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(54) METHOD AND APPARATUS FOR PRODUCING FIBRES FROM HEAT-SOFTENABLE MATERIALS

(71) We, NIPPON SHEET GLASS CO LTD a Japanese Body Corporate of No. 8, 4-chome, Doshomachi, Higashi-ku, Osaka, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to a method of and an apparatus for producing fibers from a heat-softenable material such as glass, plastics and metals, and more specifically, to a method and an apparatus for producing fibers from a heat-softenable material which comprises heating the heat-softenable material to form a viscous melt and converting the melt into a fibrous form by the action of a high speed gas stream.

Fibers produced from a heat-softenable material, for example, glass fibers can be classified roughly into two types. One type is what is called short fibers which have a diameter of up to several tens of microns and a length of several millimeters to several hundred mm. Prior suggestions for the manufacture of these short fibers include, for example, (1) a method utilizing centrifugal force (a centrifugation method or a rotary method), (2) a method which comprises producing solid fibers from a viscous mass of a heat-softenable material, heating the fibers to render them viscous and at the same time blowing the fibers by a high speed gas stream to draw them (a blow method or flame method), and (3) a method which comprises directly rendering the heat-softenable material viscous, and blowing it by a high speed gas stream (a slit method or vertical blowing method).

Another type of fibers is what is called filaments or long fibers for use in reinforcing plastics which have a diameter of several microns to several ten microns and a large length. A drum wind-up method has been largely used for producing these long fibers.

The centrifugation method (1) comprises feeding a molten heat-softenable material to a rotating disc or spinner, and blowing away a filamentary substance which comes out from holes provided on the periphery of the disc or spinner by means of a high speed gas stream. This is thermoeconomically advantageous, but has the defect that the rotating part of the apparatus which is to be elevated to a high temperature is deteriorated rapidly, or the length of the resulting fibers is short.

The blow method (2) involves introducing primary fibers formed continuously into a high speed gas stream held at high temperatures thereby to heat-soften the primary fibers and at the same time, drawing the fibers by the high speed gas stream. This method can provide short-type fibers of good quality having a small diameter and a relatively large length (for short-type fibers). However, since the re-heat-softening and drawing of the primary fibers are carried out simultaneously by the high temperature high speed gas stream, the energy of motion required for the drawing of the primary fibers cannot be balanced with the thermal energy required for heat-softening. Thus, in order to impart the energy required for heat-softening (an especially high energy is required because the efficiency of heat transmission from the gas to the heat-softenable material is poor), fuel gas is required in an amount more than necessary to impart energy required for drawing. In order to remove this defect, an attempt was made to pre-heat the primary fibers immediately before introduction into the

high speed gas stream (for example, United States Patent No. 2,607,075). But the results obtained were not entirely satisfactory.

The slit method (3), as disclosed, for example, in United States Patent No. 2,626,424 and British Patent No. 605,943, comprises heating a heat-softenable material to allow it to flow freely, passing the free flow through a nozzle or slit, and applying a high speed jet stream of gas to the stream of heat-softenable material that flows through the nozzle or slit thereby to blow away the heat-softening material in the form of fibers. According to this method, heat efficiency is extremely good. But it has the defect that the stream of the heat-softenable material that flows through the nozzle or slit is divided by the high speed gas stream and becomes discontinuous, and consequently, the diameter of the resulting fibers becomes non-uniform to form a film (flaky), balls, or shots (thick fibers). In greater detail, a high speed gas stream to be jetted out onto a stream of material that flows out through a nozzle or slit is somewhat inclined to the stream of the material. The viscous heat-softenable material forms a conical shape at a part just apart from the tip of the nozzle or slit and the heat-softenable material in the form of fibers comes out from the tip of the conical shape. The size of the cone changes periodically with time to form a discontinuous flow. As a result, non-uniformity in the amount of flow occurs, and unfiberized masses such as those called shots, films or balls are generated. The following appears to be the reason for these defects. The heat-softenable material in the viscous state which has flowed from the nozzle or slit is carried away by the action of the high speed gas stream. But since the stream of the material is a free-flowing stream, and therefore is not a sufficiently continuous stream, variations occur in the rate of transfer of the material from the nozzle or slit with varying amounts being carried away intermittently by the action of the stream of high speed gas. Since at this moment, the amount of the material to be carried away by the high speed gas stream increases, fiberization is not sufficiently performed. After the large masses have been carried away, the material becomes absent, and the high speed gas stream does not act on the material. When the forward end of the stream of the material flowing reaches a part on which the high speed gas stream acts, the high speed gas stream acts on it again to carry away the material as a large mass. The above cycle is performed instantaneously. In order to prevent it, the force of the gas stream acting on the stream of the material must be weakened. But this, on the other hand, makes it difficult to perform the drawing of the material effectively, and affords thick fibers. At the same time, the amount of flow of the material is restricted, and the efficiency becomes poor.

Accordingly, it is a primary object of this invention to provide a method of and an apparatus for producing short fibers or long fibers from a heat-softenable material effectively without involving the defects of the prior art methods described hereinabove.

According to the present invention, there is provided a method of producing fibers from a heat-softenable material, which comprises heating the heat-softenable material in a melting crucible to form a viscous melt, and continuously flowing out the melt through a melt flow nozzle provided in said crucible; and jetting out at least three substantially straight-line high-speed gas streams disposed at intervals around the melt in its peripheral direction, each of said streams having a component in the tangential direction along the cross-section of the melt and a component which gradually approaches the central axial line of the melt toward the flowing direction of the melt and then gradually departs from the central axial line, toward the melt which has flown out, whereby the melt is rotated about its central axial line and formed into a substantially conical shape in a first zone which ranges from the flow-initiating part of the melt to the part at which the gas stream most closely approaches the central axial line of the melt, and in a second zone subsequent to the first zone, the melt is allowed to fly in a fibrous form from the tip of the conical shape in a vortex form in the flowing direction and outwardly in the radial direction, the distance between the outlet of the melt-flow nozzle and the focal point at which the high-speed gas streams most closely approach the central axial line of the melt being from 0.2 to 10 times the effective hole diameter of the melt-flow nozzle.

The invention also provides an apparatus for producing fibers from a heat-softenable material, said apparatus comprising a melting crucible having at least three flow-out nozzles for heating the heat-softenable material to form a viscous melt and flowing it continuously through the flow-out nozzles; and a gas jetting means for jetting out at least three substantially straight-line high-speed gas streams disposed at intervals around each flow-out nozzle in its peripheral direction, each of said streams being directed in a direction having a component in the tangential direction along the cross-section of the melt and a component which gradually approaches the central axial line of the melt toward the flowing direction of the melt and then gradually departs from the central axial line, toward the melt which has flown out, whereby in use of the apparatus the melt is rotated about its central axial line and formed into a substantially conical shape in a first zone which ranges from the flow-initiating part of the melt to the part at which the gas stream most closely approaches the

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central axial line of the melt, and in a second zone subsequent to the first zone, the melt is allowed to fly in a fibrous form from the tip of the conical shape in a vortex form in the flowing direction and outwardly in the radial direction, said flow-out nozzles being disposed close to each other so that when a circle with a radius of 10 mm is drawn about the center of each flow-out nozzle as a central point, at least three overlapping portions of these circles occur.

The invention will be further described, by way of example, with reference to the accompanying drawings, wherein:-

Figure 1 is a simplified sectional view for illustrating the basic concept of the method of this invention;

Figure 2 is a simplified bottom view for illustrating the basic concept of the method of this invention;

Figures 3 and 4 are schematic views showing the arrangement of nozzles for jetting out a gas;

Figures 5 and 6 are schematic views showing the relation between a melt which has flown in the form of fibers and a stream of gas;

Figure 7 is a diagram showing the effective diameter of a nozzle for jetting out the gas stream on the axis of abscissas and the drawn diameter of the nozzle on the axis of ordinates;

Figures 8-a, 9-a, 10-a and 11-a, are simplified sectional views of some embodiments of the apparatus of this invention;

Figures 8-b, 9-b, 10-b and 11-b are simplified bottom views of the apparatus shown in Figures 8-a, 9-a, 10-a, and 11-a, respectively;

Figures 12 and 14 are partial sectional views showing the relation between the shape of a gas stream jetting nozzle at its exit and a gas stream;

Figures 13-a and 13-b are a simplified sectional view and a simplified bottom view of an embodiment of the apparatus of the present invention;

Figure 15 is a schematic view showing the relation between the shape of a gas stream jetting nozzle at its exit and a gas stream;

Figures 16, 17 and 20 are simplified sectional views of embodiments of the apparatus of the present invention;

Figures 18 and 19 are partial sectional views showing the details of the shape of a gas stream jetting nozzle at its exit;

Figures 21-a and 21-b are schematic views for illustrating the drawing of a melt in fibrous form by means of a gas stream;

Figures 22-a to 22-d are schematic views showing arrangements of pluralities of melt flowing nozzles;

Figures 23-a and 23-b are a simplified sectional view and a simplified bottom view, respectively, of an embodiment of the apparatus of the present invention;

Figures 24-a and 24-b are a simplified sectional view and a simplified bottom view, respectively, of an embodiment of the apparatus of this invention;

Figure 25 is a sectional view in the longitudinal direction of a glass-fiber mat manufacturing apparatus equipped with the apparatus of this invention;

Figure 26 is a cross sectional view taken along the line A-A of Figure 25;

Figures 27-a and 27-b are a simplified sectional view and a simplified bottom view, respectively, of the apparatus of this invention used in the Examples;

Figures 28 and 29 are diagrams showing the temperature-viscosity relation of the heat-softenable materials used in the Examples;

Figures 30 and 31 are diagrams showing the relation among the temperature, the fiber diameter and the proportion of unfiberized mass;

Figures 32-a, 33-a and 34-a are simplified sectional views of embodiments of the apparatus of this invention used in the Examples; and

Figures 32-b, 33-b and 34-b are simplified bottom views of the apparatus shown in Figures 32-a, 33-a and 34-a, respectively.

Referring to Figures 1 and 2, the basic concept of the method of this invention for producing fibers from a heat-softenable substance is described.

Basically, the method of this invention comprises

(1) heating a heat-softenable material to form a viscous melt and flowing it continuously; and

(2) jetting out a specified high speed gas stream to the melt that has been flowed out.

Melting and flowing of the heat-softenable material are accomplished, for example as shown in Figure 1, by heating the heat-softenable material in a melting crucible 2 (a part of which is shown in the drawings) by a suitable known method to change it into a viscous melt 4, and then directly and continuously flowing the melt 4 through a nozzle 8 provided in the crucible by the weight of the melt and/or by pressure inside the crucible. Preferably, the

flow-out nozzle 8 is provided downwardly in the bottom wall 6 of the crucible, as shown. It may be provided in another direction in the bottom wall or side wall of the crucible so as to flow out the melt in any desired direction. It is preferred that the cross-sectional shape of the flow-out nozzle be circular and thus the melt 4 be flowed out from the crucible 2 with its cross-sectional shape being rendered substantially circular. Preferably, the diameter of the cross section of the melt immediately after flowing, which depends upon the viscosity and surface tension of the melt and the diameter of the nozzle or rod, is generally 0.5 to 10 mm.

Then, a high speed gas stream is jetted out onto the melt which has been flowed continuously from the flow-out nozzle 8. In the method of this invention, at least three straight-line high speed gas streams 12 which are jetted out from at least three nozzles 10 disposed at intervals peripherally around the flow-out nozzle 8 (Figure 2 shows only a hole 8a of the nozzle 8 and a hole 10a of the nozzle 10 in order to simplify the drawing) are jetted against the melt.

It is important that the gas stream to be jetted against the melt should contain a component in the tangential direction (the direction shown by arrow A in Figure 2) along the cross-section of the melt flowing from the nozzle 8, and a component (shown by arrows B in Figure 1) which gradually approaches the central axial line of the melt toward the flowing direction of the melt and then gradually departs from the central axial line.

By the action of the high speed gas stream described above, the melt is rotated about its central axial line, and formed into a substantially conical shape 4a whose section gradually decreases toward the flowing direction in a first zone 16 which ranges from the outlet port of the flow-out nozzle 8 to a part at which the gaseous stream most closely approaches the central axial line of the melt (point 14, to be referred to as a focal point). Where the central axial lines of the straight-line gas streams most closely approach the central axial line of the melt at different points on the central axial line of the melt, this focal point is the one at which an average of the distances between the central axial lines of the gaseous stream and the central axial line of the melt becomes minimum.

In the first zone 16, at least three straight-line high speed gaseous streams 12 which act on the surface of the melt that has been flowed out have a component in the tangential direction (the direction shown by arrow A in Figure 2). Hence, a rotating moment in the direction shown by arrow C in Figure 2 acts on the melt, and causes the melt to rotate in the direction of arrow C around the central axial line of the melt. Furthermore, since in the first zone 16, the high speed gaseous stream also has a component in a direction (shown by arrow B in Figure 1) gradually approaching the central axial line of the melt toward the flowing direction of the melt, the melt is restrained so that its cross section gradually decreases toward its flowing direction, whereby it is formed into a conical shape 4a which is tapered toward the flowing direction. It will be readily understood that the rotating angular speed of the melt being rotated gradually increases towards the flowing direction of the melt.

Preferably, the conical shape of the melt formed in the first zone 16 is such that its diameter at its smallest end is 0.1 to 1 mm. Experiments of the inventors led to the confirmation that if the distance between the outlet of the nozzle 8 and the smallest end of the cone is too large, the flowing melt is likely to become discontinuous to form unfiberized masses, and therefore, this distance is adjusted to not more than 10 times the effective inside diameter of the flowout nozzle 8. On the other hand, these experiments show that if the above distance is too small, the melt which has flowed from the nozzle 8 immediately flies away in the tangential direction and can not possibly form a stable cone, and therefore, this distance is required to be larger than 20% of the effective inside diameter of the nozzle 8.

In a second zone 18 subsequent to the first zone 16, the melt continuously flows as a fiber from the tip of the cone in the flowing direction and outwardly in the radial direction in a vortex form 4b which is spiral or helical or both. As a result of the flying of the melt from the tip of the cone 4a as one fiber, a pulling force in the flowing direction of the melt acts on the cone 4a, and is transmitted to the melt within the crucible 2 to promote the flowing of the melt through the nozzle 8. Thus, the amount of the melt lost from the cone as a result of the flying out of one fiber from its tip is made up for by a fresh flow of the melt. Consequently, the cone 4a is maintained stably and continuously without the flowing of the melt from the nozzle 8 becoming discontinuous. On the other hand, the melt 4b flown in the form of fiber from the tip of the cone 4a undergoes a pulling force by the force of inertia of its rotation in a vortex and the high speed gas stream acting on it, and is thereby drawn and attenuated.

Stated in more detail, the component shown by arrow B in Figure 1 of the high speed stream 12 departs from the central axial line of the melt toward the flowing direction of the melt in the second zone 18, and therefore, no restraining force is exerted on the melt which will decrease its cross sectional area, but a force which will diffuse the melt acts. The end of

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the cone 4a is still rotating at a high speed. As a result, the melt flies out from the end of the cone 4a because of centrifugal force, and the fibrous melt that has flown away is accelerated by the action of the high speed gas stream. When the melt is slightly deviated in a certain direction from the rotating axial line of the melt by centrifugal force, a still greater centrifugal force acts on that part of the melt which has deviated, and this part flies away in a deviated direction. This is the beginning of flying of the melt. The fibrous melt which has thus flown away is accelerated by a component in the tangential direction (the direction shown by arrow A in Figure 2) and a component in the direction departing from the central axial line of the melt toward the flowing direction of the melt (the direction shown by arrow B in Figure 1).

Then, the melt at the cone 4a which is continuous to the fibrous melt which has flown away beyond the tip of the cone is subsequently dragged beyond the cone tip by the influence of the fibrous melt which has flown away. Since the end of the cone 4a is still rotating, the manner of flying changes continuously in the rotating direction. Consequently, one continuous fiber of the melt 4b flies in a vortex shape from the end of the cone 4a. The fibrous melt 4b which has flown away is accelerated by the high speed gas flow, and thereby drawn and attenuated. Thus, depending upon the extent of the drawing action of the high speed gaseous stream, continuous long fibers having a diameter of 10 to 100 microns, or short fibers having a diameter of 0.1 to 20 microns can, for example, be produced.

If required for the drawing and attenuating of the fibers, a separate high speed gas stream may further be applied to the melt that has flown away, in addition to the above-mentioned high speed gaseous stream.

The centrifugal force and the pulling force caused by the high speed gaseous stream which act on the fibrous melt in the second zone 18 are transmitted to the conical melt in the first zone 16. These forces are transmitted also to the melt within the flow-out nozzle 8 and the crucible 2. This promotes the flowing of the melt from the flow-out nozzle 8. Thus, the melt which is lost as a result of the flying of it from the end of the cone 4a is made up for by a fresh flow of the melt, and the conical shape 4a is stably maintained.

It is not altogether necessary to maintain the above gas stream at a high temperature. Preferably, it is maintained at a temperature at which the melt can be drawn as desired, for example, at a temperature of 500 to 1,500°C for glass. The preferred flow speed of the gaseous stream is 200 to 1,000 meters/sec. Examples of the gas are high pressure air, high pressure steam, and the products of combustion of gases.

According to the method described above, fibers of high quality can be produced at a high energy efficiency. The inventors further discovered that various factors exert various effects on the quality of the resulting fibers and the efficiency of production.

(a) Effective hole diameter for flow out of the melt-flowing nozzle 8:-

In order to sufficiently draw the melt which has flown away in fiber form in the second zone 18, it is important to rotate the tip of the cone at high speeds. When a plurality of straight-line high speed gas streams 12 are jetted out, the speed of rotation at the end of the cone (n in times/sec.) is expressed by $n = kv/2\pi r_0$ in which v is the component in the tangential direction of the speed of the gaseous stream, r_0 is the average of the distances between the central axial lines of the gas streams and the central axial line of the melt at focal point 14 (the drawn radius), and k is the coefficient of sliding. Accordingly, in order to increase the number of rotations (n) it is advantageous to maximize k and v and minimize r_0 . Since generally the component in the tangential direction of the speed of the gas stream (v) is nearly equal to the sonic velocity and is thus constant, it is necessary to decrease r_0 and increase k . There is a limit to r_0 since if it is decreased too much, gas streams collide with each other to generate a disturbed flow, thus failing to form a stable conical shape. Thus, the coefficient of sliding must be maximized. The value k is the ratio of the speed of the melt to the speed of the gaseous stream, and becomes smaller if the force which acts to prevent the rotation of the melt by the action of the gas stream is greater. In the feasible operating range, k is 0.01 to 0.05. Hence, increasing of the k value is very effective. It would be effective to reduce the viscosity of the melt or to decrease the diameter of the cross section of the flowing melt when it is desired to increase k while maintaining r_0 and v constant. We therefore attempted to reduce the viscosity of the melt while maintaining the diameter of the section of the melt immediately after flow out at a constant value of, say 3.0 mm, but found that since the viscosity of the melt is low in spite of the large diameter of the melt flow and the high torsion resistance due to rotation, the downstream part of the melt is blown away by the gaseous stream, unfiberized masses such as beads or flakes occur in great quantities, leading to the difficulty of forming fibers of good quality. We have also found that when the diameter of the melt at its section is adjusted to not more than 2.5 mm, preferably not more than 2 mm, the torsion resistance of the melt due to its rotation becomes exceedingly low, and therefore, phenomena such as splitting or blowing of the melt by the gaseous stream do not easily occur; and that the viscosity of the melt can be reduced to

30 to 50 poises, and the torsion resistance due to the rotation of the melt becomes even lower. The diameter of the melt that has flowed out is defined by the effective hole diameter d_2 of the flow-out port of the flow-out nozzle 8 (obtained by dividing the product of the cross-sectional area of the hole multiplied by 4, by the length of the circumference). It was found therefore that preferably this effective hole diameter is adjusted to not more than 2.5 mm, especially not more than 2.0 mm (see Example 1 appearing hereinbelow).

Reduction of the effective hole diameter d_2 of the flow-out nozzle 8 means that the amount of the melt flowing through the nozzle is restricted. This also means that the output of fibers per unit time of fiber-forming operation is limited. It is undesirable therefore to decrease the effective hole diameter d_2 too much. In this sense, too, it is desirable to set the lower limit of the effective hole diameter at 0.5 mm. Of course, fibers of good quality can be obtained even if the effective hole diameter is less than 0.5 mm. In order to increase the amount of flow of the melt, the depth of the crucible is increased, or the inside of the crucible is pressurized so that a pressure of at least 25 cm aq., preferably at least 40 cm aq., is obtained at the outlet end of the flow-out nozzle.

(b) Viscosity of the melt:-

Heat-softenable materials that can be fiberized by the method of this invention are, for example, glass, metals and plastics. When it is desired to make fibers having a diameter of 4 microns or less, controlling of the viscosity of the heat-softenable material is extremely effective for rendering the fiber diameter finer and reducing the amount of unfiberized masses (flakes, balls or shots) (see Examples 2 to 4 appearing hereinbelow).

When the viscosity of the melt immediately before rotation by the gas stream in the first zone 16 exceeds 200 poises, the rotation of the melt does not proceed at high speed because of the viscous resistance and it is difficult to draw the fibers efficiently. Furthermore, in this case, the drawing resistance is too high when drawing the melt in the second zone, and it is difficult to adjust the fiber diameter to not more than 5 microns.

On the other hand, when the viscosity of the melt becomes less than 10 poises, the melt is blown off by the high speed gas stream in the first zone and/or the second zone, and the proportion of fibers having the desired length decreases extremely, and the proportion of unfiberized masses such as balls or flakes becomes higher. The especially preferred viscosity of the melt is 50 to 100 poises. Within this viscosity range, a stable cone can be obtained in the first zone, and drawing can be performed efficiently in the second zone.

The viscosity of the melt immediately before the initiation of the rotation by the gas stream can be controlled by adjusting the temperature of the melt, for example by controlling the temperature of the pot for the melt or the nozzles.

(c) Inclination of the gas stream to the central axial line of the melt:-

As stated hereinabove, at least three straight-line gas streams are jetted out onto the melt which has flowed continuously from the flow-out nozzle 8. On the other hand, it is necessary that the gaseous stream to be jetted out onto the melt has a component in the direction shown by arrow B in Figure 1 (a direction inclined by some angle to the central axial line of the melt) as well as a component in the direction shown by arrow A in Figure 2. It has been found that when at least three straight-line gas streams are used, they preferably form an angle of 20 to 70°, especially 35 to 55°, in the direction shown by arrow B in Figure 1 with respect to the central axial line of the melt. When the angle of inclination is less than 20°, the force of pulling the melt directly in its advancing direction becomes stronger than the force to rotate the melt. This results in a tendency to the splitting of the melt and to the occurrence of unfiberized masses such as balls, shots or flakes. If the angle of inclination is more than 70°, the gas streams which have left the jet nozzles 10 spread as they advance, and as a result, collide with each other. Thus, the advancing of the gas streams is impeded, and a disturbed flow occurs to prevent the melt from advancing smoothly. In order to overcome these difficulties, the angle of inclination of the gas streams to the central axial line of the melt is preferably 35 to 55°.

(d) Arrangement of high speed gas jet nozzles using at least three straight-line high speed gas streams:-

In order to rotate the cone 4a of the melt around the central axial line of the melt as desired in the first zone 16 by jetting out at least three straight-line high speed gas streams, it is important to arrange jet nozzles 10 symmetrically about the central axial line of the melt. Accordingly, when three jet nozzles 10 are used, it is important to arrange the three jet nozzles 10 at equal intervals as shown in Figure 2 (the angle of any two adjoining jet nozzles being 120°). It has been found, however, that when more than three jet nozzles 10 are used, the jet nozzles are preferably arranged so that at least two angles formed between the adjoining jet nozzles 10 are 95 to 135° without disposing them at equal intervals although they are rotatingly symmetrical with respect to the central axial line of the melt. This facilitates the effective drawing of the melt 4b which has flown away in the form of fibers in the second zone 18. For example, when four jet nozzles 10 are used, they are

preferably arranged so that as shown in Figure 3, two angles θ_1 become 95 to 135° (the other angles θ_2 being 45 to 85°). When six jet nozzles are used, they are preferably disposed so that three (or two) angles θ_1 become 95 to 135°.

This may be ascribed to the following reason. Figure 5 is a view which illustrates the melt 4b which has flown in fiber form in the second zone 18 and the high speed gas streams 12, and in which t_1 shows the state of the fibrous melt 4b at a certain time, t_1 its state after a lapse of Δt seconds, and t_2 its state after a lapse of $2\Delta t$ seconds. The fibrous melt 4b, before entering one of the gas streams 12, advances in the radial direction by the force of inertia of rotation which it possesses. When it enters one of the gas streams, its forward end is situated outwardly of the central axial line of the gas stream 12 as shown at t_1 , and the part subsequent to it crosses the gas stream 12. On the other hand, the gas stream 12 is highest in speed at its center, and as it goes farther away from the center, the speed becomes lower. Accordingly, the fibrous melt 4b which crosses the gas stream 12 undergoes the action of the fastest gas stream at the part situated at the center of the gas stream 12, and therefore, is advanced most downwardly. The part of the melt which is apart from the center of the gas stream in the radial direction undergoes the action of a gas stream having a lower speed, and is advanced to a lesser extent downwardly. Hence, the fibrous melt 4b which enters the gas stream 12 and crosses it is advanced to the greatest extent at that part which has entered the center of the gas stream 12, and is advanced to a lesser extent downwardly at the part which is further forward or rearward of that part. By this difference in displacement, the fibrous melt 4b is drawn. This is the same when the melt has passed one of the gas streams 12 after a lapse of $6\Delta t$ seconds and enters the next gas stream 12. It is presumed therefore that the fibrous melt 4b which has flown from the end of the cone 4a advances along the locus illustrated in Figure 6.

If, however, the angle formed between two adjacent gas streams is less than 95°, the fibrous melt 4b which has passed one of the gas streams cannot advance over a sufficient distance outwardly in the radial direction before it enters the next gas stream. Hence, when it enters the next gas stream, the forward end of the fibrous melt 4b is located inwardly of the center of the gas stream, and the fibrous melt 4b has not sufficiently crossed the gas stream, but only the forward end of the fibrous melt 4b has entered the gas stream in part. For this reason, the fibrous melt 4b cannot sufficiently receive the displacement difference, and cannot be sufficiently drawn.

If the above angle is more than 135°, there is a tendency that the gas stream 12 cannot form the melt into a conical shape 4a and rotate it in good condition.

(e) Relation between the "effective hole diameter" of gas jet nozzle and the "drawn diameter" of the gas stream and relation between the "blow-out diameter" defined cooperatively by a plurality of gas jet nozzles and the "drawn diameter" of the gas stream:-

The gas stream 12 has a different speed distribution from place to place in its section. But when the central axial line of the gas stream is defined as a line which extends through the center of that part of the gas stream which has the highest flow speed and the greatest density of motion energy, it is approximately equal to the extension of the central axial line of the gas jet nozzle 10 (when the nozzle 10 is not straight, but curved, the extension of the tangential line to the center line of the nozzle at the outlet of the nozzle). If the distance between the central axial line of the melt and the central axial line of the gas stream at the focal point 14 (if this distance differs from gas stream to gas stream, an average value is determined) is the drawn radius and the value obtained by doubling it is "drawn diameter", the drawn diameter equals the diameter of a circle that inscribes the central axial lines of a plurality of gas streams at the focal point (or the average of the long diameter and the short diameter of an ellipse). Let the flow speed of a gas stream leaving the gas jet nozzle 10 be V , the number of rotations per second of the conical melt 4b be n , the coefficient of sliding be k , and the drawn diameter be D_2 , $n = kV/\pi D_2$. Hence, if the drawn diameter D_2 is decreased, the number of rotations increases. Consequently finer fibers can be produced in larger amounts per unit time. When D_2 increases, the force to confine the melt within a conical shape becomes weak, and a stable cone of the melt cannot be obtained. Accordingly, it is preferred to adjust D_2 to not more than 7 mm. If the D_2 value is made too small, gas streams collide with each other because they have a certain size. As a result, an undesirable disturbance of gas stream occurs to splash off the melt. Hence, there is an optimal relation between the effective hole diameter d_1 and the drawn diameter D_2 which determine the size of the gas stream which is required to obtain a stable cone of the melt. Preferably, a combination of the effective hole diameter d_1 and the drawn diameter D_2 is selected from the area surrounded by five straight lines as shown in Figure 7 (see Example 5). The effective diameter d_1 is expressed by the equation $d_1 = 4S/l$ wherein S is the cross sectional area of the outlet of the gas jet nozzle 10 and l is the length of the periphery. Thus, where the cross sectional area of the jet nozzle outlet is circular, d_1 equals the diameter of this circle.

The hatched area in Figure 7 is obtained by plotting the effective hole diameter d_1 in mm on the axis of abscissas X and the drawn diameter D_2 in mm on the axis of ordinates Y, and connecting points (0,0), (3.0, 5.3), (3.0, 7.0), (2.4, 7.0) and (0,2.0) successively by a straight line.

5 The effective hole diameter d_1 is difficult to decrease to less than 0.05 mm because of restrictions on working precision. When d_1 is at least 0.05 mm, the drawn diameter D_2 is preferably at least 0.1 mm. If the effective hole diameter d_1 becomes too large, the amount of the gas used increases uneconomically. Preferably, therefore, d_1 is not more than 3 mm.

10 If the average distance between the centers of the outlets of at least three gas stream jet nozzles 10 and the central axial line of the melt, multiplied by 2, is defined as the "blow-out diameter", larger blow-out diameters D_1 have the same effect as would be obtained when the effective hole diameter d_1 becomes larger. This is because the gas stream 12 gradually increases in cross sectional area after being jetted out from the jet nozzle 10. For this reason, disturbance of the gas stream tends to occur unless the drawn diameter D_2 is adjusted to at least 1/10 of the blow-out diameter D_1 . Furthermore, as mentioned above, the gas stream must gradually approach the melt after being jetted out, and therefore, it is necessary that the blow-out diameter D_1 is larger than the drawn diameter D_2 . Accordingly, the blow-out diameter D_1 must be less than 10 times, preferably 1.3 to 3.0 times, the drawn diameter D_2 .

20 (f) Length of the gas stream jet nozzle:—

In order to form the melt into a stable conical shape 4a in the first zone 16, and cause it to fly from the tip of the cone 4a as a continuous filamentary melt 4b in the second zone 18, at least three straight-line gas streams should not collide with each other to such an extent that the collision impedes a smooth advance of the melt. Preferably, they collide with each other as a mass at a position several centimeters below the focal point 14 within the second zone 18.

25 The gas streams described above form a so-called "eye of typhoon", and the center of the vicinity of the focal point 14 is at a lower pressure than the surrounding parts, whereby the melt is sucked from melt-flowing nozzle 8 to form a stable conical shape 4a within the first zone 16. When the gas streams enter the second zone 18 and collide with each other at a position several centimeters below the focal point, the turbulent flow resulting from the collision is sufficiently remote from the cone 4a, and therefore, does not disturb the formation of stable cone 4a. The gas streams which have collided with each other in the vicinity of the above-mentioned position form a mass and further by their combined forces draw the fibrous melt 4b which has entered the gas streams upstream of the second zone. Therefore, finer fibers can be obtained more effectively.

30 If the gas streams collide with each other too strongly near the focal point 14, the pressure at the center near the focal point 14 decreases to a lesser extent as compared with the pressure of the surrounding part. Thus, the force to withdraw the melt from the nozzle 8 becomes weak and unstable, and this leads to a tendency that a cone is not formed stably. When the drawn diameter is increased so that the gas streams do not collide with each other near the focal point 14, the rotating speed which is imparted to the fibrous melt 4b at the beginning of the second zone 18 decreases. This means that the number of rotations to be given to the fibrous melt 4b is smaller, and the centrifugal force becomes weak. Consequently, the force to withdraw the filamentary melt from the end of the cone is weak, and the amount of the melt flowing decreases.

35 This tends to occur when the diverging (diffusing) angle of the gas stream 12 is large. Preferably, therefore, gas streams jetted out from the gas jet nozzles 10 are those which spread to a lesser extent with a smaller diverging angle. The spreading of the gas stream 12 is closely related to the shape of the gas jet nozzle 10, and particularly with the ratio of the effective diameter of the nozzle to the length of the nozzle.

40 We have found in this connection that the length l of the nozzle 10 (see Figure 1) is preferably at least 5 times the effective hole diameter d_1 of the nozzle 10 (see Example 6).

45 The nozzle length l denotes the shortest length from the gas inlet to the outlet of a nozzle which is measured in the advancing direction of the gas stream within the nozzle.

50 When the ratio of the length l to the effective hole diameter d_1 of the gas jet nozzle 10 is less than 5, the diffusion angle of the gas stream jetted out from the nozzle increases, and the gas streams jetted out from the nozzles tend to collide strongly near the focal point 14, thus causing the above-mentioned defect.

55 When the ratio of the length l to the effective hole diameter d_1 of the nozzle 10 is adjusted to at least 5, the diffusion angle of the gas streams 12 jetted out from the nozzle can be decreased, and therefore, a stable cone can be formed. Moreover, a strong rotating force can be imparted to it, thus making it possible to attenuate the melt with good efficiency. There is no particular upper limit to the ratio of the nozzle length l to the effective hole diameter d_1 , but if it is too high, a pressure drop of the gas increases, and a working difficul-

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ty is involved. Preferably, the upper limit is set at 20, particularly at 10.

Some specific embodiments of the apparatus for performing the above method of this invention are described hereinbelow.

The apparatus shown in Figures 8-a and 8-b includes six burners 108 for jetting out a high-temperature high-speed gas which are disposed at equal intervals around a melt-flowing nozzle 8. The high-temperature high-speed gas streams jetted out from nozzles 10 of the burners 108 are directed obliquely and downwardly at a part just below the tip of the nozzle 8 in a manner such as to squeeze the melt flow. At a position where the melt flow is most squeezed, the center lines of the gases pass $3/4$ to $7/8$ of the diameter of the melt which has just been flowed out from the melt-flowing nozzle 8, as shown in Figure 8-b.

The inside of the burner 108 has such a structure that a fuel and compressed air are jetted out respectively through conduits 111 and 112 into combustion chamber 113 to burn the fuel and to jet out the resulting high-temperature high-speed gas. The surround of the combustion chamber is cooled by cooling water flowing through a conduit 109 and a discharge pipe 110. The burners 108 are disposed so that the focal point is situated at a distance about twice the inside diameter of the melt-flowing nozzle 8 from the lower end of the melt-flowing nozzle 8.

The apparatus shown in Figures 9-a and 9-b includes burners 114 for jetting out a high-temperature high-speed gas stream which is equipped with a ring-like combustion chamber 103 and six nozzles 10 for jetting out the high-temperature high-speed gas streams one end of each nozzle 10 being communicated with the combustion chamber. The jet nozzles 10, like the jet nozzles shown in Figures 8-a and 8-b, are arranged so that the high-temperature high-speed gas streams that have been jetted out are directly obliquely downwardly in such a manner as to squeeze the flow-out melt immediately below the tip of the melt-flowing nozzle 8, and at a position where it is most squeezed, the central lines of the gas streams pass $3/4$ to $7/8$ of the diameter portion of the melt which has just been flowed out from the melt-flow nozzle 8.

The apparatus shown in Figures 10-a and 10-b include three of the same burners 108 illustrated in Figures 8-a and 8-b, and three drawing burners 121 whose structure is the same as the burners 108. The melt which has been formed into a fibrous shape by the action of the gas stream from the burners 108 flies away ahead of the focal point, and is attenuated into fine fibers by the action of the high-temperature high-speed gas streams jetted out from the drawing burners 121. As shown, the drawing burners 121 are located between the burners 108.

When six burners are used, the arrangement shown in Figures 10-a and 10-b is more effective for rendering the diameters of the resulting fibers uniform than the arrangement shown in Figures 8-a and 8-b. Furthermore, in order to render the fiber diameters uniform, it is more effective to build the outlets of the jet nozzles of the drawing burners 121 in a flattened shape so that the gas streams jetted out from there may sufficiently cover the gas streams from the burners 108.

In the apparatus shown in Figures 11-a and 11-b, a melt-flowing nozzle 8 and gas jet nozzles 10 are formed in the bottom wall 203 of a crucible for melting a heat-softenable material. In this apparatus, from the feeder 208 the heat-softenable material to be fiberized is placed into a material hopper 224 in the upper part of the crucible 2, and through air-tight dampers 206 and 207, reaches a melting section 201 of the crucible 2. The crucible 2 is closed by either of the dampers 206 and 207 and maintained air-tight. The pressure of the inside of the crucible is maintained at a suitably elevated pressure by connecting a pipe 212 including a pressure-control valve 213 and a pressure gauge 211 to a bomb 214 containing an inert gas such as nitrogen or argon. This pressure also serves to control the amount of flow of the melt which flows out from the melt-flow nozzle 8. The crucible 2 is made of heat resistant steel and includes a relatively thick bottom wall 203 made of heat-resistant steel. At the bottom wall 203 a melt-flow nozzle 8 and gas jet nozzles 10 are formed. The gas fed into the gas jet nozzles 10 passes through a pipe 225 connected to a gas-generating source (not shown), a pressure-control valve 221 and a pressure gauge 220, and via a gas heating section 219, is heated to a temperature of about $1,100^{\circ}\text{C}$, and reaches the bottom wall 203. From holes 218 and 217, the heated gas stream is fed into the gas jet nozzles 10. The gas heating apparatus 219 has a combustion chamber 226 surrounding conduits through which the gas passes, and heats the gas by the combustion of a fuel from a burner 222. The combustion exhaust gas is discharged from an exhaust pipe 223. On the other hand, the crucible 2 is surrounded by a refractory material which forms a combustion chamber 210. The heat-softenable material within the crucible is heated to about $1,250^{\circ}\text{C}$ by the combustion of a fuel gas blown into the combustion chamber 210 by a burner 202. The combustion exhaust gas is released from a chimney 209.

In an apparatus of such a structure, the melt-flow nozzle 8 and the gas jet nozzles 10 are provided in the bottom wall of the crucible. Hence, the structure is compact, and has the

advantage that it is not necessary to register the positions of the melt-flowing nozzle 8 and the gas jet nozzles 10. Furthermore, since the amount of the melt flowing can be controlled by adjusting the internal pressure of the crucible, even when the diameter of the melt-flowing nozzle 8 becomes thicker as a result of corrosion, it can be compensated.

The embodiments of the apparatus of this invention described hereinabove with reference to Figures 8-a and 8-b to 11-a and 11-b can produce fibers of high quality from heat-softenable materials at a considerably high energy efficiency. By making the following improvements these apparatuses can give fibers of even higher quality at a higher energy efficiency.

(a) Improvement of the shape of the outlet part of the gas jet nozzle in an apparatus equipped with at least three gas jet nozzles for jetting out straight-line gas streams:-

Generally, a straight-line high-temperature high-speed gas stream jetted out from gas jet nozzle 10 gradually diverges into a conical shape after it has left nozzle 10. On the other hand, the outlet of gas jet nozzles 10, illustrated, for example, in Figures 8-a and 8-b and 9-a and 9-b cross the central axial line of the jet nozzle (i.e., the gas stream advancing direction within the jet nozzle) at right angles thereto, and have a circular cross section. For this reason, the gas stream 12 from nozzle 10, as shown in Figure 12, diverges symmetrically with respect to the extension of the central axial line of the jet nozzle 10 as a center. As shown in Figure 12, the gas stream 12 that has been jetted out has a central stream 13 having a high density energy and an accompanying stream 15 having a relatively low density energy. To bring the outlet of the gas jet nozzle 10 as close as possible to the melt 4a flowing from the melt-flowing nozzle 8 (Figure 1) is preferred because it results in an increase in the rotating speed of the melt and a decrease in the diameter of the resulting fibers. However, if the outlet of the nozzle 10 is caused to approach too closely to the melt 4a, not only the accompanying stream 15 which serves for the rotation of the melt, but also the central stream 13 collide with the melt 4a, and it is difficult to form a stable cone of the melt. Accordingly, this leads to the defect that the fibers which have flown from the end of the cone and are drawn contain unfiberized masses such as beads or flakes. When the central axial line of the gas jet nozzle 10 is inclined downwardly and excessively apart downwardly from the outlet face of the melt-flow nozzle 8 in an attempt to prevent the central stream 13 of the gas stream 12 from directly contacting the cone 4a, the position at which the accompanying stream 15 of the gas stream acts on the melt moves downwardly, the length of the heat-softenable material after flowing out becomes excessively large, and its advancing becomes discontinuous. Thus, stable continuous filaments cannot be formed, and lumps of the melt, called shots, are prone to occur. Theoretically, the length of the heat-softenable material after flow out would become smaller to obviate the defect if the gas jet nozzle 10 is inclined more downwardly to bring it closer to the melt-flow nozzle. In actual operation, this is difficult.

The above defect can be remedied by cutting away a part of the inner wall in the vicinity of the outlet of gas jet nozzle 10 which is farther from the flow-out melt 4a. In the apparatus shown in Figures 17-a and 17-b, the inner wall is cut out at a part farther from the melt-flowing nozzle 8. The outlet of the jet nozzle 10, as shown in Figure 13-b, is an ellipse elongated in the radial direction from the central axial line of the flow-out melt 4a. Hence, the compressed gas stream which has passed through the gas jet nozzle is released into a fiber blowing atmosphere faster at its outer peripheral portion than at its inner peripheral portion, and becomes an expanded gas stream. Thus, at the outlet of the gas jet nozzle, the gas stream 12 is jetted out deviatingly outwardly as shown in Figure 14, as compared with the case of Figure 12.

The gas stream which has been jetted out from the gas jet nozzle is schematically shown in Figure 15 at its section perpendicular to the central axial line of the melt at a position (focal point) closest to the melt. In Figure 15, the reference numeral 4a represents the melt, and portions 13 and 15 surrounded by a solid line show the central stream and the accompanying stream of the gas stream when the outlet end surface of the jet nozzle is perpendicular to the central axial line of the jet nozzle and its section is circular (Figure 12). Portions 13 and 15 surrounded by a dotted line show the central stream and the accompanying stream of the gas stream when that part of the inner wall of the outlet of the jet nozzle which is farther from the melt 4a is cut away (Figure 14). In the former, the central stream 13 is relatively close to the melt, but in the latter, the position of the accompanying stream near the melt remains the same while the central stream is considerably remote from the melt as compared with the original position. In the former, the formation of a stable cone of the melt is prone to be impeded by the approaching central stream 13. But in the case of the latter, the central stream departs from the melt, and therefore, the formation of a stable cone of the melt is not impeded.

A fibrous melt 4b flies from the end of the conical melt 4a rotated by the accompanying stream 15, and rotates about the end of the cone as a center. By the effect of the centrifugal

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force, the fibrous melt 4b enters the central stream 13 of the gas stream 12, and is drawn downwardly to a remote place to become fibers having the desired fine diameter.

When the fibrous melt 4b is drawn by the central stream, the drawing action is performed to a greater extent when the central stream is apart from the central axial line of the melt than when it is close to the central axial line, and therefore fibers having a smaller diameter can be obtained. The reason for this additional advantage has not yet been elucidated, but is presumed to be as follows: The fibrous melt 4b delivered from the end of the cone 4a of the melt is of a tapered shape which gradually becomes finer as it departs from the central axial line of the melt. In the latter case where the fibrous melt 4b enters the central stream of the gas stream at a portion which is relatively fine, a stronger drawing action will be exerted than in the case of the former wherein it enters the central stream at a portion which is relatively thick.

This is more effective when the melt-flow nozzle 8 and the gas jet nozzle 10 are formed in an integral unit 28 (usually the bottom wall of a crucible) (the apparatus shown in Figures 11-a and 11-b). In this case, as shown in Figure 16, no space exists between the melt-flow nozzle 8 and the gas jet nozzle 10 unlike the case where the nozzle 8 and the nozzle 10 are made of different pieces. Furthermore, the thicknesses of both nozzles can be used conjointly, and they can be brought very close to each other.

When the nozzles are brought closer to each other, there is more likelihood that beads and flakes will be generated owing to the local contact of the central stream of the gas stream with the flow-out melt 4a. But by cutting away that part of the outlet portion of the nozzle 10 which is apart from the melt to form a substantially elliptical outlet, the central stream 13 can be deviated towards that side which is farther away from the melt-flowing nozzle 8 while maintaining the accompanying stream 15 on that side which is nearer the melt. This ensures the production of fibers substantially free from the above defects.

Figure 17 shows an example where a hole having a central axial line which forms an angle of 45° with the gas jet nozzle 10, the same hole diameter as the gas jet nozzle 10 (for example, a diameter of 1 mm), and a central axis at a point farthest from the melt-flow nozzle 8 at the outlet end of the gas jet nozzle 10 is provided so as to cut away that part of the inner wall in the vicinity of the outlet of the gas stream jet nozzle 10 which is farther from the melt. Figure 16 shows an enlarged view of the outlet portion of the gas jet nozzle.

Preferably the inner wall in the vicinity of the outlet of the gas jet nozzle is cut away at a portion which is farthest from the melt and is detracted along the central axial line of the gas jet nozzle by a distance x which is $1/5$ to 2 times the diameter of the nozzle d , as shown in Figure 19. Or it is preferred that the inner wall be cut away in a direction apart from a cylindrical stream of the melt by the distance y which is the same as distance x , as shown in Figure 18.

(b) Projecting length of the melt-flowing nozzle in an apparatus in which a melt-flowing nozzle and a gas jet nozzle are formed in separate members:-

The apparatus of this invention for producing fibers from heat-softenable materials are classified into a separate-type in which the melt-flow nozzle and the gas jet nozzle are formed in separate members as shown in Figures 8-a and 8-b to Figures 10-a and 10-b, and an integral type in which the two nozzles are formed in one member (for example, in the bottom wall of a crucible) as shown in Figures 11-a and 11-b.

In the separate-type apparatus, the outlet of the gas jet nozzle 10 is brought as close as possible to the melt-flow nozzle 8 fitted to the bottom wall 5 of crucible 2 in fitting a gas flow jet burner in an attempt to use the energy of the jet gas stream effectively. Hence, the length of the melt-flow nozzle 8 ranging from the bottom wall of the crucible to the tip (to be referred to as the length of the melt-flow nozzle) is determined approximately by the size (thickness) of the gas jet burner.

When a high viscosity heat-softenable material such as glass is made into fibers, a crucible made of a thermally stable metal such as a platinum-rhodium alloy is used, and an electrical current of high current and low voltage is applied to both end edges of the crucible to heat the crucible. However, since the melt-flowing nozzle projects from the bottom wall of the crucible, electric current is difficult to flow therethrough, and heat is hardly generated. Hence, the temperature of the melt-flow nozzle must be maintained at a suitable point by heat transmission between the melt and thermally stable metal. However, the forward end of the melt-flow nozzle becomes lower in temperature as the nozzle length becomes larger. For example, when the nozzle length is 10 mm and the temperature of the bottom wall of the crucible is about $1,000^\circ\text{C}$, the temperature of the forward end of the nozzle becomes at least 100°C lower than the crucible bottom.

When fibers having a diameter of about 4 microns or less are to be formed using such a material as glass, metal or plastics, the viscosity of the heat-softenable material which has just been flowed out from the nozzle must be adjusted to 10-200 poises, preferably 50-100 poises, in order to render the fiber diameter finer and reduce the amounts of unfiberized

masses (such as flakes, balls, or shots). It is important therefore how efficiently the viscosity of the heat-softenable material at the outlet of the melt-flowing nozzle should be adjusted to the above range.

In view of the above fact, it has been found important to reduce the thickness of the gas jet burner to not more than 10 mm thereby to shorten the length of the melt-flow nozzle to not more than 10 mm, and to reduce the temperature drop from the undersurface of the bottom wall of the crucible to the forward end of the melt-flow nozzle.

As previously stated, in order to utilize the energy of the gas stream after jetting out from the jet nozzle effectively, and to draw the melt with good efficiency, it is desirable to maintain the diffusion angle of the gas stream after jetting out at a constant value by adjusting the length of the gas jet nozzle to at least 5 times as large as its effective hole diameter.

Accordingly, it is important to reduce the size of the gas jet nozzle under the above-mentioned conditions.

As one method, the inventors have contrived the shape of the combustion chamber (hollow part) of the gas jet burner as shown in Figure 20. Specifically, the gas jet nozzle 10 is of such a shape that it crosses the hollow part substantially at right angles thereto at its inlet. For this reason, the length of the gas jet nozzle can be very effective. When the length l of the melt-flow nozzle 8 exceeds 10 mm, the viscosity of the melt flowing from the nozzle cannot be adjusted as desired unless the temperature of the crucible is rendered extremely high.

By reducing the thickness of the gas jet burner and shortening the melt-flowing nozzle, there is no need to raise the temperature of the crucible excessively in order to adjust the viscosity of the melt at the outlet of the melt-flow nozzle 8 to the desired value. Consequently, the wear of the crucible material by deformation or evaporation due to the high temperatures is reduced, and the service life of the crucible has been prolonged exceedingly. Shorter lengths of the melt-flow nozzle are better, but if the length is too short, the gas jet burner cannot be provided. The lower limit to the length of the melt-flow nozzle is usually 1.5 mm.

(c) Arrangement of a plurality of melt-flow nozzles:-

As already described with reference to Figure 1, according to the method and apparatus of the present invention, the melt which has flowed from the melt-flow nozzle 8 is formed into a conical shape 4a in the first zone 14 and rotated around its central axial line. In the second zone 16, the melt flies away from the tip of the cone 4a in the form of fiber 4b in a vortex shape, and is accelerated and undergoes a pulling force thereby to be drawn and made into fine fibers. High-speed gas stream 12 for transforming the melt into a conical shape 4a and simultaneously rotating it in the first zone 14 is used as the high-speed gas stream for drawing and attenuating the fibrous melt 4a which has flown from the tip of the cone 4a. If required, another high-speed gas stream for drawing can be used. In any case, the high speed gas streams used for drawing must have a high energy in order to form fibers of fine diameters sufficiently drawn and attenuated. Generally, the energy required to draw and attenuate the fibrous melt 4b in the second zone 16 is greater than that required for transforming the melt into conical shape 4a and rotate it in the first zone 14. Sometimes, the former becomes several times as high as the latter. For this reason, the saving of the energy required for drawing and attenuating the fibrous melt can result in a remarkable saving of the entire energy required for fiber formation.

The inventors have found that the energy required for drawing and attenuation can be markedly saved by arranging at least three melt-flow nozzles 8 closely such that when a circle with a radius of 10 mm is drawn with the center of each nozzle as a central point, at least three over-lapping portions between the circles appear, and thereby utilizing the high speed gas stream for the flowing of melt from the adjoining flowing nozzles also as high speed gas streams for drawing and attenuation (See Example 7).

In other words, when a first high speed gas stream (to be referred to as a primary high speed gas stream) is caused to act on the fibrous melt 4b, and at the same time, a second high speed gas stream (to be referred to as a secondary high speed stream) which is in substantially the same direction as the primary gas stream is caused to act on it, the fibrous melt 4b can be very effectively drawn and attenuated.

The reason for this is not well known, but the inventors presume as follows:-

As shown in Figure 21-a, when the fibrous heat-softenable material 3 is introduced into the primary high speed gas stream 5, the degree of its attenuation has to do with the force F which acts on the material 3. The force F is generated by the action of the high speed gas stream on the softenable material, and its magnitude becomes larger as the length L over which the high speed gas stream acts on the attenuated fibers becomes larger. This is because the material rapidly solidifies as a result of attenuation, and the pulling force is transmitted upstream. When the secondary high speed gas stream 7 is further applied as shown in Figure 21-b in addition to the primary high speed gas stream 5, the length L' over which

nozzles 514 onto the fibers 504 which enter a hood 517. A mesh conveyor 519 is provided at the open bottom of the hood 517. A sucking chamber 518 is provided at that position of the mesh conveyor 519 which is below the fiber-forming unit 513. The sucking chamber 518 is connected to an air exhausting device (not shown) of an ordinary structure for providing pressures below atmospheric pressure within the chamber 518 through a suction tube 523. The negative pressure within the chamber 518 promotes the collection of fibers on the conveyor, and exhaust gases of the blast for fiberization through the suction pipe 523. The fibers 504 formed from the fiber-forming unit 513 accumulate and become a fibrous layer 525. The conveyor 519 carries the plate-like fibrous layer 525 to a position beneath a sizing roll 521 which press-forms it to a mat 526 of a relatively high density. The mat 526 is carried through a curing chamber 522 where the resin binder on the fiber is cured by heating, according to an ordinary method, air circulating in the curing chamber. The cured fibrous mat is compressed in order to obtain the desired hardness.

The following Examples further illustrate the present invention.

Example 1

Using an apparatus of the type shown in Figures 27-a and 27-b, the following experiment was conducted. The results are shown in Table 1.

In Figures 27-a and 27-b, the molten glass was flowed out from crucible 2 through flow-out nozzle 8. It was formed into a conical shape 4a by high speed air streams 12 jetted out from air jet nozzles 10, and left in the form of a fibrous melt 4b. The gas streams 12 most closely approached the central axis of the cone 4a at a position about 2 mm below the tip of the flow-out nozzle 8. Each air jet nozzle 10 was of a circular shape with a sectional diameter of 1.0 mm with an angle of 45° with respect to the horizontal surface. Three nozzles 10 formed an angle of 120° to each other when determined by their projected images onto the horizontal surface. The outlets of the jet nozzles 10 did not contact the outlet of the flow-out nozzle 8, but were situated as close thereto as possible. The test was performed by adjusting the depth of the tank so that the amount of glass flow was 1 kg per hour. Air was at a pressure of 10 kg/cm².G, and the glass had a viscosity of about 50 poises at the outlet of the flow-out nozzle 8.

Table 1

Effective hole diameter of the melt-flowing nozzle (mm)	Fiber diameter (microns)	Proportions of unfiberized masses (%)
3	30	50
2.5	10	30
2	5	10
1.5	4	7
1	3	2
0.5	less than 2	less than 1

When the effective hole diameter of the flow-out nozzle was 0.5 mm, it was impossible to adjust the amount of glass flow to 1 kg/hour.

It can be seen from Table 1 that when the effective hole diameter of the flow-out nozzle is 3 mm, the proportion of unfiberized masses reaches 50%, but when the effective hole diameter decreases to 2.5 mm or below, the proportion of the fiberized masses decreases, and the fiber diameter also decreases.

Example 2

Three glasses A, B, C having a temperature-viscosity curve shown in Figure 28 were fiberized by an apparatus of the type shown in Figures 9-a and 9-b. It was found that they could be fiberized when the temperatures of the three glasses A, B and C immediately before rotation by gas stream were 870-990°C, 1040-1300°C, 1230-1300°C, respectively. The qualities of the fibers obtained were as shown by lines A, B and C in Figure 30. When the temperatures of the glasses exceeded the above ranges immediately before rotation, the viscosity of the glass became less than 10 poises, and the resulting fibers contained more than 20% of unfiberized masses. When the temperatures of the glasses were lower than the lower limits of the temperature ranges specified above, the viscosity of the glasses exceeded

200 poises. Thus, the diameters of the resulting fibers became more than 10 microns, and an efficient drawing of the fibers became difficult.

Example 3

- 5 Glasses A, B and C shown in Figure 28 were fiberized using three air jet nozzles obtained by removing every other air jet nozzle in the apparatus shown in Figures 9-a and 9-b. The results are substantially the same as in Example 2 with regard to the temperature ranges within which fiberization was possible, and the quality of the fibers were as shown in Figure 35. 5

Example 4

- 10 Millet jelly having a temperature-viscosity curve as shown in Figure 29 was fiberized using an apparatus of the type shown in Figures 9-a and 9-b. It could be fiberized at a temperature of 55 to 90°C. At a temperature below 55°C, thick shots flew away intermittently, and at a temperature of above 90°C, it did not form fibers, but remained atomized. 10

Example 5

- 15 In Figures 32-a and 32-b, high pressure air at 2 to 10 kg/cm² gauge was passed through an inlet 611, and via a passage 612, was jetted out from gas jet nozzles 10. Thus, glass having a viscosity of about 50 poises at 1,300°C was flowed through melt-flowing nozzle 8. 15

- 20 As shown in Table 2, ten samples having different inclination angles α , blow-out diameters D_1 , drawn diameters D_2 and effective hole diameters d_1 were prepared, and tested. The results are shown in Table 2. 20

- 25 The relation between the drawn diameter D_2 and the effective hole diameter d_1 was plotted in Figure 7 with respect to each of the samples. In Table 2, "good" means that a stable cone was obtained, and in this case, substantially continuous glass fibers with a diameter of about 10 microns were obtained. In Table 2, "poor" means that a stable cone could not be obtained, and glass fibers containing much unfiberized masses such as shots, balls and films resulted. As is clear from Table 2, the results were all "poor" in Samples Nos. 2 and 3 whose inclination angle were outside the range of 20 to 70°, Sample No. 6 whose ratio of the blow-out diameter D_1 to the drawn diameter D_2 was more than 10, and Sample Nos. 7 and 8 whose effective hole diameters and drawn diameters were not within the hatched ranges shown in Figure 7. 30

Table 2

Sample No.	Conditions			Effective diameter d_1 mm	D1 D2	Results
	Inclination angle α_0	Blow-out diameter D1 mm	Drawn diameter D2 mm			
1	50	5	3	1	1.7	Good
2	75	5	3	1	1.7	Poor
3	15	5	3	1	1.7	Poor
4	45	5	1.5	0.5	3.3	Good
5	45	10	3	0.6	3.3	Good
6	45	10	0.8	0.3	12.5	Poor
7	45	5	3	2	1.7	Poor
8	45	5	5	0.5	1.0	Poor
9	45	5	2.5	0.6	2.0	Good
10	45	4	3	1	1.3	Good

Example 6

Using an apparatus of the type shown in Figures 27-a and 27-b, test was performed with varying diameters d_1 and lengths l of the gas stream jet nozzles 10. The results are shown in Table 3. The gas jet nozzles 10 had a circular cross sectional shape.

Table 3

10	Effective hole diameter (d_1) (mm)	Nozzle length (l , mm)	Results	10
	0.6	2	Cone unstable; much beads and flakes	
		2.5	Cone somewhat unstable	
15		3	Cone stable; reduced beads	15
		5	Cone stable; reduced beads	
20	1.0	3	Cone not stable; much beads and flakes	20
		4.5	Cone somewhat unstable	
		5	Cone stable; reduced beads	
25		10	Cone stable; reduced beads	25
	1.5	6	Cone somewhat unstable	
30		7.5	Cone stable; reduced beads	30
		10	Cone stable; reduced beads	

35 The temperature of the glass in the cone was 1,200°C (50 poises), and the inside diameter of the glass melt-flow nozzle 8 was 2 mm. The angle formed between the central axial line of the gas jet nozzles 10 and the central axial line of the glass melt was 45°. The distance between the outlet of the gas jet nozzles 10 and the central axial line of the glass melt was about 2.0 mm, and the drawn diameter at the focal point was 0.7 to 1.7 mm. The pressure of the high pressure air to be fed to the gas jet nozzles was about 5 kg/cm². G.

Example 7

40 In an integral glass fiber-forming unit 2 shown in Figures 33-a and 33-b, a molten glass 4 having a viscosity of 50 poises and a temperature of 1,100°C was stored, and in the lower part of the unit 2, a molten glass flow nozzle 8 having an inverted frustoconical shape at the upper part with the diameter of the thinnest part being 1.5 mm was perforated. Around the flow-out nozzle 8 were provided four gas stream jet nozzles 10 having a diameter of 0.6 mm. Air at high temperatures and pressures was conducted to nozzles 10 through conduits 625 and gas fed hole 624, and was jetted out to form gas streams. Each two of the nozzles 10 constituted a pair, and formed an angle of 60° to each other at the horizontal surface. Each of the nozzles was symmetrical with respect to the central axial line of the fiber-forming unit. Using this apparatus, air at 1000°C and 8 kg/cm². G was jetted out to form glass fibers having an average fiber diameter of 8 microns.

55 When an apparatus of the type shown in Figures 34-a and 34-b in which ten fiber-forming units of the same structures as in Figure 33a and b were arranged in a straight-line at a pitch of 3 mm, fibers having a diameter of less than 3 microns were obtained under quite the same conditions as above. In order to obtain fibers with a diameter of 8 microns, a pressure of 3 kg/cm². G was sufficient.

WHAT WE CLAIM IS:-

60 1. A method of producing fibers from a heat-softenable material, which comprises heating the heat-softenable material in a melting crucible to form a viscous melt, and continuously flowing out the melt through a melt flow nozzle provided in said crucible; and jetting out at least three substantially straight-line high-speed gas streams disposed at intervals around the melt in its peripheral direction, each of said streams having a component in the tangential direction along the cross-section of the melt and a component which gradually approaches the central axial line of the melt toward the flowing direction of the melt and

Example 6

Using an apparatus of the type shown in Figures 27-a and 27-b, test was performed with varying diameters d_1 and lengths l of the gas stream jet nozzles 10. The results are shown in Table 3. The gas jet nozzles 10 had a circular cross sectional shape.

Table 3

10	Effective hole diameter (d_1) (mm)	Nozzle length (l , mm)	Results	10
	0.6	2	Cone unstable; much beads and flakes	
		2.5	Cone somewhat unstable	
15		3	Cone stable; reduced beads	15
		5	Cone stable; reduced beads	
20	1.0	3	Cone not stable; much beads and flakes	20
		4.5	Cone somewhat unstable	
		5	Cone stable; reduced beads	
25		10	Cone stable; reduced beads	25
	1.5	6	Cone somewhat unstable	
30		7.5	Cone stable; reduced beads	30
		10	Cone stable; reduced beads	

35 The temperature of the glass in the cone was 1,200°C (50 poises), and the inside diameter of the glass melt-flow nozzle 8 was 2 mm. The angle formed between the central axial line of the gas jet nozzles 10 and the central axial line of the glass melt was 45°. The distance between the outlet of the gas jet nozzles 10 and the central axial line of the glass melt was about 2.0 mm, and the drawn diameter at the focal point was 0.7 to 1.7 mm. The pressure of the high pressure air to be fed to the gas jet nozzles was about 5 kg/cm². G.

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then gradually departs from the central axial line, toward the melt which has flown out, whereby the melt is rotated about its central axial line and formed into a substantially conical shape in a first zone which ranges from the flow-initiating part of the melt to the part at which the gas stream most closely approaches the central axial line of the melt, and in a second zone subsequent to the first zone, the melt is allowed to fly in a fibrous form from the tip of the conical shape in a vortex form in the flowing direction and outwardly in the radial direction, the distance between the outlet of the melt-flow nozzle and the focal point at which the high-speed gas streams most closely approach the central axial line of the melt being from 0.2 to 10 times the effective hole diameter of the melt-flow nozzle.

2. A method according to claim 1, wherein said crucible has at least three melt flow nozzles, said flow nozzles being disposed close to each other so that when a circle with a radius of 10 mm is drawn about the center of each flow nozzle as a central point, at least three overlapping portions of these circles occur.

3. A method according to claim 1 or 2, wherein said straight-line high-speed gas stream is inclined at an angle of 20 to 70° to the central axial line of the melt.

4. A method according to claim 3, wherein the angle is 35 to 55°.

5. A method according to any one of claims 1 to 4, wherein said high speed gas streams are arranged symmetrically with respect to the central axial line of the melt to be continuously flowed out as a rotating symmetrical axis, and at least two of the angles formed between the central axial lines of a pair of adjoining gas streams are in the range of 95 to 135°.

6. A method according to any one of claims 1 to 5, wherein each of the straight-line high-speed gas streams is jetted out from a jet nozzle having an effective hole diameter d_1 , and the drawn diameter D_1 defined by the straight-line high-speed gas stream has a dimension that is selected from an area obtained by connecting points (0, 0), (3.0, 5.3), (3.0, 7.0), (2.4, 7.0), and (0, 2.0) in a diagram with d_1 (mm) on the axis of abscissas and D_1 (mm) on the axis of ordinates.

7. A method according to any one of claims 1 to 6, wherein the viscosity of the melt immediately before rotation in the first zone is adjusted to 10 to 200 poises.

8. A method according to claim 7, wherein the viscosity of the melt is adjusted to 50 to 100 poises.

9. A method according to any one of claims 1 to 8, wherein the blow-out diameter D_2 defined by the straight-line high-speed gas stream establishes the following relation with respect to the drawn diameter D_1 .

$$D_2 < D_1 \leq 10D_2$$

10. A method according to claim 9, wherein the above relation is expressed by the following equation.

$$1.3D_2 \leq D_1 \leq 3D_2$$

11. A method according to any one of claims 1 to 10, wherein each of the straight-line high-speed gas streams is jetted out from a jet nozzle whose length l is at least 5 times as large as the effective hole diameter d_1 .

12. A method according to any one of claims 1 to 11, wherein the thinnest tip portion of the cone formed in the first zone has a diameter of from 0.1 to 1 mm.

13. A method according to any one of claims 1 to 12, wherein the melt stream leaving the nozzle has a substantially circular cross-sectional shape with a diameter of 0.5 to 10 mm.

14. A method according to any one of claims 1 to 13, wherein the effective hole diameter d_2 of the melt-flow nozzle is 0.5 to 2.5 mm.

15. A method according to claim 14, wherein the effective hole diameter d_2 is 0.5 to 2.0 mm.

16. An apparatus for producing fibers from a heat-softenable material, said apparatus comprising a melting crucible having at least three flow-out nozzles for heating the heat-softenable material to form a viscous melt and flowing it continuously through the flow-out nozzles; and a gas jetting means for jetting out at least three substantially straight-line high-speed gas streams disposed at intervals around each flow-out nozzle in its peripheral direction, each of said streams being directed in a direction having a component in the tangential direction along the cross-section of the melt and a component which gradually approaches the central axial line of the melt toward the flowing direction of the melt and then gradually departs from the central axial line, toward the melt which has flown out, whereby in use of the apparatus the melt is rotated about its central axial line and formed into a substantially conical shape in a first zone which ranges from the flow-initiating part of the melt to the part at which the gas stream most closely approaches the central axial line of the melt, and in a second zone subsequent to the first zone, the melt is allowed to fly in a fibrous form from the tip of the conical shape in a vortex form in the flowing direction and outwardly in the radial direction, said flow-out nozzles being disposed close to each other so that when a circle with a radius of 10 mm is drawn about the center of each flow-out nozzle



as a central point, at least three overlapping portions of these circles occur.

17. Apparatus according to claim 16, wherein each said flow-out nozzle has an effective hole diameter d_1 of 0.5 to 2.5 mm.

18. Apparatus according to claim 17, wherein said effective hole diameter d_1 is 0.5 to 2.0 mm.

19. Apparatus according to any one of claims 16 to 18, wherein means are provided for controlling heat-melting of the heat-softening material within the crucible so that the viscosity of the melt immediately before the rotation of the melt in the first zone becomes 10 to 200 poises.

20. Apparatus according to claim 19, wherein the control means are adapted to control the viscosity of the melt to be within the range of 50 to 100 poises.

21. Apparatus according to any one of claims 16 to 20, wherein for each nozzle said gas jetting means is adapted to jet out a high speed gas stream inclined at an angle of 20 to 70° to the central axial line of the melt stream.

22. Apparatus according to claim 21, wherein said angle is 35 to 35°.

23. Apparatus according to any one of claims 16 to 22, wherein said gas jetting means includes at least three jet nozzles disposed symmetrically with respect to the central axial line of the melt to be flowed out continuously from the flow-out nozzle as a rotating symmetrical axis in such a manner that at least two of the angles formed between the adjacent jet nozzles become 95 to 135°.

24. Apparatus according to any one of claims 16 to 23, wherein said gas jet means includes at least three jet nozzles for jetting out straight-line high speed gas streams, and the effective hole diameter d_1 of each of said jet nozzles and the drawn diameter D_2 defined by straight-line high speed gas streams jetted out from the jet nozzles have a dimension that is selected from an area obtained by connecting points (0, 0), (3.0, 5.3), (3.0, 7.0), (2.4, 7.0), and (0, 2.0) in a diagram with d_1 (mm) on the axis of abscissas and D_2 (mm) on the axis of ordinates.

25. Apparatus according to claim 24, wherein the blow-out diameter D_1 defined by the straight-line high speed gas stream is in the following relation with respect to the drawn diameter D_2 .

$$D_2 < D_1 \leq 10D_2$$

26. Apparatus according to claim 25, wherein the above relation is expressed by the following equation.

$$1.3D_2 \leq D_1 \leq 3D_2$$

27. Apparatus according to any one of claims 23 to 26 wherein the length l of said jet nozzle is at least 5 times its effective hole diameter d_1 .

28. Apparatus according to any one of claims 23 to 27, wherein that part of the inside wall in the vicinity of the outlet of the jet nozzle which is farther away from the flow-out nozzle is cut out.

29. Apparatus according to any one of claims 16 to 28, wherein said flow-out nozzle projects from the undersurface of the bottom wall of the crucible by a length of not more than 10 mm, and said jetting means is formed in a member provided around said flow-out nozzle.

30. Apparatus according to any one of claims 16 to 29, wherein both of the flow-out nozzle and the jetting means are formed on the bottom wall of crucible, said wall being made of one integral member.

31. Apparatus according to claim 30, wherein the bottom wall of the crucible is adapted to be heated electrically.

32. Apparatus according to claim 31, wherein a passage for feeding a gas into the jetting means is provided along that part of the bottom wall of the crucible where the flow-out nozzle and jetting means are not provided, and the gas passing this passage prevents the above part from attaining a markedly high temperature due to the electric heating of the bottom wall.

33. Apparatus according to any one of claims 16 to 31, wherein means for jetting out a gas for drawing is provided so as to jet out a separate high speed gas stream onto the melt which has flown from the tip of the conical shape in the form of fiber.

34. Apparatus according to any one of claims 16 to 33, wherein gas feeding passages are provided on both sides of the flow-out nozzles that are disposed in straight alignment in said crucible, and said jetting means are communicated to said gas feeding passages.

35. A method of producing fibers from a heat-softenable material as claimed in claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

36. Fibers obtained by a process according to any one of claims 1 to 15 and 35.

37. Apparatus for producing fibers from a heat-softenable material as claimed in claim 16 constructed and arranged to operate substantially as hereinbefore described with refer-



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ence to and as illustrated in the accompanying drawings.

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