable major contributor to this variation. The per cent coefficient of variation of the diameter measurements ranged from 12.6% to 28%. The effect of winder movement probably accounted for much of this short-term variation.

There are certain inherent disadvantages in spinning directly from a melt pool. Disadvantages of the first type of apparatus used (Fig. 1), in which molten polymer entered the top of the heated container and left through an adjustable opening in the bottom, were long holdup times and poor heat transfer from the outside edges to the center of the melt. These disadvantages resulted in large temperature gradients across the surface of the pool and different degrees of thermal degradation in the polymer melt; the thermal degradation caused poor spinning efficiencies. Control of surface temperatures and quench conditions will be difficult to achieve.

The second type of apparatus used (Fig. 2) was one in which molten polymer was forced up through the bottom of a heated container and out the top. A monofilament was spun from the free surface of the pool. It was difficult to control the position of the monofilament so that it was spun from fresh polymer because the entering polymer tended to push it to one side of the container.

The spinning rate (take-up velocity) for any particular melt viscosity appeared to control final denier per filament. Therefore, for a particular denier fiber, the spinning rate would be fixed as would the production rate.

The same melt viscosity, quenching conditions, and take-up velocity would have to be maintained among filaments in order to assure acceptable denier uniformity. Control of these conditions would be more critical and more difficult than control in the normal melt-spinning process. Average birefringence was a function of final filament denier in the evaluations reported here; close control of melt pool surface temperatures and filament quenching rate would be necessary to assure control of orientation for all filaments. For small deniers (large take-up velocities), the fiber produced exhibited curliness.

In the spinning of multifilament yarns from a melt pool, each filament would probably require a separate guide and/or melt pool compartment during spinning to prevent migration and fusing of adjacent filaments. Design, start-up, and maintenance of such a system present engineering problems of considerable magnitude.

CONCLUSIONS

Monofilament or multifilament fibers can be spun continuously from the free surface of a pool of molten PET. Denier of the final product over the range of conditions investigated was an inverse power function of take-up velocity. Birefringence of the final fibers produced increased from 0.001 to 0.068 as take-up velocities increased from 12 to 400 ft/min. Birefringence was an inverse power function of filament diameter.

Monofilament spinning efficiency was poor. The following spinning conditions would be necessary to increase the efficiency: melt pool with a large surface-to-volume ratio, recycle of feed polymer, and spinning of multifilaments. Product quality could be insured only through rigid control of melt viscosity and quenching conditions. Production rates were directly dependent on the denier of the fiber produced.

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