

[54] **SPINNING APPARATUS WITH  
CONVERGING GAS STREAMS**

[75] Inventors: **Paul H. McGinnis**, Kings Mountain;  
**William D. McLaughlin, Jr.**; **Robert  
E. Swander**, both of Charlotte, all of  
N.C.

[73] Assignee: **Celanese Corporation**, New York,  
N.Y.

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**Related U.S. Application Data**

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No. 3,787,265.

[52] U.S. Cl. .... **425/72, 65/16, 264/210 F**

[51] Int. Cl. .... **D01d 3/00, B29c 25/00**

[58] Field of Search ..... **425/72; 264/210 F; 65/5,  
65/16**

[56] **References Cited**

**UNITED STATES PATENTS**

3,509,009 4/1970 Hartmann ..... **265/210 F X**

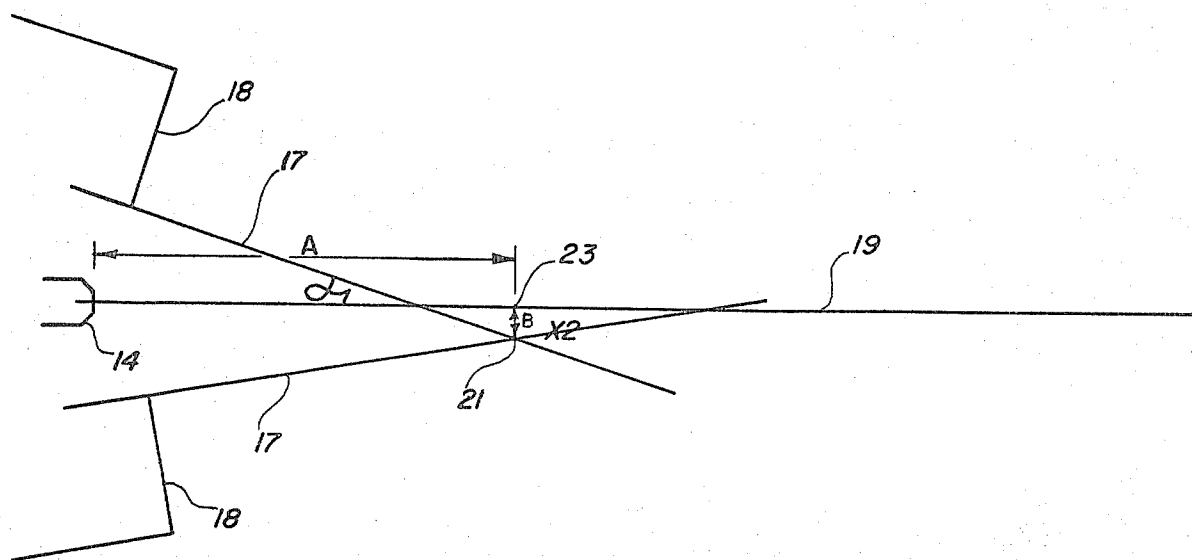
3,543,332 12/1970 Wagner ..... **425/72**  
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*Primary Examiner*—Robert D. Baldwin  
*Attorney, Agent, or Firm*—Andrew F. Sayko, Jr.

[57] **ABSTRACT**

Apparatus and method for producing filamentary material by extruding substantially axially through an orifice comprising contacting the extruded filament stream downstream of the orifice and prior to hardening with a plurality of converging, substantially planar, high velocity gas streams, each moving substantially in the direction of the filament stream such that they converge upon the filament stream at an angle of from about 45° to 5° from the axis of the polymer extrusion nozzle. The planes of the gas streams intersect at a point which is at a distance measured perpendicularly from the axis of the extrudate stream at least equal to the diameter of the extrudate stream.

**1 Claim, 8 Drawing Figures**



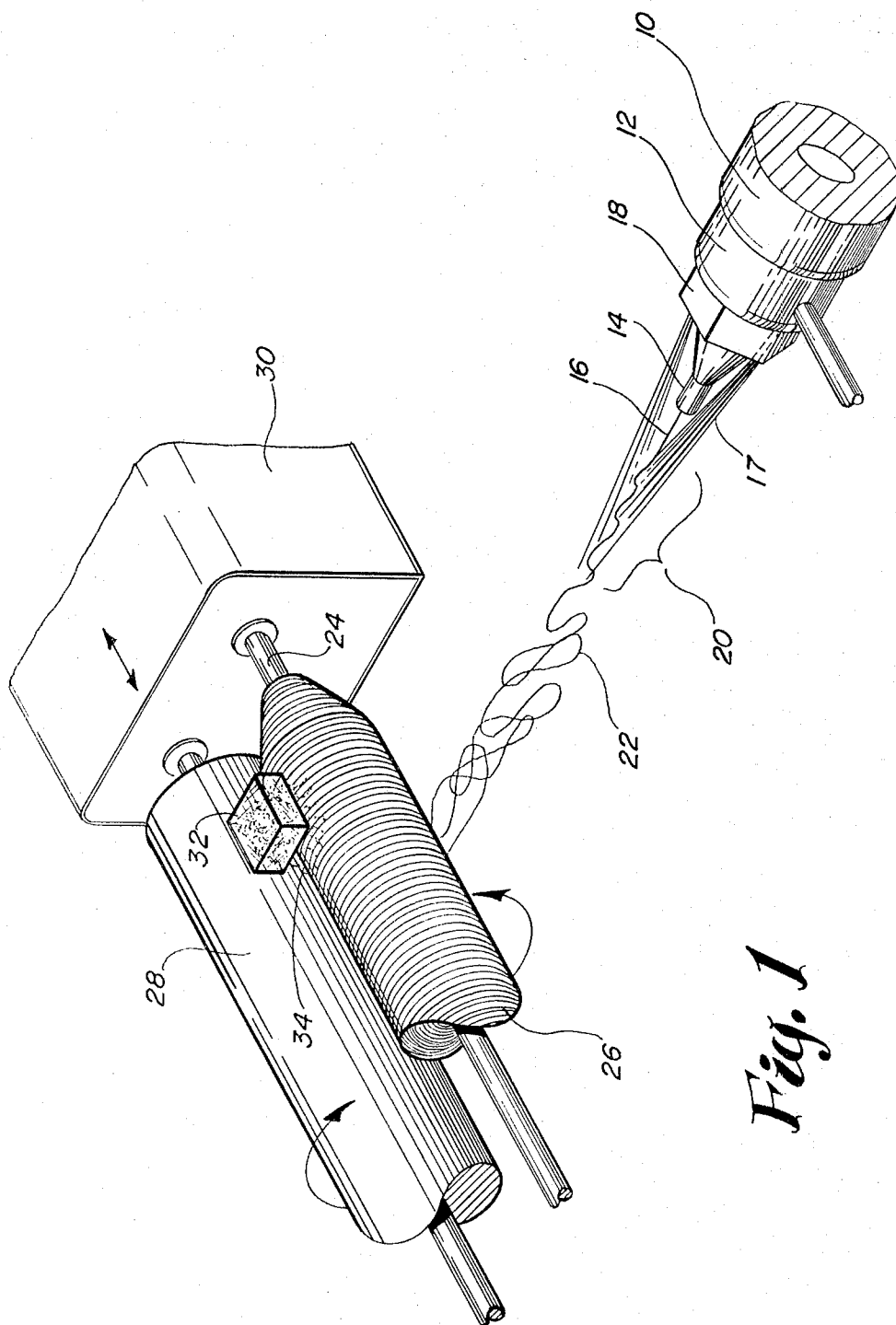


Fig. 2

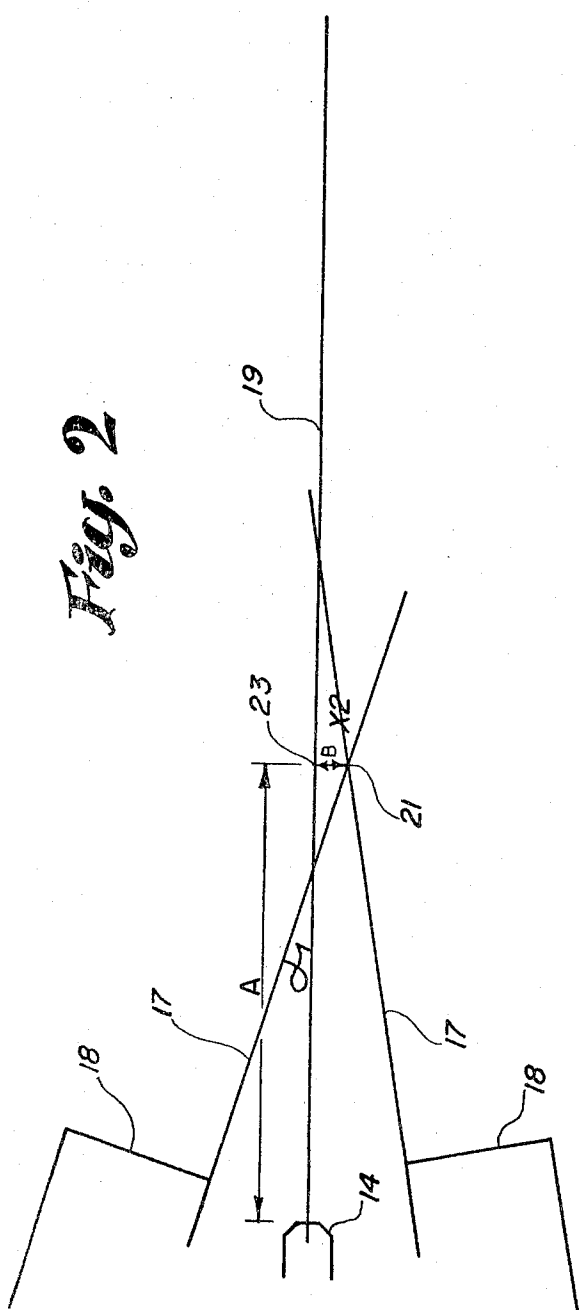


Fig. 4

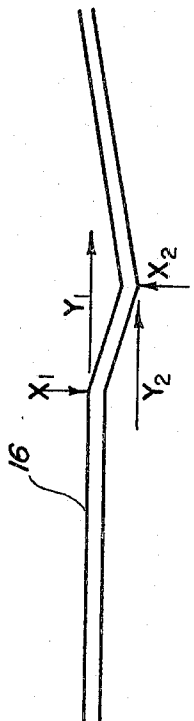
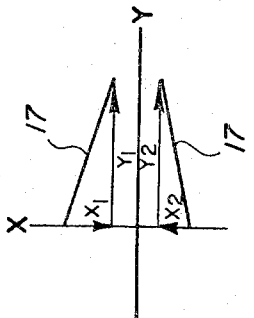


Fig. 3



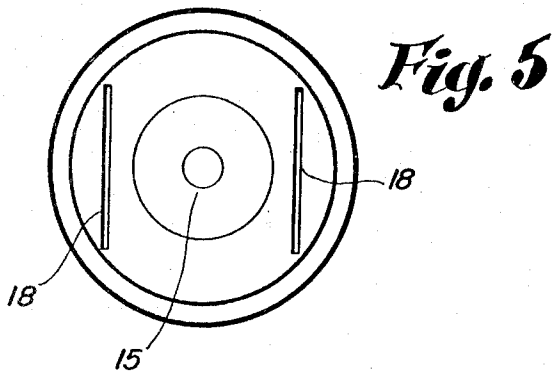


*Fig. 7*

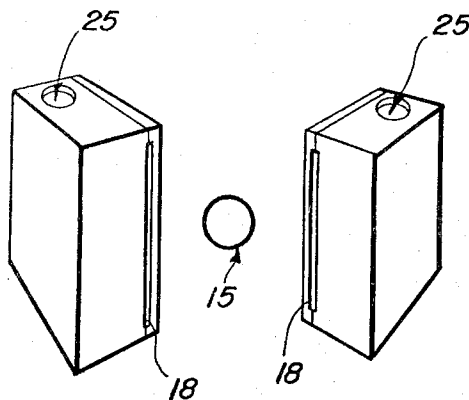
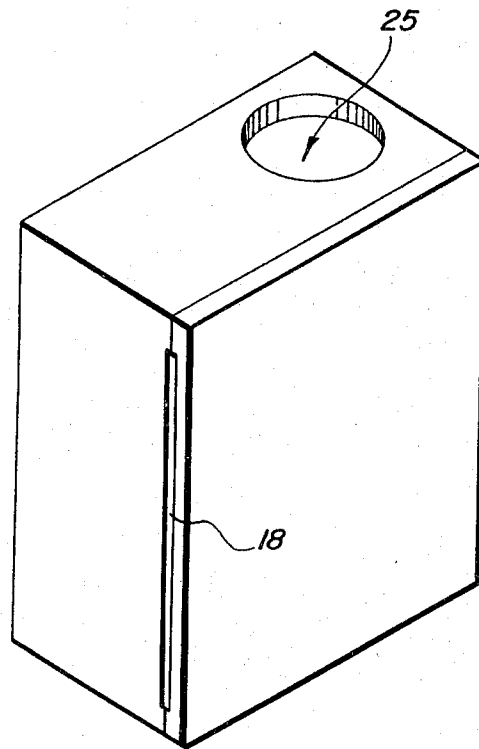
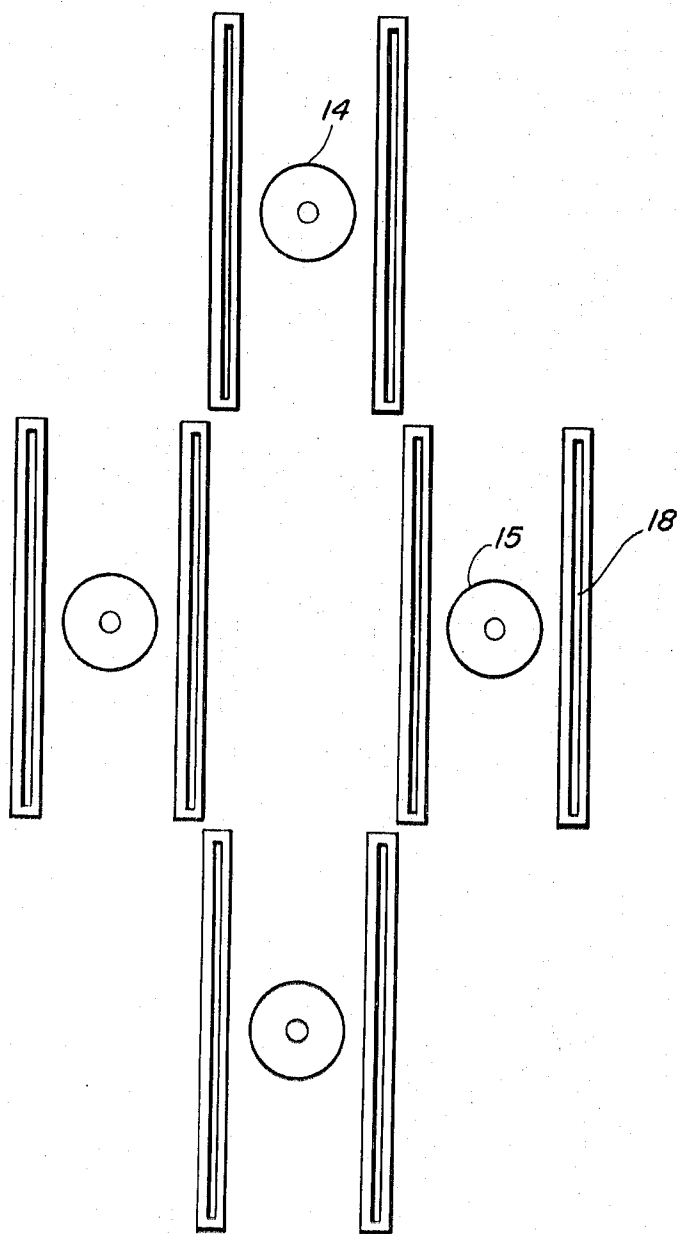


*Fig. 6*

*Fig. 8*



## SPINNING APPARATUS WITH CONVERGING GAS STREAMS

This is a division, of application Ser. No. 237,832, filed Mar. 24, 1972, now Pat. No. 3,787,265 issued Jan. 22, 1974.

### BACKGROUND OF THE INVENTION

This invention relates to the production of filamentary material. It is particularly concerned with novel apparatus for spray spinning molten fiber-forming polymers to form nonwoven structures.

Various proposals have been advanced heretofore in connection with integrated systems for forming fibrous assemblies, such as nonwoven fabrics and the like, directly from molten fiber-forming materials. In general, the proposed systems envisioned an extrusion operation followed by collection of the extruded filamentary material in the form of a continuous fabric, web or other desired fibrous assembly. When details are considered, however, the various proposals differed in substantial ways.

In recently issued U.S. Pat. No. 3,543,332, a novel method for spray spinning molten fiber-forming polymers is shown. Filamentary material is extruded substantially axially through an orifice and contacted downstream prior to hardening by a plurality of high velocity gas streams, each moving in a direction having a major component in the direction of extrusion of the filament stream in a shallow angle of tangential convergence therewith to attenuate the filament stream. The axis of the gas passages and corresponding gaseous streams are skewed about the extrusion orifice such that they have non-intersecting axes spaced about the axis of the extrusion orifice.

The present invention is concerned with an improved apparatus for the direct production of filamentary materials. It is an object of the present invention to provide improved apparatus for spray spinning molten fiber-forming materials at production rates much higher than the prior art processes. At the same time, it is a further object of the invention to produce a substantially uniform spray-spun fibrous structure while minimizing the formation of shot or objectionally short fibers which detract from the desirability of the collected fibrous assembly.

In accordance with an embodiment of the invention, spinning nozzle means are provided with an extrusion orifice with a fiber-forming material and with a plurality of substantially rectangular gas outlet passages spaced apart from the extrusion orifice to supply jets of high velocity gas for attenuating the extruded filament stream prior to hardening of the filaments. The molten polymer and attenuating gas do not flow through the same nozzle or any other part of the spray-spinning equipment. The gas passages are separated from the extrusion orifice by an insulating means such as an air space. As a consequence, the gas flow, if it is not heated, would not cause heat transfer from the polymer to the gas. Such an arrangement eliminates the need for either heating the attenuating gas or heating the polymer to a sufficiently high degree above the required extrusion temperature such that the heat transfer would only lower the polymer temperature to the required extrusion temperature. The direction of the gas jets are such that substantial drag forces are applied to the extruded filament stream in the direction of extrusion for

attenuating or drawing the material leaving the extrusion orifice. Further, the gas passages are positioned such that the planar gas streams are directed substantially in the direction of flow of the extrudate stream in such a manner that the gas streams converge upon the extrudate stream. The planes of the gas streams and the planar projections of the gas outlet passages intersect at a point which is at a distance measured perpendicularly from the axis of the extrudate stream at least equal to the diameter of the extrudate stream. The planes of the attenuating gas streams contact the polymer extrudate stream at an angle of from about 45° to 5° from the axis of the polymer extrusion nozzle to project it away from the extrusion orifice.

Briefly, a relatively heavy monofil is extruded and a plurality of streams of gas, e.g., steam or air, are directed at a shallow angle in the direction of flow of the freshly extruded monofil. This attenuates the monofil into relatively fine denier material and, like the more conventional drawing, also increases the tenacity of the solidified extrudate. Depending upon the conditions of extrusion, the filamentary material will be one or more substantially continuous structures, or relatively long staple fibers, or conventional length fibers, possibly mixed with varying amounts of solid debris or "shot."

The severity of the gas streams varies the attenuation and determines the denier of the resulting fibrous material which may range from about 0.1 up to about 50, although for maximum surface and strength the fiber denier is preferably mostly below about 25 denier. Actually each product will include a range of deniers which will add to its strength and performance.

The extrudate is discharged onto a suitable collection surface such as a rotating collector drum. The height or length of the resulting structure can be set by traverse or by use of multiple side-by-side extruders whose spray patterns overlap. The duration of spray obviously controls the thickness of the resulting structures. The conditions of extrusion and collection are such that each new layer when deposited is sufficiently tacky so as to adhere to the preceding layer so that the total structure will be shape-retaining without further treatment.

The filament-forming material may comprise any known suitable polymeric material which is plasticizable, soluble or fusible. If soluble materials are used in conjunction with a solvent, the problem of solvent removal is encountered which, of course, is avoided where fusible materials are employed. Representative fusible materials include polyolefins such as homopolymers and copolymers of olefins, e.g. ethylene and propylene, especially stereospecific or crystalline polyethylene and polypropylene; polyamides such as nylon 66, nylon 6, and the like; polyesters such as polyethyleneterephthalate; cellulose esters such as cellulose acetate, and especially the secondary triacetate; polyurethanes; polystyrene; polymers of vinylidene monomers such as vinyl chloride, vinyl acetate, vinylidene chloride, and especially acrylonitrile; and mixtures thereof.

### DESCRIPTION OF THE DRAWINGS

A more complete understanding of these and other features of the invention will be gained from a consideration of the following detailed description of an embodiment illustrated in the accompanying drawings in which:

FIG. 1 is a schematic illustration of an extrusion and collection apparatus in accordance with the present invention;

FIG. 2 is a schematic plan view of the extrusion apparatus and process in accordance with the present invention;

FIG. 3 is a graph illustrating vectorially the forces resulting from two converging planar gas streams;

FIG. 4 is a schematic illustration showing how the vector force equipment illustrated in FIG. 3 both deflect and accelerate the filament stream.

FIG. 5 is a front elevation of one embodiment of an extrusion nozzle and planar attenuating gas jets useful in the apparatus and process illustrated in FIG. 2;

FIG. 6 is a schematic perspective illustration of an extrusion nozzle having a pair of planar attenuating gas jets positioned on each side of the extrusion nozzle;

FIG. 7 is a perspective view of a planar attenuating gas jet shown in FIG. 6.

FIG. 8 is a schematic front elevation of the preferred arrangement for utilizing four extrusion nozzles.

Referring now more particularly to the drawings, in FIG. 1 a fiber-forming, thermoplastic polymer, preferably a polyolefin, is fed to an extruder 10 provided with an adapter section 12 to which a gas, such as steam or air, is supplied. While extrusion temperatures may be anywhere above the melting point of the polymer, it has been found that best results are obtained by heating the polymer to at least 150°C., and preferably from about 250° to about 350°C. above the softening point of the polymer being extruded. For example, polypropylene having hereinafter defined characteristics will generally be heated to temperatures of from about 325° to about 400°C. Polyethylene, on the other hand, will be heated to from about 350° to about 450°C. A hot, molten stream of polymer 16 is discharged through a nozzle 14.

It is to be understood that nozzles having one or more polymer orifices may be used. Also, a plurality of nozzles per collector may be employed. However, there must be at least two planar gas streams per polymer orifice. The attenuating gas orifices 18 are of an elongated rectangular cross section, as shown in FIGS. 5 and 6, to emit substantially planar gas streams 17.

The gas streams 17 act on the polymer stream 16 in convergence region 20 to form an attenuated filament 22 wherein it cools and partially solidifies while moving toward collection surface 24 on which it is collected as a cylindrical structure 26. The collection surface 24 is ordinarily rotated at a speed sufficient to provide a moving surface of from about 25 to about 125 feet per minute by a motor drive. Collection surface 24 is in surface contact with roller 28, which acts as an idler roll and whose bias against the mandrel can be adjusted; the extent of the bias will effect how tightly the tacky filament packs against previous layers on the cartridge 26. Both the collection surface 24 and the roller 28 are reciprocated laterally by a traversing mechanism 30 whose throw determines the shape of the cylinder; the throw may be of constant length or may change in the course of package build-up to produce a particular shape as may be needed for acceptance in a receptacle of predetermined corresponding shape.

The force of the attenuating gas on the polymer stream causes the polymer to attenuate greatly, e.g., from 10 to 500 times, based on diameter ratios, and possibly fibrillate to a slight degree to produce a sub-

stantially continuous fiber. Some turbulence and resultant whipping about of the polymer stream occurs. Consequently, a generally random, stereo reticulate structure of fiber results as the material impinges on the collector. Since the polymer is still in a somewhat molten or tacky state when it strikes the collector, some sticking together occurs at the points where fiber intersects. For brevity, this sticking will be referred to as interfiber bonding, although it is to be understood that this bonding will ordinarily result from an individual fiber looping about and sticking or bonding to itself.

For best results, the collection surface 24 should be from about 6 to about 48 inches, preferably 10 to 30 inches, from polymer exit nozzle 14. With greater distances the spray pattern is difficult to control and the resultant web tends to be nonuniform. Shorter distances result in a web which contains too great a quantity of "shot," i.e., beads of non-attenuated polymer, which undesirably affects subsequent processing, web uniformity and surface area.

In FIG. 2 there is schematically shown a top view of the apparatus of this invention. A plurality of converging substantially planar gas streams 17 (corresponding substantially to planar projections of gas outlet passages 18) issue from substantially rectangular gas outlet passages 18. The axis 19 of the nozzle 14 corresponds to the direction in which the polymer stream is extruded. The gas jets 17 are positioned along side the extrusion nozzle 14 in such a manner that the gas streams 17 are directed substantially in the direction of flow of the polymer extrudate along the nozzle axis 19. The planes of the gas streams and planar projections of the gas outlet passages intersect at a point 21 which is at a distance B measured perpendicularly from intersection point 21 to the nozzle axis 19. The distance B is at least equal to the diameter of the extrudate stream at a point 23 along the nozzle axis in juxtaposition to the point of intersection 21. Preferably B is at least 0.06 inch, most preferably from about 0.2 to 2.0 inches. The point 23, which defines the perpendicular distance from the nozzle 14 to the intersection point 21 is a distance A of at least 2.0 inches from the point of extrusion nozzle 14, preferably from about 2.5 to 7.0 inches. The attenuating gas jets 18 are positioned along side the extrusion nozzle such that the planes of the attenuating gas streams 17 intersect the nozzle axis 19 (also the axis of the extrudate stream) at an angle ( $\alpha_1$  and  $\alpha_2$ ) less than 45° to more than about 5°, preferably from about 10° to 40°, to project the extrudate stream away from the extrusion nozzle.

In FIG. 3 the force of the gas streams 17 are shown vectorially. The Y force component is in the direction of the extrusion nozzle axis and polymer extrudate stream, and serves to accelerate and attenuate the extrudate stream.

Angles  $\alpha_1$  and  $\alpha_2$ , shown in FIG. 2, are not the same so that the intersection point of the planes of the gas streams is off the nozzle axis and extrudate stream. FIG. 4 shows that the effect of this is to deflect the extrudate stream 16, first to one side and then to the other, in addition to attenuating the extrudate. If  $\alpha_1$  and  $\alpha_2$  are identical, the planar filament streams 18 would intersect on the nozzle axis and substantially on the extrudate stream. As can be seen from the examples, this leads to much lower surface area when compared to the method of this invention illustrated in FIG. 2. It is probable that the effect of the gas streams intersecting

on the extrudate stream is to cut the stream and produce a less open, lower surface area product.

The illustrated extrusion nozzle 14 has a center polymer exit orifice 15, as shown in FIG. 5, which ordinarily has a diameter of from about 0.01 to about 0.10 inch, and preferably from about 0.015 to about 0.030 inch.

In the preferred embodiment, polymer is generally extruded through the nozzle at 1 to about 30 lb./hr., and desirably at 5 to 15 lb./hr.

Along side polymer exit orifice 15, as shown in FIGS. 5 and 6, are a plurality of attenuating substantially rectangular elongated gas orifices 18 having a width of from about 0.002 to about 0.050 inch, preferably from about 0.004 to about 0.025 inch, and a length of at least about 0.5 inch, preferably from about 1.0 to about 3.0 inches. Attenuating gas nozzles 18 emit substan-

sect the axis of the extrudate stream at angles  $\alpha_1$  and  $\alpha_2$  of about 30° and 25° respectively. The polypropylene extrudate is collected on a metal drum having a diameter of 1 inch to produce annular cylindrical structures. The total throughput of polypropylene is about 6 lb./hr.

The procedure is repeated, except that the extruder throughput is increased such that the total throughput of polypropylene being spray spun is 9 lb./hr.

#### EXAMPLE 2

Polypropylene, as in Example 1, is spray spun through one or more circular orifices, utilizing planar attenuating gas jets, as shown in FIG. 6, spaced at a distance of 2 inches from the axis of each extrusion orifice. The spray spun structure was collected on a cylindrical drum. The process conditions for 14 runs are summarized in Table 1 below:

TABLE 1

| Run No. | Extrusion Temp. (°C) | Extrusion orifice diameter (in) | No. of orifices | Air Flow (CFM) | Air Pressure (PSIG) | Polymer Throughput (lbs/hr) | A (in) | B (in) | $\alpha_1$ (°) | $\alpha_2$ (°) | Collector Speed (Feet per min.) | Distance from Nozzle to Collection drum (in) | Surface area (square meters per gram) |
|---------|----------------------|---------------------------------|-----------------|----------------|---------------------|-----------------------------|--------|--------|----------------|----------------|---------------------------------|----------------------------------------------|---------------------------------------|
| 2       | 395                  | 0.016                           | 4               | 56             | 65                  | 6                           | 4      | 5/16   | 30             | 25             |                                 | 36.0                                         | 0.46                                  |
| 2a      | 395                  | 0.016                           | 4               | 56             | 65                  | 6                           | 4      | 5/16   | 30             | 25             |                                 | 28.5                                         | 0.45                                  |
| 2b      | 395                  | 0.016                           | 4               | 56             | 65                  | 9                           | 4      | 5/16   | 30             | 25             |                                 | 36.0                                         | 0.33                                  |
| 2c      | 395                  | 0.016                           | 4               | 56             | 65                  | 9                           | 4      | 5/16   | 30             | 25             |                                 | 8.5                                          | 0.35                                  |
| 2d      | 380                  | 0.016                           | 4               | 59             | 65                  | 6                           | 4      | 0      | 27             | 27             |                                 | 32.0                                         | 0.31                                  |
| 2e      | 380                  | 0.016                           | 4               | 59             | 65                  | 9                           | 4      | 0      | 27             | 27             |                                 | 32.0                                         | 0.27                                  |
| 2f      | 395                  | 0.016                           | 4               | 57             | 60                  | 6                           | 3      | 5/16   | 38             | 29             | 73                              | 39.5                                         | 0.53                                  |
| 2g      | 395                  | 0.016                           | 4               | 57             | 60                  | 9                           | 3      | 5/16   | 38             | 29             | 73                              | 39.5                                         | 0.42                                  |
| 2h      | 395                  | 0.016                           | 4               | 57             | 60                  | 6                           | 3      | 0      | 34             | 34             | 73                              | 39.5                                         | 0.36                                  |
| 2i      | 395                  | 0.016                           | 4               | 57             | 60                  | 9                           | 3      | 0      | 34             | 34             | 73                              | 39.5                                         | 0.31                                  |
| 2j      | 350                  | 0.018                           | 1               | 30             | 35                  | 2.5                         | 3      | 0      | 34             | 34             | 20                              | 41.0                                         | 0.48                                  |
| 2k      | 350                  | 0.018                           | 1               | 30             | 35                  | 2.5                         | 3      | 5/16   | 38             | 29             | 20                              | 41.0                                         | 0.58                                  |
| 2l      | 350                  | 0.018                           | 1               | 30             | 35                  | 2.5                         | 4      | 0      | 27             | 27             | 20                              | 41.0                                         | 0.38                                  |
| 2m      | 350                  | 0.018                           | 1               | 30             | 35                  | 2.5                         | 4      | 5/16   | 30             | 25             | 20                              | 41.0                                         | 0.43                                  |

tially planar gas streams 17 and are positioned, as illustrated in FIGS. 2 and 8.

FIGS. 6 and 7 show, in perspective, a preferred embodiment of a gas jet for emitting a substantially planar gas stream. The gas enters through gas inlet passage 25 and is emitted through rectangular elongated gas orifice 18.

#### EXAMPLE 1

Isotactic polypropylene having an intrinsic viscosity of 1.5 and a melt flow rating of 30 is spray-spun at a melt temperature of 390°C. through four extrusion orifices arranged as shown in FIG. 8. Each orifice is of a substantially circular crosssection having a diameter of about 0.016 inch. Referring to FIG. 8, two planar attenuating gas jets, as shown in FIG. 6, were spaced at a distance of 2 inches from the axis of each extrusion nozzle, in approximately parallel relationship to each other along side each extrusion orifice. The elongated rectangular air jets had an orifice width of 0.010 inch and a length of about 1.88 inches and each emitted ambient air flowing at a rate of about 56 cubic feet per minute at a pressure of about 65 p.s.i.g.

Referring to FIG. 2, the gas jets 17 are positioned so that the planes of gas streams 18 intersect at a point 21 which is at a distance B of five-sixteenths inch from the axis of the extrudate stream which corresponds to nozzle axis 19. The distance A which defines the distance from the orifice 14 to the intersection point 21, is 4 inches. As a result, the planes of the gas streams inter-

The molecules in the surface layer of a solid are bound on one side to inner molecules but there is an imbalance of atomic and molecular forces on the other. The surface molecules attract gas, vapor, or liquid molecules in order to satisfy these latter forces. The attraction may be either physical or chemical, depending on the system involved and the temperature employed. Physical adsorption (frequently referred to as van der Waal's adsorption) is the result of a relatively weak interaction between a solid and a gas. This type of adsorption has one primary characteristic. Essentially all of a gas adsorbed can be removed by evacuation at the same temperature at which it was adsorbed.

While the first gas molecules to contact a clean solid are held more or less rigidly by van der Waal's forces, the forces active in the condensation of vapors become increasingly responsible for the binding energy in subsequent layer development. The expression

$$V_a = V_m CP / (P_s - P) [1 + (C-1) P / P_s] \quad (1)$$

where  $V_a$  is the volume of gas adsorbed at pressure  $P$ ,  $V_m$  the volume adsorbed when the entire surface is covered by a monomolecular layer,  $C$  a constant, and  $P_s$  the saturation pressure of the gas (actually the vapor pressure at a given temperature of a large quantity of gas condensed into a liquid), is obtained by equating the rate of condensation of gas molecules onto an adsorbed layer to the rate of evaporation from that layer

and summing for an infinite number of layers. The expression describes the great majority of low temperature adsorption data. Physical measurements of the volume of gas adsorbed as a function of pressure at a fixed temperature, therefore, permit calculation of  $V_m$ , the volume of gas required to form a layer 1 molecule thick. Equation 1 can be rearranged to the linear form

$$(P)/V_a(P_s - P) = 1/V_m C + (C - 1/V_m C) P/P_s$$

Then a plot of data for  $P/V_a(P_s - P)$  versus  $P/P_s$  gives a straight line, the intercept and slope of which are  $1/V_m C$  and  $(C - 1)V_m C$ , respectively. The value of  $V_m$  is thus readily extracted from a series of measurements. From this information and knowledge of the physical dimensions of single molecules, the surface area of the adsorbing solid is computed.

As shown in Table 1 above, surface area measurements were taken utilizing Orr Surface - Area Pore - Volume Analyzer (Model 2100A). The runs using the preferred process of this invention (2, 2a, 2b, 2c, 2f, 2g, 2k and 2m) exhibited a higher surface area than the runs wherein the attenuating gas streams intersected on the axis of the extrudate stream. A direct comparison can be between runs 2f and 2h, 2g and 2i, 2j and 2k, and 2l and 2m. Increases in surface area of from 0.05 to 0.17 meters<sup>2</sup>/gram are achieved.

The higher the surface area, the greater the filtration efficiency of the structure.

The preferred fiber-forming polymers employed in the present invention are the polyolefins, such as polyethylene or polypropylene. The melt index of the polyolefin prior to extrusion will ordinarily be from about 5 to 60 and preferably from about 15 to 40. The intrinsic viscosity will be from about 1.0 to about 2.5 and preferably from about 1.0 to about 2.0.

Instead of the polyolefins, one may also employ other thermoplastic, melt-extrudable, fiber-forming polymers such as polyamides, polyesters, phenol-formaldehyde resins, polyacetals, and cellulose esters, e.g., cellulose acetate. With some of the polymers, spray spinning is aided by mixing the polymer with a melt depressant to

facilitate melting without decomposition.

Air will normally be employed as the attenuating gas for reasons of economy. Other gases, e.g., steam, nitrogen, helium, etc., are also suitable. Usually, the attenuating gas will be at ambient temperature. Heated gas, e.g., at a temperature of 250° to 500°C., may also be advantageously used, however.

It will be appreciated that the instant specification and examples are set forth by way of illustration and not limitation, and that various modifications and changes may be made without departing from the spirit and scope of the present invention.

We claim:

1. Apparatus for producing organic thermoplastic filamentary material comprising nozzle means having an extrusion orifice for fiber-forming material and a plurality of substantially rectangular gas outlet passages shaped so as to emit substantially planar gas streams, said gas outlet passages being spaced from said extrusion orifice and separated from said nozzle means by an insulating means, said gas outlet passages being so positioned with respect to the nozzle means such that: 1) the gas passages are closer to the axis of the extrusion orifice at the outlet end of the passage than at an interior zone of the passage so as to direct the gas stream in a convergence angle with the axis of the extrusion orifice of from about 5° to 45°, 2) no two of the planar projections of the gas outlet passages converge and intersect with the axis of the extrusion orifice at the same angle, and 3) planar projections of the gas outlet passages intersect at a point which is at a distance measured perpendicularly from the axis of the extrusion orifice at least equal to the diameter of the extrudate stream at a point along the extrudate stream in juxtaposition to the point of intersection of the planar projections of the gas outlet passages, and means for supplying said gas passages with gas under pressure to be projected from said passages to contact and attenuate the stream of fiber-forming material issuing from said extrusion orifice.

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