May 4, 1971 TATSUKI MATSUO ET AL 3,577,498

METHOD OF PRODUCING CRIMPED POLYPROPYLENE FIBERS

Filed Oct. 25, 1968 2 Sheets-Sheet 1

Fig. 1

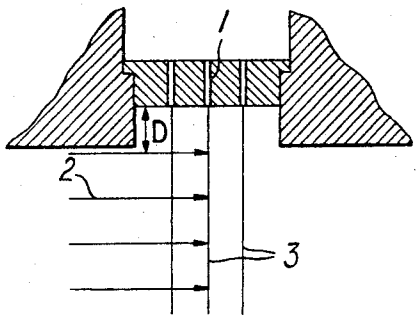


Fig. 2

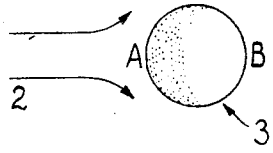
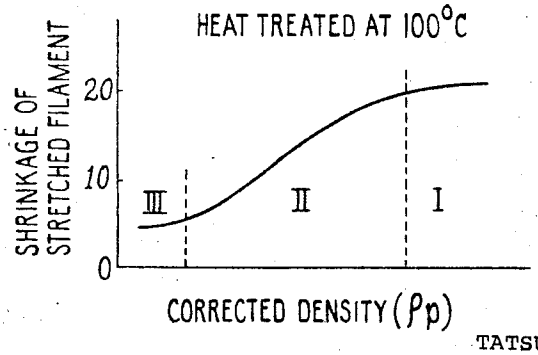


Fig. 3



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Fig. 4

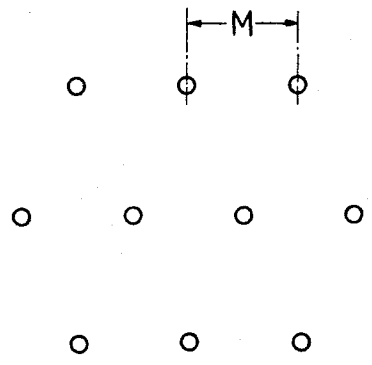


Fig. 5

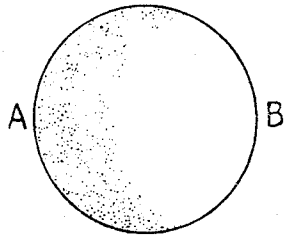
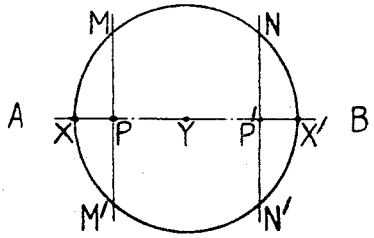


Fig. 6



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METHOD OF PRODUCING CRIMPED POLYPROPYLENE FIBERS

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Continuation-in-part of abandoned application Ser. No. 678,616, Oct. 27, 1967. This application Oct. 25, 1968, Ser. No. 770,776

Claims priority, application Japan, Nov. 1, 1966, 41/72,222

Int. Cl. D01d 5/22

U.S. Cl. 264—168 10 Claims

ABSTRACT OF THE DISCLOSURE

Bulky crimped polypropylene fibers, the coil crimps of which have a coil diameter of e.g. less than 0.7 mm., and are of good reproducibility, are made by cooling or quenching polypropylene filament, immediately after coming out of the spinning orifice, asymmetrically in the cross-sectional direction of the filament so as to create a cross-sectional anisotropy in the filament structure, and then stretching the filament and heat treating the same in a relaxed state. Use is made of a spinnerette in which the minimum distance between the orifices is more than 4.0 mm. Cooling is effected by cooling gas under particular conditions of velocity and distance between spinnerette face and gas. The fiber is stretched 2.5 or more times its length at a particular temperature so that the fine voids are distributed asymmetrically in the cross section of the fiber.

This application is a continuation-in-part of application Ser. No. 678,616, filed Oct. 27, 1967 and now abandoned.

This invention relates to a process for making crimped continuous polypropylene fibers having excellent properties.

A process for making bulky polypropylene fibers has already been suggested in Belgian Pat. No. 566,641. According to this patent, the process is characterized by stretching a continuous polypropylene filament at a temperature of 20 to 80° C. at a feeding speed of 30 to 150 meters per minute and then subjecting the stretched filament in a perfectly relaxed state to a heat-treatment at a temperature of 50 to 170° C. for a time not exceeding 10 minutes.

However, according to this method, it is difficult to consistently obtain fibers having excellent crimps for practical uses. According to the present invention, especially excellent bulky fibers can be easily and positively produced.

The object of the present invention is to provide optimum conditions for producing helically crimped polypropylene fibers by cooling or quenching polypropylene filaments, immediately after emerging from the spinning orifice, asymmetrically in the cross-sectional direction of the filament so as to create a cross-sectional anisotropy in the fine structure of the filament, and then stretching the filament and heat treating the same in a relaxed state. By adopting the particular conditions of the invention to be explained in detail hereinafter, crimped polypropylene fibers having excellent coil crimps (e.g. crimps having a coil diameter less than 0.7 mm.) can be produced with high reliability and consistency.

The present invention will be described in detail by referring to the accompanying drawings wherein:

FIG. 1 is a schematic cross-section of a part of a spinning device illustrating the mode of cooling extruded filaments according to this invention;

FIG. 2 is a magnified cross-section of a filament being asymmetrically cooled according to the invention and showing the cross-sectional anisotropy in the fine structure of the filament;

FIG. 3 is a graph showing the relation between corrected density of an unstretched filament and shrinkage of the resulting stretched and heat-treated filament;

FIG. 4 is an enlarged plane view of a part of a spinnerette which aids in explaining the minimum orifice interval intended by this invention;

FIG. 5 is a magnified cross-section of a filament showing the cross-sectional anisotropy in the fine structure of the filament; and

FIG. 6 is a view similar to FIG. 5, explaining the measurement of the mean birefringence.

Referring to FIG. 1, molten polypropylene is extruded in a usual manner through spinning orifices 1 to form filaments 3. According to the invention, the extruded filaments are cooled asymmetrically in the cross-sectional direction (in the direction indicated by the arrows in FIG. 1) of the filament by a stream 2 of a cooling medium.

When a cooling or quenching gas stream 2 is blown across or transversely to a melt-extruded filament, the cooling degree will be different in the windward or upstream part A as compared to the leeward or downstream part B in the cross section of the filament 3 as shown in FIG. 2, and therefore the crystallinity will be different in the part corresponding to the section A of the unstretched filament as compared to the part corresponding to B. When the asymmetrically cooled unstretched filament is stretched and then heat-treated in the relaxed state, crimps will develop due to the difference in the shrinkage of parts A and B of the filament, which in turn is caused by the difference in the crystallinity between the parts A and B. Therefore, in order to obtain crimped fibers having coils of a small radius or curvature, it would be necessary (a) to select a spinning process wherein the difference in the crystallinity between the parts A and B will be large and (b) to select a spinning, stretching and heat-treating process wherein the difference in shrinkage between the parts A and B will be large due to the difference in the crystallinity between the parts A and B.

Generally, in polypropylene fibers, as shown in FIG. 3, the higher the corrected density of the unstretched filament or, in other words, the higher the crystallinity, the higher the shrinkage of the filament after stretching. The curve showing the relation between these two factors will be S-shaped. In FIG. 3, if the corrected densities of the parts A and B respectively are both in the range of I or III, no substantial difference in shrinkage will appear between the parts A and B. The density difference between the parts A and B cannot be generally taken to be very large within these ranges. However, if the corrected densities of the parts A and B respectively are in the range II, the difference in shrinkage between the parts A and B will be sufficient. Therefore, in order to positively obtain an excellent crimped fiber, it is necessary that the corrected density of the unstretched filaments as a whole be a value falling within the range II.

The corrected density of an unstretched or undrawn filament (that is the filament before being stretched or drawn) is a density ρ_p (g./cm.^{3}) corrected according to the following formula to eliminate the influence of ingredients other than the polypropylene on the density:

$$\rho_p=\frac{1}{V_p}(\rho-\rho_a+V_p\rho_a) \quad (g/cm^3)$$

wherein ρ is the density of the undrawn filament, ρ_a is the density of polymers or additives other than the polypropylene, and V_p is the percentage by volume of the polypropylene. The density ρ of the undrawn filament is

measured by a viscosity gradient tube method with an isopropanol-water system at 30° C.

It has been found that the corrected density ρ_p of the unstretched (undrawn) filament should satisfy the formula

$$1.67\times10^{-6}d^2-3.4\times10^{-6}d+0.9040\leqq\rho_p \leqq1.67\times10^{-6}d^2-3.4\times10^{-6}d+0.9058 \quad (1)$$

wherein d is the monofilament denier of the unstretched filament.

In order to bring the corrected density ρ_p of the unstretched filament within a range satisfying the above Formula 1, a proper molecular weight, molecular weight distribution, and polymerization degree should be selected, and further a proper spinning temperature and cooling conditions should be selected. For example, when the distance D, which is the distance between the spinning nozzle face and the uppermost cooling gas plane (FIG. 1), is increased from zero, the corrected density ρ_p of the unstretched filament is lowered. The corrected density of the unstretched filament may also be lowered by increasing the spinning temperature and/or by employing a polymer with a higher degree of thermal degradation.

Further, concretely speaking, a very effective condition for satisfying the Formula 1 to make an unstretched filament in which the intrinsic viscosity, of the polypropylene is 1.05 to 1.5. That is to say, in order that the corrected density ρ_p of the unstretched filament may be within the range of the Formula 1, it is necessary to extrude a molten polymer having a proper rate of crystallization, and to cool the extruded filament at a proper cooling speed. On the other hand, the rate of crystallization from a molten state of polypropylene depends largely on the polymerization degree of the polymer. The preparation of an unstretched filament having an intrinsic viscosity in the range of 1.05 to 1.50 would result in the extrusion of a molten polymer having a proper crystallization rate.

It has also been discovered that in order to obtain excellent crimps, it is necessary to use a spinnerette having a minimum distance between the orifices of more than 4.0 mm. This minimum distance between the adjacent orifices is the distance between the centers of the most adjacent spinnerette orifices, i.e. the distance M shown in FIG. 4.

The reason why the minimum distance M between the orifices must be above such a fixed value is that in the present invention, it is necessary to satisfy a more strict condition in cooling each single filament than in an ordinary melt-spinning process. However, when a spinnerette in which the minimum distance between the orifices is below 4.0 mm. is used, the cooling gas blown across any one filament will be so strongly interfered with by the other filaments being spun as to make it more difficult to uniformly cool each single filament. On the other hand, if a spinnerette having a minimum distance between the orifices of above 4.0 mm. (preferably above 6.0 mm.) is utilized, it will be possible for the cooling gas to pass through between the individual filaments smoothly without being substantially disturbed and therefore the uniform cooling of each single filament will be guaranteed.

The cooling gas is blown across the extruded filaments. It is preferable that such cooling gas have a temperature of 0–25° C. and be directed substantially at right angles with the longitudinal axis of the filament. However, it may be blown against the filament at an angle in the range of 90°±30° with respect to the longitudinal axis of the filament.

Further, it is also necessary to blow the cooling gas at a rate of above 0.3 m./sec. (preferably 0.45–1.2 m./sec.) against a melt-extruded filament, and to satisfy the condition defined by the formula

$$D\ (\text{cm.})\leqq\frac{V_d}{300} \quad (2)$$

wherein V is the wind-up speed (m./min.) of the unstretched filament and d is the monofilament denier of the unstretched filament, in order to create a sufficient difference in cooling degree between the windward part A and the leeward part B of the filament in FIG. 2. Under such conditions, the difference in the crystal state between the windward and leeward parts in the cross-section of the filament will become large enough and therefore an unstretched filamant having latent coil crimps of a diameter of less than 0.7 mm. will be obtained.

The unstretched filament obtained as above may be stretched by any method in air, in a medium such as water, on a hot plate or on a hot pin. However, it is necessary that the temperature T (° C.) of the filament being stretched be within the range of the formula

$$\text{Ordinary temp.}\leqq T\leqq120-d \quad (3)$$

wherein d is the denier value of the unstretched filament. Preferably, the temperature is above 10° C. (more preferably above 50° C.) and below (120–d) ° C. The temperature of the filament being stretched can be measured by means of a thermocouple based on the principle mentioned, for example, in J. Scientific Instruments 36, 28 (1959). However, when a pre-heating treatment is conducted prior to stretching as herein later explained, the stretching should be conducted at a temperature lower than pretreatment temperature +30° C. but higher than the ordinary temperature (e.g. 20° C.).

The filament should be stretched at a draw rate of 2.5 times or higher. Preferably, the draw rate is 2.5–4.5 times.

When the filament is so stretched there is obtained a filament wherein fine voids are asymmetrically distributed in the cross-section of the filament as shown in FIG. 5. The so-stretched fiber is then heat-treated at a temperature of 80–150° C. in a relaxed state to develop coily crimps in the fiber. The length of time for this treatment may vary from less than 1 second to several hours or longer.

As mentioned before, an important feature of the invention is to prepare an unstretched filament having n anisotropic crystalline structure in the cross-section of the filament. This anistropy can be expressed as the "index of difference in mean birefringence values" (referred to as "As"). The mean birefringence ($\bar{\Delta}_n$) can be measured by the formula

$$\bar{\Delta}_n=\frac{\Gamma}{d}$$

wherein Γ is the retardation (a difference between the light path of a polarized light parallel to the longitudinal axis of the filament and the light path of a polarized light intersecting said axis at right angles, the light being sodium D rays) obtained in the direction M–M′ (or N–N′) perpendicular to the direction XY (or Y–X′) which is the direction of the flow of the quenching gas (refer to FIG. 6), A (in FIG. 6) indicating the windward side and B indicating the leeward side. In the above formula, d is the length (chord in FIG. 6) by which the line M–M′ (or N–N′) transverses the filament cross-section.

The direction in which the difference in the mean birefringence, between the positions on the filament which are symmetrical in respect to the center of the filament, is maximum, can be determined by measuring the mean birefringences at various chords of the cross section of the filament. It will be understood that this direction is normal to the direction of the flow of the quenching gas on the cross-section of the filament, that is the direction A–B (or X–X′) in FIG. 6.

The "index of difference in mean birefringence values" is measured by the formula

$$\text{As}=\frac{\Delta_{np}-\Delta_{np'}}{\frac{\Delta_{np}+\Delta_{np'}}{2}}\times100\ (\text{percent})$$

wherein Δ_{np} is the mean birefringence as measured along M–P–M′ ($2XP=PY$) and $\Delta_{np'}$ is the corresponding value measured along N–P′–N′ ($2X'P'=P'Y$), referring to FIG. 6 wherein line M–M′ (N–N′) is perpendicular to line X–Y (Y–X′). Δ_{np} shall be referred to as windward

side mean birefringence, while Δ_{np}, shall be referred to as leeward side mean birefringence.

The unstretched filament according to this invention has an As value of 5% or higher.

It is preferable that the unstretched or undrawn filament according to this invention has a denier number of 5–40.

As explained before, the unstretched filament is stretched. If desired, however, a preheating-treatment may be conducted prior to stretching. Thus, the unstretched filament is heat treated at a temperature of 60–140° C., preferably 70–135° C. The time of this pretreatment is not critical and may range from 0.1 sec. to 10 minutes or longer. Generally, the higher the pretreatment temperature the shorter the time of pretreatment. Such preheat-treatment promotes the cross-sectional anisotropy of the micro-structure in the unstretched filament.

The preheating-structure promotes the cross-sectional anisotropy of the micro-structure of the unstretched filament of the present invention.

When such preliminary heat treatment is conducted, it is necessary that the subsequent stretching be conducted at a temperature lower than pretreatment temperature +30° C.

The unstretched filament of this invention has latent coil crimps, which for purposes of this invention, may be defined as those coil crimps which would be developed upon stretching and relaxation under the particular conditions explained herein. The diameter of such latent coil crimps is measured by stretching the unstretched filament 3.0 times its length in air at 20° C. and at a rate of 30%/sec. The stretched filament is immediately relaxed and left standing in a relaxed state for 10 minutes to develop coil crimps in respect to which the coil diameter is measured. The latent coil crimps of the unstretched filament according to this invention are 0.7 mm. or less in diameter.

The stretched fibers of this invention have micro fine voids (about 10 mμ–100 mμ) distributed asymmetrically in the cross section of the fiber. This can be demonstrated by dyeing the fiber and observing the cross section. Thus, for example, when an unstretched filament having a high density (for example, 0.908 g./cm.^{3}) and obtained by melt-spinning an isotactic polypropylene is stretched, for example, about 3 times the length at the normal temperature, fine voids will be developed in the filament. When this stretched filament is dyed with a dispersed dye (for example, Celliton Fast Red 4G, of BASF, Germany) at about 40° C., the dye will be deposited in the voids and the filament will be dyed. Further, when such fibers having voids are heated in the relaxed state, a high shrinkage will be shown. On the other hand, in a case where an unstretched filament low in the density (for example, 0.888 g./cm.^{3}) is stretched, no void will be produced, and, even if it is dyed under the above mentioned conditions, it will be dyed to a small extent, and further its thermal shrinkage will be low. In the unstretched filament in the present invention, a part of the filament high in density and a part low in density are integrally but successively formed in the cross-sectional direction of the single fiber. That is to say, when the unstretched filament in the present invention is stretched for example, 3 times the length at the normal temperature and is then dyed with a dispersed dye under the above mentioned conditions, one side of the cross-section will be dyed but the other side will be dyed only to a small extent, as shown in FIG. 5. The dyed side is the windward side and undyed side is the leeward side in respect to the cooling gas. This means that the dyed part (windward side) is higher in density and higher in crystallinity than the undyed part (leeward side). However, when the filament is subsequently heat-treated in a relaxe dstate the voids will vanish to a great extent so that, when the final crimped filament is dyed, the difference in dyeing rate between the two portions will not be clearly observed.

The term "polypropylene," as used in the present invention, means isotactic polypropylene or a polymer composed mainly of isotactic polypropylene. The term "polymer composed mostly of an isotactic polypropylene" as used in the method of the present invention is a polypropylene in which isotactic polypropylene is a main constituent, a small amount of an atactic polypropylene being contained therein; also less than 20% by weight of such other homopolymer or copolymer as a polyolefin, polyester, polyamide or polyether may be present. The intrinsic viscosity of the polymer before the spinning is about 1.1 to 1.8. It is preferable to subject the polymer to a melt-spinning process accompanied by a thermodecomposition. Further, the intrinsic viscosity of the polymer is of a value measured with a tetraline solution at 135° C.

The following examples illustrate but in no way limit the invention. In these examples, the number of crimps is the number per 25 mm. as counted in respect to a sample applied with an initial load of 2 mg. per denier.

EXAMPLE 1

Two different polypropylene resins having different intrinsic viscosities were melt-spun respectively at the below mentioned spinning temperature, to obtain unstretched filaments having a single filament denier of 30. The winding speed was 400 m./min. A spinnerette having 80 orifices of a diameter of 1.2 mm. and a minimum distance between the orifices of 6 mm. was used. A cooling air current was blown at a speed of 0.5 m./sec. at right angles with the filaments from less than 10 mm. below the spinnerette (that is, D in FIG. 1 is 10 mm.). The results are shown in Table 1.

TABLE 1.—SPINNING CONDITIONS AND PROPERTIES OF UNSTRETCHED FILAMENTS

	Intrinsic viscosity of resin	Spinnerette temperature (° C.)	Intrinsic viscosity of unstretched filament	Corrected density ρ_p of unstretched filament	Diameter of latent crimps in unstretched filament (mm.)	Asymmetry degree (As. percent)
Number:						
1	1.60	220	1.55	0.9075	0.92	3
2	1.60	230	1.41	0.0964	0.50	11
3	1.60	240	1.33	0.9052	0.74	4
4	1.33	220	1.26	0.9071	0.45	12
5	1.33	230	1.17	0.9063	0.49	11
6	1.33	240	1.08	0.9050	1.08	2

The samples of Nos. 2, 4 and 5 satisfying the condition of the Formula 1 had a favorable crimpability (coil diameter of latent coil crimps was below 0.7 mm.) but the samples of Nos. 1, 3 and 6, deviating from the condition of the Formula 1, had a crimpability insufficient for practical uses, though some crimps were developable in them. When the unstretched filament of No. 4, was subsequently stretched 3 times its length on a hot pin at 60° C. and then heat-treated in a relaxed state, excellent crimped continuous fibers having a crimp number of 30 were obtained.

EXAMPLE 2

A polypropylene resin having an intrinsic viscosity of 1.55 was spun through two kinds of spinnerettes having a different minimum distance between the orifices so as to vary the cooling condition. The fineness of the

unstretched filament was 15 deniers, and the extruded filament was taken up at a winding rate of 600 m./min. The diameter of the spinnerette orifice was 0.8 mm. The velocity of the cooling gas current was 0.5 m./sec. The number of orifices was 180.

As shown in Table 2, the minimum distance between the orifices was less than 4.0 mm. in Nos. 7 and 9', and, in Nos. 9 and 9'', the distance D was outside the range defined by the Formula 2. Therefore, in the unstretched filaments of Nos. 7, 9, 9' and 9'', although the density ρ_p satisfied the Formula 1, the crimp developing capacity was not high. No. 8 had a satisfactory crimp developing capacity. When the unstretched filament of No. 8 was stretched 4.0 times its length in water at 65° C., cut into staples and heat-treated in a relaxed state at 120° C. for 5 minutes, there were obtained staples of 18 crimps having a high bulkiness.

TABLE 3.—STRETCHING CONDITIONS AND CRIMP CHARACTERISTICS OF FIBERS

	Deniers of unstretched filaments	Draw ratio	Filament temperature in stretching (° C.)	Number of crimps	Preheating-treatment at 90° C.
Number:					
10	5	3.2	120	3	
11	5	3.2	80	15	
12	30	3.5	95	4	
13	30	3.5	70	20	
14	30	2.2	70	6	
15	30	2.2	102	2	4 seconds.
16	30	4.0	102	32	Do.
16'	30	4.0	130	1	Do.

As shown in the above table, Nos. 11, 13 and 16, satisfying the stretching ratio and temperature required by the invention, had excellent crimps, but Nos. 10, 12 and 16' (where the stretching temperature was too high) and Nos. 14 and 15 (where the stretch ratio was too low) had poor crimps.

TABLE 2.—SPINNING CONDITIONS AND PROPERTIES OF UNSTRETCHED FILAMENTS

	Minimum distance (M mm.) between spinnerette orifices	Cooling gas blown D cm. below the orifice	Spinnerette temperature (° C.)	Corrected density ρ_p of unstretched filament	Coil diameter (mm.)	Intrinsic viscosity of unstretched filament	Asymmetry degree (As, percent)
Number:							
7	2.5	1.0	253	0.9054	0.76	1.28	4
8	8.0	1.0	253	0.9052	0.57	1.28	10
9	8.0	40.0	232	0.9051	1.20	1.39	2
9'	3.0	1.0	250	0.9055	0.78	1.29	4
9''	8.0	35.0	239	0.9048	0.96	1.35	4

EXAMPLE 3

An isotactic polypropylene resin having an intrinsic viscosity of 1.5 was extruded through a spinnerette in which the minimum distance between the orifices was 10 mm., the orifice diameter was 1.0 mm. and the number of orifices was 120. Thus unstretched filaments having a single filament denier of 5 were spun at a spinnerette temperature of 260° C., and unstretched filaments having a single filament denier of 30 were spun at a spinnerette temperature of 240° C. In each case, the filaments were wound up at 600 m./min. A cooling gas current was blown across and against the filaments at 0.8 m./sec. and at a distance of 20 mm. below the spinnerette. The corrected density ρ_p of the obtained unstretched filaments was 0.9048 in the single filament of 5 deniers and 0.9061 in that of 30 deniers. The intrinsic viscosities of these filaments were 1.15 and 1.38 respectively. The asymmetry degrees As were 11 and 16% respectively. The latent coil-crimp diameters were 0.50 and 0.38 respectively. All these values were within the ranges required in the present invention.

The unstretched filaments were stretched in contact with a hot plate between two Nelson rollers, cut to a staple length of 51 mm., and heat-treated in a relaxed state in a dryer at 120° C. for 30 minutes to develop crimps. The results are as shown in Table 3.

EXAMPLE 4

A mixture of 10% by weight of a low density polyethylene resin and 90% by weight of a polypropylene resin having an intrinsic viscosity of 1.28 was melt-spun. By using a spinnerette having a minimum distance between the orifices of 10 mm. and an orifice diameter of 1.0 mm., unstretched filaments having a single filament denier of 20 were formed at various spinnerete temperatures, and were wound up at 600 m./min. In all cases, a cooling air stream was blown at 0.6 m./sec. just below the spinnerette, but within the range dictated by Formula 2. The results are shown in Table 4.

TABLE 4.—SPINNING CONDITIONS AND PROPERTIES OF UNSTRETCHED FILAMENTS

	Spinnerette temperature (° C.)	Intrinsic viscosity of unstretched filament	Density ρ of unstretched filament	Corrected density ρ_p of unstretched filament	Latent coil crimp diameter (mm.)	Asymmetry degree (As, percent)
Number:						
17	230	1.23	0.9080	0.9066	0.81	3
18	240	1.12	0 9072	0.9056	0.55	14
19	250	1.08	0.9059	0.9044	0.74	5
19'	255	1.05	0.9055	0.9040	1.08	2
19''	225	1.30	0.9082	0.9068	0.94	3

The unstretched filaments of No. 18 were then stretched 4 times their length in water at 50° C. and then heat-treated at 120° C. for 5 minutes in a relaxed state to obtain excellent crimped continuous fibers having a crimp number of 18.

In the above table, Nos. 17 and 19'' were too high in ρ_p while Nos. 19 and 19' were too low in ρ_p so that their latent coil crimp diameter was large and therefore not satisfactory.

What is claimed is:

1. A process for producing crimped polypropylene fibers which comprises melt-spinning a polymer composed

substantially of an isotactic polypropylene through a spinnerette having a minimum distance of greater than 4.0 mm. between its orifices to form filaments, cooling the filaments by blowing a cooling gas having a velocity of greater than 0.3 m./sec. and a temperature of 0–25° C. across the filaments at an angle of 90°±30° with respect to the longitudinal axis of the filaments, the distance D (cm.) between the spinnerette face and the uppermost plane of the cooling gas satisfying the formula

$$D \leqq \frac{V_d}{300}$$

wherein V is the winding rate of the filament within the range 400–600 m./min. and d is the denier value of the filament up to 110, to prepare an unstretched filament having a corrected density ρ_p (g./cm.^{3}) satisfying the formula

$$1.67\times10^{-6}d^2-3.4\times10^{-6}d+0.9040 \leqq \rho_p \leqq 1.67\times10^{-6}d^2-3.4\times10^{-6}d+0.9058$$

wherein d is as defined above, stretching the unstretched filament at least 2.5 times at a filament temperature T (° C.) satisfying the formula

$$10 \leqq T \leqq 120-d$$

wherein d is as defined above, to prepare a fiber having fine voids distributed asymmetrically in the cross-section thereof, and heat-treating the fiber in a relaxed state.

2. A process according to claim **1** wherein the minimum distance between the orifices is greater than 6 mm.

3. A process according to claim **1** wherein the temperature of the cooling gas is 0 to 25° C.

4. A process according to claim **1** wherein the velocity of the cooling gas is 0.45 to 1.2 m./sec.

5. A process according to claim **1** wherein the unstretched filament has an index of difference in mean birefringence values of greater than 5%.

6. A process according to claim **1** wherein the unstretched filament has latent coil crimps having a coil diameter of less than 0.7 mm.

7. A process according to claim **1**, wherein the unstretched filament has an intrinsic viscosity of 1.05–1.50.

8. A process according to claim **1**, wherein the heat-treating is conducted at a temperature of 80–150° C.

9. A process for producing crimped polypropylene fibers which comprises melt-spinning a polymer composed substantially of an isotactic polypropylene through a spinnerette having a minimum distance of greater than 4.0 mm. between its orifices to form filaments, cooling the filaments by blowing a cooling gas having a velocity of greater than 0.3 m./sec. and a temperature of 0–25° C. across the filaments at an angle of 90°±30° with respect

to the longitudinal axis of the filaments, the distance D (cm.) between the spinnerette face and the upper-most plane of the cooling gas satisfying the formula

$$D \leqq \frac{V_d}{300}$$

wherein V is the winding rate of the filament within the range 400–600 m./min. and d is the denier value of the filament up to 110, to prepare an unstretched filament having a corrected density ρ_p (g./cm.^{3}) satisfying the formula

$$1.67\times10^{-6}d^2-3.4\times10^{-6}d+0.9040 \leqq \rho_p \leqq 1.67\times10^{-6}d^2-3.4\times10^{-6}d+0.9058$$

wherein d is as defined above, preheating the unstretched filament at 60–140° C., stretching the unstretched filament at least 2.5 times at a temperature less than the preheating temperature +30° C. to prepare a fiber having fine voids distributed asymmetrically in the cross-section thereof, and heat-treating the fiber in a relaxed state.

10. A process according to claim **9** wherein the preheating is conducted at 70–135° C.

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