



(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
26.01.2022 Bulletin 2022/04

(51) International Patent Classification (IPC):
D04H 3/16 (2006.01) **D01D 5/08** (2006.01)

(21) Application number: **20782329.5**

(52) Cooperative Patent Classification (CPC):
D01D 5/08; D04H 3/16

(22) Date of filing: **27.03.2020**

(86) International application number:
PCT/JP2020/014392

(87) International publication number:
WO 2020/203932 (08.10.2020 Gazette 2020/41)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(72) Inventors:
• **NAGAMINE, Kazuya**
Osaka-shi, Osaka 530-8288 (JP)
• **MIYAMOTO, Takayuki**
Osaka-shi, Osaka 530-8288 (JP)
• **MAEDA, Takekazu**
Osaka-shi, Osaka 530-8288 (JP)

(30) Priority: **29.03.2019 JP 2019068822**

(74) Representative: **Vossius & Partner**
Patentanwälte Rechtsanwälte mbB
Siebertstraße 3
81675 München (DE)

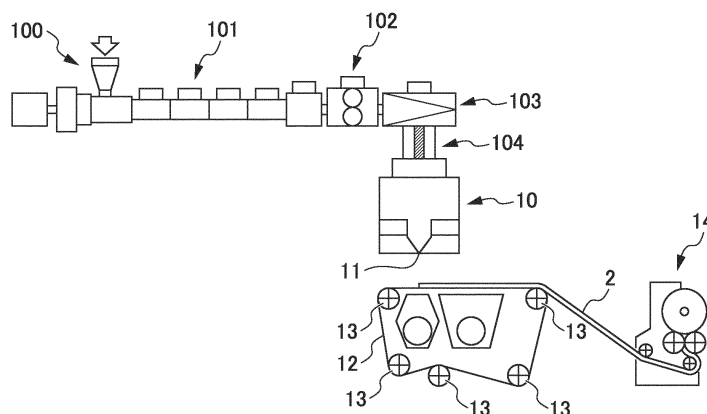
(71) Applicant: **KANEKA CORPORATION**
Osaka 530-8288 (JP)

(54) **MELT-BLOWN NONWOVEN FABRIC MANUFACTURING METHOD AND MELT-BLOWN NONWOVEN FABRIC**

(57) Provided are: a melt-blown nonwoven fabric manufacturing method that enables manufacturing of a melt-blown nonwoven fabric having high strength without performing a calendering process; and a melt-blown nonwoven fabric that can be manufactured by the manufacturing method. This melt-blown nonwoven fabric manufacturing method includes setting, in the respective suit-

able ranges, the temperature of a resin to be discharged from a spinning die head, the amount and the temperature of hot air to be blown to a nozzle hole from which the resin is discharged, the amount of the resin discharged from the nozzle hole, and a distance between the nozzle hole and a conveyor for conveying a melt-blown nonwoven fabric.

FIG. 1



Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a melt-blown nonwoven fabric manufacturing method and a melt-blown nonwoven fabric.

BACKGROUND ART

- 10 **[0002]** A melt-blown nonwoven fabric is manufactured by a so-called melt-blowing method including:
- a resin discharging step of discharging a molten resin from a spinning die head provided with a nozzle having a plurality of holes;
 - 15 a fiberization step of forming fibers by blowing hot gas toward the nozzle holes, and thus making the discharged molten resin into fibers, the hot gas flowing from the nozzle holes toward a conveyor opposed to the spinning die head; and
 - a nonwoven fabric formation step of forming a melt-blown nonwoven fabric by depositing the fibers on the conveyor using a flow of the hot gas.
- 20 **[0003]** Such a method allows for low-cost and easy manufacture of a nonwoven fabric made of microfibers and having a large specific surface area. If unprocessed after being deposited on the conveyor, the melt-blown nonwoven fabric manufactured by the above-described method is insufficient in terms of strength because fiber-to-fiber bonding is weak. The melt-blown nonwoven fabric is therefore used after being strengthened through a heat compression process referred to as calendering using calendering rolls (see, for example, Patent Document 1).
- 25 **[0004]** Patent Document 1: Japanese Unexamined Patent Application, Publication No. H06-136656

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

- 30 **[0005]** However, the melt-blown nonwoven fabric becomes less air-permeable through calendering because of compressed surfaces thereof while becoming stronger. Air permeability is an important performance for a melt-blown nonwoven fabric to be used for filter applications and the like.
- 35 **[0006]** The present invention was achieved in consideration of the above-described problems, and an objective thereof is to provide a melt-blown nonwoven fabric manufacturing method that allows for manufacture of a melt-blown nonwoven fabric having a good strength without performing calendering and to provide a melt-blown nonwoven fabric that can be manufactured by the foregoing manufacturing method.

Means for Solving the Problems

- 40 **[0007]** In order to solve the above-described problems, the inventors of the present invention conducted intensive studies, and consequently completed the present invention.
- [0008]** That is, the present invention provides the following (1) to (8).

- 45 (1) A melt-blown nonwoven fabric manufacturing method including:
- a resin discharging step of discharging a molten resin from a spinning die head provided with a nozzle having a plurality of holes;
 - 50 a fiberization step of forming fibers by blowing hot gas toward the holes of the nozzle, and thus making the discharged molten resin into fibers, the hot gas flowing from the holes of the nozzle toward a conveyor opposed to the spinning die head; and
 - a nonwoven fabric formation step of forming a melt-blown nonwoven fabric by depositing the fibers on the conveyor using a flow of the hot gas, wherein
 - calendering is not performed after the nonwoven fabric formation step,
 - 55 the hot gas has a temperature greater than or equal to a melting point of the resin and less than or equal to (the melting point + 100°C),
 - the hot gas has a flow rate of greater than or equal to 1000 NL/min/m and less than or equal to 7000 NL/min/m,
 - the resin is discharged through each of the holes of the nozzle at a discharging rate of greater than or equal to

0.006 cm³/min and less than or equal to 0.3 cm³/min,
the resin has, at the holes of the nozzle, a temperature greater than or equal to the melting point of the resin
and less than or equal to (the melting point + 100°C),
a minimum distance between the conveyor and the holes of the nozzle is greater than or equal to 10 mm and
less than or equal to 75 mm, and
an atmosphere between the conveyor and the holes of the nozzle has a temperature of greater than or equal
to 110°C and less than or equal to 160°C.

(2) The melt-blown nonwoven fabric manufacturing method according to (1), wherein the resin is a polyester-based
resin or a polyolefin-based resin.

(3) The melt-blown nonwoven fabric manufacturing method according to (1) or (2), wherein the melt-blown nonwoven
fabric has two opposite surfaces from which ultrasound is reflected at different reflection intensities,

one of the reflection intensities is 1.2 times or more and 3.0 times or less larger than the other of the reflection
intensities, and
the reflection intensities are each the average of values measured at 100 or more points under measurement
conditions including:

a distance of 155 mm between an ultrasound transceiver and a surface of the nonwoven fabric;
a frequency of 360 kHz;
a measurement temperature of 22°C;
an applied voltage of 500 V;
a wavenumber of 5 for burst waves;
a chirp ratio of 100%; and
100 or more measurement points within an area of 25 mm × 40 mm.

(4) A melt-blown nonwoven fabric, having two opposite surfaces from which ultrasound is reflected at different
reflection intensities,

one of the reflection intensities being 1.2 times or more and 3.0 times or less larger than the other of the reflection
intensities, wherein
the reflection intensities are each the average of values measured at 100 or more points under measurement
conditions including:

a distance of 155 mm between an ultrasound transceiver and a surface of the nonwoven fabric;
a frequency of 360 kHz;
a measurement temperature of 22°C;
an applied voltage of 500 V;
a wavenumber of 5 for burst waves;
a chirp ratio of 100%; and
100 or more measurement points within an area of 25 mm × 40 mm.

(5) The melt-blown nonwoven fabric according to (4), having a thickness of greater than or equal to 0.1 mm and
less than or equal to 0.4 mm.

(6) The melt-blown nonwoven fabric according to (4) or (5), having an apparent density of greater than or equal to
50 kg/m³ and less than or equal to 350 kg/m³.

(7) The melt-blown nonwoven fabric according to any one of (4) to (6), having an average pore size of greater than
or equal to 2.5 μm and less than or equal to 5.0 μm as measured using a permeability porometer.

(8) The melt-blown nonwoven fabric according to any one of (4) to (7), having an average fiber diameter of greater
than or equal to 0.5 μm and less than or equal to 3.0 μm, the average fiber diameter being an average of values of
diameter of 100 or more fibers as determined based on an electron microscope image.

Effects of the Invention

[0009] According to the present invention, it is possible to provide a melt-blown nonwoven fabric manufacturing method
that allows for manufacture of a melt-blown nonwoven fabric having a good strength without performing calendaring and
to provide a melt-blown nonwoven fabric that can be manufactured by the foregoing manufacturing method.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIG. 1 is a diagram illustrating an overview of a configuration of a melt-blown nonwoven fabric manufacturing device. FIG. 2 is a perspective view illustrating an overview of a spinning die head of the melt-blown nonwoven fabric manufacturing device.

FIG. 3 is a graph showing a relationship between fiber occupancy and location in a thickness direction of melt-blown nonwoven fabrics of Examples 2 and 4 as analyzed by x-ray computed tomography.

FIG. 4 is a graph showing a relationship between fiber occupancy and location in a thickness direction of melt-blown nonwoven fabrics of Comparative Examples 6 and 7 as analyzed by x-ray computed tomography.

FIG. 5 is a grayscale image of a central portion of the melt-blown nonwoven fabric of Example 2 in the thickness direction as obtained through an x-ray computed tomography analysis.

PREFERRED MODE FOR CARRYING OUT THE INVENTION

«Melt-blown Nonwoven Fabric Manufacturing Method»

[0011] The following describes a melt-blown nonwoven fabric manufacturing method by referring to the drawings as necessary. FIG. 1 illustrates an overview of a melt-blown nonwoven fabric manufacturing device. FIG. 2 is a perspective view illustrating an overview of a spinning die head of the melt-blown nonwoven fabric manufacturing device.

[0012] The melt-blown nonwoven fabric manufacturing method includes:

a resin discharging step of discharging a molten resin from a spinning die head 10 having a plurality of nozzle holes 11; a fiberization step of forming fibers by blowing hot gas toward the nozzle holes 11, and thus making the discharged molten resin into fibers, the hot gas flowing from the nozzle holes 11 toward a conveyor 12 opposed to the spinning die head 10; and

a nonwoven fabric formation step of forming a melt-blown nonwoven fabric by depositing the fibers on the conveyor using a flow of the hot gas. Calendering is not performed after the nonwoven fabric formation step.

<Resin Discharging Step>

[0013] In the resin discharging step, a molten resin is discharged from the spinning die head 10 having the plurality of nozzle holes 11.

[0014] No particular limitations are placed on the method for feeding the molten resin to the spinning die head 10. Typical methods include a method involving melting a resin fed from a hopper 100 by causing the resin to pass through an extruder 101 and feeding the molten resin to the spinning die head 10 through a kneader 104.

[0015] No particular limitations are placed on the type of the extruder 101 as long as the extruder 101 is capable of melting the resin. Examples of types of extruders that can be used as the extruder 101 include single-screw extruders, intermeshing co-rotating twin-screw extruders, non-intermeshing co-rotating twin-screw extruders, non-intermeshing counter-rotating twin-screw extruders, and other multi-screw extruders. In particular, single-screw extruders are preferable, which allow the resin to accumulate at fewer locations in the extruders and are therefore capable of preventing or reducing heat-induced deterioration of the resin during the extrusion. Single-screw extruders are preferable also in terms of reducing device cost. The extruder 101 may have a vent structure in a case where a resin that generates residual volatiles is used.

[0016] With respect to the form of the resin being a material to be placed in the extruder 101, the resin is preferably in a solid state. More preferably, the resin is used in the form of pellets. The resin in the form of pellets is generally fed into the extruder 101 through the hopper 100 attached to a material feed port of the extruder 101.

[0017] Preferably, the resin is heated and dried before being fed to the extruder 101 in order to prevent or reduce deterioration of the resin due to hydrolysis and oxidation. Preferably, the resin has a moisture content of less than or equal to 200 mass ppm. Preferable conditions for the drying, which depend on the type of the resin, are a temperature of 100°C and a time of three hours or longer.

[0018] Preferably, oxygen is removed from an atmosphere in which the resin is dried, and oxygen is removed from the resin. Preferably, the atmosphere in which the resin is dried is an inert gas atmosphere such as a nitrogen atmosphere. Examples of methods that can be suitably employed for the drying in view of the time required for drying and the time for resin consumption include a method involving the use of a hopper dryer obtained by providing the hopper 100 for feeding the pellets to the extruder 101 with a drying mechanism, a method involving drying the resin using a dryer before feeding the resin to the hopper 100 and preventing the resin from absorbing moisture while feeding the resin to the

hopper 100, and a method including both the forgoing methods.

[0019] Of these methods, the method involving the use of the hopper dryer is preferable because this method keeps the resin dried until immediately before the resin is fed to the extruder 101. Further preferably, in terms of keeping out moisture at low temperatures, a dehumidified atmosphere is established to prevent moisture from entering the hopper dryer by providing a dryer upstream of the hopper 100 and quickly drying the resin at a high temperature using the dryer upstream of the hopper 100. Note that heating the resin to an overly high temperature in the hopper 100 can lead to a problem such as blocking. In order to avoid such a problem, specifically, the resin is dried at 120°C for three hours or longer using the dryer provided upstream of the hopper 100, and the inner temperature of the hopper dryer is set to 40°C to 100°C. Thus, extrusion stability is easily achieved while also keeping the moisture content of the resin to a low level.

[0020] The extruder 101 may be, for example, a single-screw extruder including a screw (not shown). As the screw, a vented or unvented extruder screw in a general full-flight configuration having a compression ratio of 2 to 3 may be used. Note that a special kneading mechanism such as a barrier flight may be employed so that no unmelts are left.

[0021] In the resin discharging step, the molten resin is discharged through each of the nozzle holes 11 of the spinning die head 10 at a resin discharging rate of greater than or equal to 0.006 cm³/min and less than or equal to 0.3 cm³/min. The discharging rate is a rate of the discharging with respect to each of the nozzle holes 11. In terms of facilitating stable extrusion of the resin and in terms of facilitating formation of well crystallized fibers having an excellent strength, the resin is preferably discharged through each of the nozzle holes 11 at a discharging rate of greater than or equal to 0.01 cm³/min and less than or equal to 0.2 cm³/min, and more preferably greater than or equal to 0.02 cm³/min and less than or equal to 0.1 cm³/min.

[0022] Furthermore, in the resin discharging step, the molten resin is discharged while having, at the nozzle holes 11, a temperature greater than or equal to the melting point of the resin and less than or equal to (the melting point + 100°C). Extrusion conditions in the extruder 101, such as a cylinder temperature, a resin residence time, and an extrusion rate, are therefore adjusted so as to satisfy the aforementioned conditions, that is, the discharging rate and the temperature of the resin being discharged. In the subsequent fiberization step, the temperature of the resin at the nozzle holes 11 is preferably greater than or equal to the melting point of the resin and less than or equal to (the melting point + 70°C), in terms of facilitating favorable fiberization of the resin discharged.

[0023] The molten resin obtained through a melter such as the extruder 101 is preferably fed to the spinning die head using a gear pump 102. The use of the gear pump 102 helps accommodate variation in the discharging rate at the extruder 101, significantly improves stability in volumetric feeding, and stabilizes the discharging of the resin through the nozzle holes 11 of the spinning die head 10. The molten resin is volumetrically fed by the gear pump 102 or is directly fed from the extruder 101 to the spinning die head 10 through, for example, a tubular channel, and then discharged through the plurality of nozzle holes 11 of the spinning die head 10.

[0024] Preferably, a foreign matter remover such as a filter 103 is provided in the resin channel from the gear pump 102 to the die or, in a case where the resin does not go through the gear pump 102 or the like, in the resin channel from the melter such as the extruder 101 to the spinning die head 10. The foreign matter remover helps reduce contamination of the nonwoven fabric by foreign matter by trapping foreign matter derived from the raw material resin and trapping foreign matter generated in the extruder and the gear pump 102.

[0025] Examples of the filter 103 that can be used as the foreign matter remover include screen meshes, pleated filters, and leaf disc filters. Of these filters, leaf disc filters are preferable in terms of filtration accuracy, filtration area, pressure resistance, time to clogging of filter by foreign matter, and the like. Examples of filter media that can be used for the filter 103 include sintered nonwoven fabrics of metal fibers.

[0026] The molten resin discharged from the gear pump 102 is fed to the spinning die head 10 with or without going through the filter 103. The molten resin is, for example, fed from the gear pump 102 or the filter 103 to the spinning die head 10 through the kneader 104.

[0027] The molten resin fed to the spinning die head 10 as described above is discharged through the plurality of nozzle holes 11 of the spinning die head 10 as illustrated in FIG. 2. No particular limitations are placed on the arrangement of the plurality of nozzle holes 11 in the spinning die head 10 as long as the arrangement allows for manufacture of a melt-blown nonwoven fabric 2 having desired properties. Typically, the plurality of nozzle holes 11 are arranged in a line at appropriate intervals in the same direction as a width direction of the melt-blown nonwoven fabric 2 to be formed on the conveyor 12 described below. For example, the intervals between the nozzle holes 11 are preferably greater than or equal to 0.10 mm and less than or equal to 1.0 mm, and more preferably greater than or equal to 0.25 mm and less than or equal to 0.75 mm. The intervals between the nozzle holes 11 may be regular or irregular, but are preferably regular in terms of facilitating manufacture of a homogeneous nonwoven fabric.

[0028] No particular limitations are placed on the shape of an opening of each nozzle hole 11. Typically, for example, the opening is circular, substantially circular, oval, or substantially oval in shape. The opening diameter of each nozzle hole 11 is not particularly limited, and is selected as appropriate according to the fiber diameter of the fibers that form the nonwoven fabric.

[0029] No particular limitations are placed on the resin to be used in the resin discharging step as a material of the

melt-blown nonwoven fabric 2 other than being a resin conventionally used as a material of melt-blown nonwoven fabrics. Examples of such resins include polyolefin-based resins, polystyrene-based resins, (meth)acrylic acid-based resins, polyester-based resins, polyamide-based resins, and polycarbonate-based resins.

[0030] Examples of polyolefin-based resins include low density polyethylene, high density polyethylene, polypropylene, ethylene-propylene copolymers, poly(1-butene), and poly(4-methyl-1-pentene). Examples of (meth)acrylic acid-based resins include polymers of at least one (meth)acrylate monomer selected from (meth)acrylates such as methyl (meth)acrylate, ethyl (meth)acrylate, n-propyl (meth)acrylate, n-butyl (meth)acrylate, phenyl (meth)acrylate, and benzyl (meth)acrylate. Examples of preferable (meth)acrylic acid-based resins include polymethyl(meth)acrylate. Examples of polyester-based resins include polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polyethylene naphthalate (PNE), and polylactic acid (PLA). Examples of polyamide-based resins include nylon 6, nylon 6,6, nylon 12, nylon 6,12, and MXD nylon.

[0031] Of these resins, in terms of providing good processability when the melt-blown nonwoven fabric is manufactured, polyolefin-based resins and polyester-based resins are preferable, and polypropylene, polyethylene terephthalate, and polybutylene terephthalate are more preferable.

<Fiberization Step>

[0032] In the fiberization step, fibers are formed by blowing, toward the nozzle holes 11, hot gas flowing from the nozzle holes 11 toward the conveyor 12 opposed to the spinning die head 10, and thus making the discharged molten resin into fibers.

[0033] The hot gas blown onto the nozzle holes 11 and the vicinity thereof stretches the molten resin being discharged through the nozzle holes 11, and thus makes the molten resin into fibers. Furthermore, the hot gas flows from the vicinity of the nozzle holes 11 toward the conveyor 12 opposed to the spinning die head 10. The fibers stretched by the hot gas are therefore carried by the flow of the hot gas and deposited on the conveyor 12 to form the melt-blown nonwoven fabric 2 in the subsequent nonwoven fabric formation step.

[0034] No particular limitations are placed on the method for blowing the hot gas. Typically, the hot gas can be generated by heating, using a heater (not shown), inert gas such as air or nitrogen pressurized by a compressor (not shown). Furthermore, hot gas flowing in a direction of forward movement of the conveyor 12 and hot gas flowing in an opposite direction to the direction of the forward movement of the conveyor 12 are caused to collide with each other in the vicinity of the nozzle holes 11, so that the directions of the flows of hot gas toward the vicinity of the nozzle holes 11 can be changed to the direction from the nozzle holes 11 toward the conveyor 12.

[0035] The hot gas has a temperature greater than or equal to the melting point of the resin and less than or equal to (the melting point + 100°C), preferably greater than or equal to (the melting point + 30°C) and less than or equal to (the melting point + 90°C), and more preferably greater than or equal to (the melting point + 40°C) and less than or equal to (the melting point + 80°C). The temperature of the hot gas being within the above-specified range facilitates good stretching of the resin being discharged through the nozzle holes 11 and facilitates good thermal fusion bonding between the fibers on the conveyor 12 in the subsequent nonwoven fabric formation step.

[0036] The hot gas has a flow rate of greater than or equal to 1000 NL/min/m and less than or equal to 7000 NL/min/m, preferably greater than or equal to 2000 NL/min/m and less than or equal to 6800 NL/min/m, and more preferably greater than or equal to 3000 NL/min/m and less than or equal to 6500 NL/min/m. The flow rate of the hot gas being within the above-specified range facilitates good stretching of the resin being discharged through the nozzle holes 11 and facilitates good thermal fusion bonding between the fibers on the conveyor 12 in the subsequent nonwoven fabric formation step.

<Nonwoven Fabric Formation Step>

[0037] In the nonwoven fabric formation step, the fibers are deposited on the conveyor 12 using the flow of the hot gas generated in the fiberization step to form the melt-blown nonwoven fabric 2.

[0038] In the nonwoven fabric formation step, the minimum distance between the conveyor 12 and the nozzle holes 11 is set to a range of greater than or equal to 10 mm and less than or equal to 75 mm. The nonwoven fabric formation step is performed under an atmosphere between the conveyor 12 and the nozzle holes 11 set at a temperature of greater than or equal to 110°C and less than or equal to 160°C. The minimum distance between the conveyor 12 and the nozzle holes 11 being within the above-specified range, and the temperature of the atmosphere between the conveyor 12 and the nozzle holes 11 being within the above-specified range allow the thermal fusion bonding performance of the resin fibers on or near a surface of the conveyor 12 to be in a favorable range for achieving formation of a melt-blown nonwoven fabric having good mechanical properties. As a result, it is possible to manufacture the melt-blown nonwoven fabric 2 having a good strength without performing calendering. The uncalendered melt-blown nonwoven fabric has a good air permeability.

[0039] No particular limitations are placed on the method for adjusting the temperature of the atmosphere between

the conveyor 12 and the nozzle holes 11 to the above-specified range. For example, the space between the conveyor 12 and the nozzle holes 11 may be surrounded by a wall for the purpose of preventing lowering of temperature. Any wall works as long as the wall is capable of preventing outside air from flowing into the space between the conveyor 12 and the nozzle holes 11. The material of such a wall may be a heat-resistant insulation material such as glass wool, rock wool, or porous ceramics. Furthermore, a heater may be provided to heat the space between the conveyor 12 and the nozzle holes 11. In a case where the temperature of the space between the conveyor 12 and the nozzle holes 11 becomes too high due to the temperature of the hot gas and the temperature of the resin, a cooler may be provided to cool the space between the conveyor 12 and the nozzle holes 11.

[0040] The minimum distance between the conveyor 12 and the nozzle holes 11 is set within a range of greater than or equal to 10 mm and less than or equal to 75 mm as appropriate in consideration of the thickness and the strength of the melt-blown nonwoven fabric. With an increase in the minimum distance between the conveyor 12 and the nozzle holes 11, the thickness of the resulting melt-blown nonwoven fabric 2 tends to increase, and the apparent density and the tensile strength thereof tend to decrease. If the minimum distance between the conveyor 12 and the nozzle holes 11 is greater than 75 mm, the apparent density of the resulting melt-blown nonwoven fabric significantly decreases, and the melt-blown nonwoven fabric cannot maintain a desired strength unless calendering is performed thereon.

[0041] The temperature of the atmosphere between the conveyor 12 and the nozzle holes 11 is, as described above, greater than or equal to 110°C and less than or equal to 160°C, preferably greater than or equal to 115°C and less than or equal to 155°C, and more preferably greater than or equal to 125°C and less than or equal to 150°C. The temperature of the atmosphere between the conveyor 12 and the nozzle holes 11 can be, for example, measured in accordance with a method described below. Specifically, the temperature of the atmosphere between the conveyor 12 and the nozzle holes 11 is measured through thermography at a location two meters away from a front surface (a surface parallel to the width direction of the melt-blown nonwoven fabric 2 to be manufactured) of the spinning die head 10. More specifically, with respect to the atmosphere between the conveyor 12 and the nozzle holes 11, temperature data are obtained through thermography for 100 pixels equivalent to a 2.5-mm square in actual size at a location approximately right above the nonwoven fabric within a range of ± 250 mm in the width direction from a widthwise central location on the spinning die head 10. An average of the temperature data obtained for the 100 pixels is taken to be the temperature of the atmosphere between the conveyor 12 and the nozzle holes 11.

[0042] No particular limitations are placed on the material of the conveyor 12 other than being a material that has heat resistance against the temperature conditions for the manufacture of the melt-blown nonwoven fabric 2, and that is not excessively fused to the melt-blown nonwoven fabric 2 and is thus separable from the melt-blown nonwoven fabric 2. Preferably, the conveyor 12 is formed from an air-permeable material, and the flow of the hot gas is drawn from a side of the conveyor 12 where the melt-blown nonwoven fabric is formed toward a back side thereof by a suction (not shown). Such a configuration readily prevents the resin fibers from bouncing on the conveyor 12 and facilitates formation of the melt-blown nonwoven fabric 2 in which the fibers are fused together well.

[0043] The conveyor 12 is driven by rollers 13 to convey the melt-blown nonwoven fabric 2 formed on the conveyor 12 to a winding device 14. The rate of movement of the conveyor 12 is determined as appropriate in consideration of the apparent density of the melt-blown nonwoven fabric 2 to be obtained in view of the discharging rate of the resin. Typically, the rate of movement of the conveyor is within a range of greater than or equal to 1.5 m/min and less than or equal to 6.0 m/min. The melt-blown nonwoven fabric 2 that has been formed in the nonwoven fabric formation step is wound into roll form by the winding device 14. Note that the melt-blown nonwoven fabric 2 may be cut into predetermined lengths and collected as a product in sheet form instead of in roll form.

[0044] The method described above makes it possible to manufacture the melt-blown nonwoven fabric 2 having a good strength without performing calendering. After the nonwoven fabric formation step, various conventional treatments and processes for nonwoven fabrics can be performed on the melt-blown nonwoven fabric 2. However, calendering is not performed on the melt-blown nonwoven fabric 2 after the nonwoven fabric formation step. This is because calendering reduces the air permeability of the melt-blown nonwoven fabric 2.

[0045] The surface state of the melt-blown nonwoven fabric 2 manufactured by the melt-blown nonwoven fabric manufacturing method described above differs between a surface thereof that has been in contact with the conveyor 12 and a surface thereof opposite to the surface that has been in contact with the conveyor 12. The ultrasound reflection intensity depends on the elasticity and the density of the surface of the nonwoven fabric. Immediately after being manufactured, the original melt-blown nonwoven fabric normally has top and bottom sides different from each other. Calendering reduces the difference between the top and bottom sides of the nonwoven fabric, which means that the elasticity and the density are changed at least at one side. This is considered the reason of how calendering reduces the air permeability.

[0046] Thus, when the ultrasound reflection intensity is measured with respect to the opposite surfaces of the melt-blown nonwoven fabric 2, ultrasound is reflected at different reflection intensities from the opposite surfaces. Specifically, the larger one of the reflection intensities is preferably 1.2 times or more and 3.0 times or less the smaller one of the reflection intensities, and more preferably 1.2 times or more and 2.5 times or less the smaller one of the reflection intensities. The melt-blown nonwoven fabric with the ultrasound reflection intensity ratio between the opposite surfaces

falling within the above range tends to have high strength and excellent air permeability.

[0047] The ultrasound reflection intensity is the average of values measured at 100 or more points under the measurement conditions shown below. Note that a gain may be applied to an output signal as necessary if reflected waves are weak.

(Reflection Intensity Measurement Conditions)

[0048]

Distance between ultrasound transceiver and nonwoven fabric surface: 155 mm
 Frequency: 360 kHz
 Measurement temperature: 22°C
 Voltage applied: 500 V
 Wavenumber: 5 (bursts)
 Chirp ratio: 100%
 Number of measurement points: 100 or more points within a range of 25 mm × 40 mm

[0049] The melt-blown nonwoven fabric satisfying the above-specified reflection intensity ratio preferably has a thickness of greater than or equal to 0.1 mm and less than or equal to 0.4 mm, and more preferably greater than or equal to 0.1 mm and less than or equal to 0.3 mm. The melt-blown nonwoven fabric having a thickness within the above-specified range is readily manufactured in a stable manner, and tends to be formed homogeneous.

[0050] The melt-blown nonwoven fabric satisfying the above-specified reflection intensity ratio preferably has an apparent density of greater than or equal to 50 kg/m³ and less than or equal to 350 kg/m³, and more preferably greater than or equal to 100 kg/m³ and less than or equal to 350 kg/m³. The melt-blown nonwoven fabric having an apparent density within the above-specified range tends to achieve both a good strength and a good air permeability.

[0051] The melt-blown nonwoven fabric satisfying the above-specified reflection intensity ratio preferably has an average pore size of greater than or equal to 2.5 μm and less than or equal to 5.0 μm as measured using a permeability porometer, and more preferably greater than or equal to 2.5 μm and less than or equal to 4.6 μm. The melt-blown nonwoven fabric having an average pore size within the above-specified range tends to achieve both a good air permeability and a good filtration performance.

[0052] The melt-blown nonwoven fabric satisfying the above-specified reflection intensity ratio preferably has an average fiber diameter of greater than or equal to 0.5 μm and less than or equal to 3.0 μm, which is an average of values of the diameter of 100 or more fibers as determined based on an electron microscope image, and more preferably greater than or equal to 0.5 μm and less than or equal to 2.5 μm.

[0053] The melt-blown nonwoven fabric satisfying the above-specified reflection intensity ratio preferably has a tensile strength in an MD direction of greater than or equal to 2.0 N/m² and less than or equal to 15.0 N/m², and more preferably greater than or equal to 3.0 N/m² and less than or equal to 10.0 N/m². The melt-blown nonwoven fabric preferably has a tensile elasticity in the MD direction of greater than or equal to 100 MPa and less than or equal to 400 MPa, and more preferably greater than or equal to 120 MPa and less than or equal to 350 MPa. The melt-blown nonwoven fabric preferably has a tensile strength in a TD direction of greater than or equal to 2.0 N/m² and less than or equal to 8.0 N/m², and more preferably greater than or equal to 2.5 N/m² and less than or equal to 6.0 N/m². The melt-blown nonwoven fabric preferably has a tensile elasticity in the TD direction of greater than or equal to 50 MPa and less than or equal to 200 MPa, and more preferably greater than or equal to 70 MPa and less than or equal to 130 MPa. The tensile strength and the tensile elasticity are values that are measured in accordance with measurement methods employed for working examples described below. The MD direction refers to a direction along a direction in which the melt-blown nonwoven fabric moves during the manufacture of the melt-blown nonwoven fabric. The TD direction refers to a direction perpendicular to the MD direction.

[0054] Fiber occupancy in different locations in the melt-blown nonwoven fabric in a thickness direction of the melt-blown nonwoven fabric can be determined by performing an x-ray computed tomography analysis involving scanning the melt-blown nonwoven fabric in the thickness direction of the melt-blown nonwoven fabric and obtaining data of fiber distributions on planes in the melt-blown nonwoven fabric that are perpendicular to the thickness direction, in accordance with a method described below for the working examples. The x-ray computed tomography analysis allows for calculation of an average fiber occupancy FO1 in a range extending across 15% of the thickness from one surface of the melt-blown nonwoven fabric, an average fiber occupancy FO2 in a range extending across 15% of the thickness from the other surface, and an average fiber occupancy AFO across the melt-blown nonwoven fabric. The melt-blown nonwoven fabric having a gradient in fiber occupancy on planes perpendicular to the thickness direction tends to be excellent in air permeability while also being excellent in strength. Specifically, an occupancy variation rate as calculated in accordance with the following equation is preferably greater than or equal to 10%, more preferably greater than or equal to

12% and less than or equal to 30%, and further preferably greater than or equal to 13% and less than or equal to 25%. The melt-blown nonwoven fabric having an occupancy variation rate within the above-specified range tends to be excellent in air permeability while also being excellent in strength. Occupancy variation rate (%) = $(|FO1 - FO2|)/AFO \times 100$

[0055] The melt-blown nonwoven fabric described above can be readily manufactured by the above-described method.

The melt-blown nonwoven fabric described above, which achieves both a good strength and a good air permeability, is suitably used for filter applications. More specifically, the melt-blown nonwoven fabric described above is suitably used as a filter for treatments of extracorporeal circulation, purification of antibody drugs, purification of viruses for gene therapy, and the like.

EXAMPLES

[0056] The following describes the present invention in further detail using working examples. However, the present invention is not limited to these working examples.

[Examples 1 to 4, and Comparative Examples 1 to 7]

[0057] Melt-blown nonwoven fabrics each having a width of 600 mm were manufactured using a melt-blown nonwoven fabric manufacturing device 1 having a configuration illustrated in FIG. 1 under conditions shown in Table 1. Polyethylene terephthalate (PET, melting point: 260°C) was used as a resin. A spinning nozzle with 1200 holes having a nozzle hole size of 0.25 mm and a hole interval of 0.25 mm was used. The rate of movement of the conveyor was 2.9 m/min.

[0058] In each of Examples, calendering was not performed after the melt-blown nonwoven fabric had been manufactured. In each of Comparative Examples, calendering was performed on the melt-blown nonwoven fabric using calendering rolls at a roll temperature shown in Table 1 under a condition of a roll-to-roll clearance of 0.10 mm to 0.11 mm.

[0059] With respect to each of the melt-blown nonwoven fabrics obtained in Examples 1 to 4 and the calendered melt-blown nonwoven fabrics obtained in Comparative Examples 1 to 7, the thickness and the apparent density were measured. Furthermore, the average pore size, the average fiber diameter, the variation coefficient, the tensile strength, the tensile elasticity, the ultrasound reflection intensity, and the air permeability were measured in accordance with methods described below. Tables 2 to 4 show results of these measurements.

<Average Pore Size>

[0060] A mean flow pore size was measured and taken as the average pore size using a permeability porometer (manufactured by Porous Materials Inc.).

<Average Fiber Diameter, Variation Coefficient>

[0061] A portion of each melt-blown nonwoven fabric was used as a sample and was observed by scanning electron microscopy. Based on an electron microscope image obtained, the diameter of 100 or more randomly selected fibers was measured. A number average of 100 or more measured values was calculated as the average fiber diameter. The variation coefficient was determined by dividing a standard deviation of the fiber diameter by the average fiber diameter.

<Tensile Strength, Tensile Elasticity>

[0062] With respect to each melt-blown nonwoven fabric, the tensile strength and the tensile elasticity in the MD direction, and these in the TD direction were measured. The MD direction refers to a direction along the direction in which the melt-blown nonwoven fabric moves during the manufacture of the melt-blown nonwoven fabric. The TD direction refers to a direction perpendicular to the MD direction. A test piece having a width of 8 mm and a length of 40 mm was cut out of each of the melt-blown nonwoven fabrics obtained. A universal testing instrument (RTG-1210, manufactured by A & D Company, Limited) was used. The test piece was fixed at opposite ends thereof using chucks set at an interval of 20 mm, and was pulled at a pulling rate of 20 mm/min. The relationship between the chuck-to-chuck distance and the load was plotted, and the tensile strength and the tensile elasticity were respectively calculated based on the following equations. Tensile strength (N/m²) = (load at break)/cross-sectional area of test piece

Tensile elasticity (MPa) = (load change corresponding to 0% to
 2% increase in chuck-to-chuck distance relative to before
 initiation of test/cross-sectional area of test piece)/(0% to
 2% increase/initial length of test piece)

<Ultrasound Reflection Intensity>

[0063] The ultrasound reflection intensity was measured at 100 or more points in an area of 75 mm × 75 mm of each melt-blown nonwoven fabric under the measurement conditions listed below. The ultrasound reflection intensity is defined as the average of the values measured at 100 or more points. The ultrasound reflection intensity was measured for each of a surface that had been in contact with the conveyor 12 during the manufacture of the melt-blown nonwoven fabric and a surface that had been facing toward the nozzle holes 11.

(Reflection Intensity Measurement Conditions)

[0064]

Distance between ultrasound transceiver and nonwoven fabric surface: 155 mm

Frequency: 360 kHz

Measurement temperature: 22°C

Voltage applied: 500 V

Wavenumber: 5 (bursts)

Chirp ratio: 100%

Number of measurement points: 100 or more points within a range of 25 mm × 40 mm

[0065] Specifically, ultrasound was transmitted and received by an ultrasonic vibrator (ultrasound transceiver) connected to a pulser/receiver (ULTRA SONIC RECEIVER JPR600C, manufactured by JAPAN PROBE) to measure the ultrasound reflection intensity. The pulser/receiver was connected to a high-speed digitizer (NI PIX-1033 (chassis), NI PIX-5114, manufactured by NATIONAL INSTRUMENTS CORP.), and the high-speed digitizer was connected to a personal computer for data processing.

<Air Permeability>

[0066] With respect to each of the melt-blown nonwoven fabrics obtained in the Examples and the Comparative Examples, four sheets or eight sheets of the melt-blown nonwoven fabric were stacked, and 300 mL of air was caused to pass through the stack from an air-permeable surface thereof having an area of 642 mm² through application of a weight of 567 g. The time (seconds) required for all of the 300 mL of air to pass through was measured, and thus the air permeability was evaluated. The air permeability was evaluated using a Gurley type densometer (manufactured by Toyo Seiki Seisaku-sho, Ltd. Japan). The sheets of the melt-blown nonwoven fabric were stacked so that surfaces A, which had been in contact with the conveyor 12 during the manufacture of the melt-blown nonwoven fabric, of the melt-blown nonwoven fabric would not make contact with one another, and surfaces B, which had been facing toward the nozzle holes 11, of the melt-blown nonwoven fabric would not make contact with one another. The air was supplied in a direction from the surfaces B. As for Example 2 and Comparative Example 1, the air permeability of a 32-sheet stack of the melt-blown nonwoven fabric was further evaluated.

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[Table 1]

	Resin		Resin temp. at nozzle holes (°C)	Hot gas temp. (°C)	Hot gas flow rate (NL/ min./ m)	Resin discharging rate (cm ³ / min./ hole)	Distance between conveyor and nozzle holes (mm)	Temp. between nozzle holes and conveyor (°C)	Calendering (Roll temp. (°C))
	Type	Melting point (°C)							
Ex. 1	PET	260	270	320	6100	0.05	20	148	Not Performed
Ex. 2	PET	260	270	320	6100	0.05	30	140	Not Performed
Ex. 3	PET	260	270	320	6100	0.05	40	131	Not Performed
Ex. 4	PET	260	270	320	6100	0.05	60	115	Not Performed
Comp. Ex. 1	PET	260	270	320	6100	0.05	80	100	Not Performed
Comp. Ex. 2	PET	260	270	320	6100	0.05	30	140	Performed (60)
Comp. Ex. 3	PET	260	270	320	6100	0.05	60	115	Performed (60)
Comp. Ex. 4	PET	260	270	320	6100	0.05	80	100	Performed (60)
Comp. Ex. 5	PET	260	270	320	6100	0.05	30	140	Performed (80)
Comp. Ex. 6	PET	260	270	320	6100	0.05	60	115	Performed (80)
Comp. Ex. 7	PET	260	270	320	6100	0.05	80	100	Performed (80)

[Table 2]

	Thickness (mm)	Apparent density (kg/m ³)	Average pore size (μm)	Average fiber diameter (μm)	Variation coefficient
Ex. 1	0.13	308	2.69	1.40	0.14
Ex. 2	0.15	267	3.14	1.57	0.17
Ex. 3	0.17	235	3.39	1.65	0.17
Ex. 4	0.22	182	4.01	1.80	0.19
Comp. Ex. 1	0.24	167	4.52	2.10	0.20
Comp. Ex. 2	0.14	286	3.14	1.44	0.15
Comp. Ex. 3	0.14	286	3.99	1.84	0.18
Comp. Ex. 4	0.13	308	4.74	2.03	0.16

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(continued)

	Thickness (mm)	Apparent density (kg/m ³)	Average pore size (μm)	Average fiber diameter (μm)	Variation coefficient
Comp. Ex. 5	0.14	286	3.25	1.48	0.18
Comp. Ex. 6	0.15	267	4.10	1.75	0.18
Comp. Ex. 7	0.15	286	4.62	2.17	0.19

[Table 3]

	MD (Machine direction)		TD (Transverse direction)	
	Tensile strength (N/m ²)	Tensile elasticity (MPa)	Tensile strength (N/m ²)	Tensile elasticity (MPa)
Ex. 1	9.77	309.89	5.74	125.25
Ex. 2	7.38	256.34	5.18	124.30
Ex. 3	5.40	218.70	4.61	106.31
Ex. 4	4.06	172.22	3.69	101.18
Comp. Ex. 1	3.03	139.12	2.80	75.26
Comp. Ex. 2	8.05	280.98	5.45	112.77
Comp. Ex. 3	4.66	200.25	4.22	100.13
Comp. Ex. 4	4.73	171.58	4.47	103.24
Comp. Ex. 5	8.30	294.07	5.61	120.35
Comp. Ex. 6	4.72	202.12	4.54	113.24
Comp. Ex. 7	4.34	146.94	4.16	101.50

[Table 4]

	Ultrasound reflection intensity			Air permeability (Time for 300 mL of air to pass through)		
	Conveyor-ward surface	Nozzle hole- ward surface	Ratio	4 sheets (Seconds)	8 sheets (Seconds)	32 sheets (Seconds)
Ex. 1	0.42	0.35	1.20	6.9	12.7	-
Ex. 2	0.38	0.31	1.23	5.8	10.8	38.5
Ex. 3	0.29	0.23	1.26	4.6	9.4	-
Ex. 4	0.27	0.17	1.59	3.8	7.6	-
Comp. Ex. 1	0.23	0.07	3.29	2.5	5.6	-
Comp. Ex. 2	0.25	0.26	1.04	5.8	12.0	42.6
Comp. Ex. 3	0.25	0.23	1.09	4.5	9.6	-
Comp. Ex. 4	0.23	0.23	1.00	3.5	6.8	-

(continued)

	Ultrasound reflection intensity			Air permeability (Time for 300 mL of air to pass through)		
	Conveyor-ward surface	Nozzle hole-ward surface	Ratio	4 sheets (Seconds)	8 sheets (Seconds)	32 sheets (Seconds)
Comp. Ex. 5	0.27	0.27	1.00	6.0	11.5	-
Comp. Ex. 6	0.25	0.23	1.09	4.7	8.6	-
Comp. Ex. 7	0.24	0.24	1.00	3.5	7.3	-

[0067] The melt-blown nonwoven fabric of Example 2 and the melt-blown nonwoven fabrics of Comparative Examples 2 and 3, for example, had similar results regarding the thickness, the apparent density, the average pore size, and the average fiber diameter. However, comparison therebetween indicates that the tensile strength and the tensile elasticity of the melt-blown nonwoven fabric of Example 2 were comparable to or higher than the tensile strength and the tensile elasticity of the melt-blown nonwoven fabrics of Comparative Examples 2 and 3, despite the fact that the melt-blown nonwoven fabric of Example 2 was not calendered. Comparison between the melt-blown nonwoven fabric of Example 2 and the melt-blown nonwoven fabric of Comparative Example 2 indicates that the air permeability of the uncalendered melt-blown nonwoven fabric of Example 2 was better than that of the calendered melt-blown nonwoven fabric of Comparative Example 2.

[0068] Table 4 indicates that the ultrasound reflection intensity ratio between the opposite surfaces of the melt-blown nonwoven fabric of each Example was greater than or equal to 1.2 and less than or equal to 3.0 as a result of the melt-blown nonwoven fabric being uncalendered. Furthermore, Tables 1 to 3 indicate that the melt-blown nonwoven fabric of Comparative Example 1, which was obtained under a condition of a distance of greater than 75 mm between the conveyor and the nozzle holes, had a low apparent density and a relatively low strength.

[Example 5, Example 6, and Comparative Examples 8 to 10]

[0069] Melt-blown nonwoven fabrics were manufactured using the melt-blown nonwoven fabric manufacturing device 1 having the configuration illustrated in FIG. 1 under conditions shown in Table 5. Polypropylene (PP, melting point: 160°C) was used as a resin. With respect to each of the melt-blown nonwoven fabrics obtained in Examples 5 and 6, and Comparative Examples 8 to 10, the thickness, the apparent density, the average pore size, the average fiber diameter, and the variation coefficient were measured in the same manner as in Example 1. Tables 2 to 6 show results of these measurements.

[Table 5]

	Resin		Resin temp. at nozzle holes (°C)	Hot gas temp. (°C)	Hot gas flow rate (NL/min./m)	Resin discharging rate (cm ³ /min. / hole)	Distance between conveyor and nozzle holes (mm)	Temp. between nozzle holes and conveyor (°C)	Calendering (Roll temp. (°C))
	Type	Melting point (°C)							
Ex. 5	PP	160	220	220	5300	0.06	40	131	Not Performed
Ex. 6	PP	160	220	220	5050	0.06	60	125	Not Performed
Comp. Ex. 8	PP	160	220	220	5050	0.06	100	85	Not Performed
Comp. Ex. 9	PP	160	220	220	5050	0.06	150	70	Not Performed

(continued)

	Resin		Resin temp. at nozzle holes (°C)	Hot gas temp. (°C)	Hot gas flow rate (NL/min./m)	Resin discharging rate (cm ³ /min. / hole)	Distance between conveyor and nozzle holes (mm)	Temp. between nozzle holes and conveyor (°C)	Calendering (Roll temp. (°C))
	Type	Melting point (°C)							
Comp. Ex. 10	PP	160	220	220	5050	0.06	200	60	Not Performed

[Table 6]

	Thickness (mm)	Apparent density (kg/m ³)	Average pore size (μm)	Average fiber diameter (μm)	Variation coefficient
Ex. 5	0.23	174	2.79	1.21	0.22
Ex. 6	0.38	105	4.80	1.31	0.22
Comp. Ex. 8	0.44	91	7.50	1.37	0.26
Comp. Ex. 9	0.49	82	7.08	1.41	0.23
Comp. Ex. 10	0.49	82	8.15	1.54	0.30

[0070] With respect to each of the melt-blown nonwoven fabrics of Examples 5 and 6, the ultrasound reflection intensity ratio between the opposite surfaces was determined in the same manner as in Example 1 to be greater than or equal to 1.2 and less than or equal to 3.0. The melt-blown nonwoven fabrics of Comparative Examples 8 to 10, which were manufactured under a condition of a distance of greater than 75 mm between the conveyor and the nozzle holes, each resulted in a significantly low apparent density. Consequently, it was impossible to ensure a desired strength for the melt-blown nonwoven fabrics of Comparative Examples 8 to 10 without performing calendering.

[0071] Furthermore, an x-ray computed tomography analysis was performed on the melt-blown nonwoven fabrics of Examples 2 and 4, and Comparative Examples 6 and 7. This analysis determines the fiber occupancy in different locations in each melt-blown nonwoven fabric in the thickness direction of the melt-blown nonwoven fabric. FIGS. 3 and 4 are graphs showing results of the analysis. In each of the graphs in FIGS. 3 and 4, a positive side of an axis representing thickness direction (μm) corresponds to a direction toward the conveyor-ward surface of each melt-blown nonwoven fabric in the thickness direction of the melt-blown nonwoven fabric. A negative side of the axis corresponds to a direction toward the nozzle-ward surface of each melt-blown nonwoven fabric in the thickness direction of the melt-blown nonwoven fabric.

[0072] Specifically, the x-ray computed tomography analysis was performed by a method described below. A micro x-ray computed tomography scanner (MicroXCT-400) manufactured by Xradia was used as an x-ray computed tomography device. Data of fiber distributions in each melt-blown nonwoven fabric was obtained by scanning the melt-blown nonwoven fabric in the thickness direction using the x-ray computed tomography device. Two-dimensional data related to the fiber distributions was obtained at a thickness interval of 0.05 mm from the scan data. Next, images were formed through grayscale processing of the thus obtained two-dimensional data. FIG. 4 shows a grayscale image of a central portion of the melt-blown nonwoven fabric of Example 2 in the thickness direction as an example of the images formed through the grayscale processing. Pixel values were generated from data of the images formed through the grayscale processing. Based on the thus obtained pixel values, predetermined binarization was performed on the grayscale images. With respect to each of the binarized grayscale images, the percentage of the total area of the fibers relative to the entire area of the image (fiber occupancy (%)) was determined.

[0073] The following describes the binarization. In preparation for the binarization, first, a histogram of a per-luminance (for each of 256 (0 to 255) shades in an 8-bit image) distribution of pixels was obtained based on each image formed through the grayscale processing. The thus obtained histogram, in which the horizontal axis represents luminance, had two peaks. Based on the thus obtained histogram, a maximum value $I_{\max}$ of the luminance, a minimum value $I_{\min}$ of the

luminance, and an average value μ_0 of the luminance were determined. A value between $I_{\max}$ and $I_{\min}$ was selected as a threshold T. The histogram was divided into two classes, a class 1 and a class 2, based on the threshold T. The class 1 and the class 2 were to each include one peak. Variance σ_1^2 , mean μ_1 , and frequency n_1 were determined with respect to the class 1. Variance σ_2^2 , mean μ_2 , and frequency n_2 were determined with respect to the class 2.

[0074] Next, intra-class variance σ_w^2 and inter-class variance σ_b^2 were determined in accordance with the following equations.

[Equation 1]

$$\sigma_w^2 = \frac{n_1 \sigma_1^2 + n_2 \sigma_2^2}{n_1 + n_2}$$

$$\sigma_b^2 = \frac{n_1 (\mu_1 - \mu_0)^2 + n_2 (\mu_2 - \mu_0)^2}{n_1 + n_2}$$

[0075] Based on the thus obtained intra-class variance σ_w^2 and inter-class variance σ_b^2 , a degree of separation S was determined in accordance with the following equation.

[Equation 2]

$$S = \frac{\sigma_b^2}{\sigma_w^2}$$

[0076] The degree of separation S was determined for each of all possible thresholds T between the maximum value $I_{\max}$ and the minimum value $I_{\min}$ by the method described above. The threshold T that provides the highest degree of separation S was taken to be the threshold for the banalization.

[0077] Table 7 below shows an average (AFO) of values of the fiber occupancy (%) in different locations in the thickness direction of each melt-blown nonwoven fabric, an average fiber occupancy (FO1) in a range extending across 15% of the thickness from the nozzle hole-ward surface, and an average fiber occupancy (FO2) in a range extending across 15% of the thickness from the conveyor-ward surface, which were determined based on results of the above-described x-ray computed tomography analysis, and a difference (|FO1 - FO2|) of the average fiber occupancy between the opposite surfaces (ranges extending across 15% of the thickness from the respective surfaces) and an occupancy variation rate (%) calculated in accordance with the following equation. Occupancy variation rate (%) = (|FO1 - FO2|)/AFO $\times 100$

[Table 7]

	Fiber occupancy			Average fiber occupancy difference between opposite surfaces (%)	Occupancy variation rate
	Average	Average fiber occupancy in range extending across 15% of thickness from surface (nozzle hole-ward surface)	Average fiber occupancy in range extending across 15% of thickness from surface (conveyor-ward surface)		
Ex. 2	38.5	31.7	41.1	9.32	24.2
Ex. 4	35.4	30.3	35.3	5.04	14.2
Comp. Ex. 6	50.1	50.7	48.5	2.19	4.4
Comp. Ex. 7	26.3	25.1	27.0	1.92	7.3

[0078] As described above, the melt-blown nonwoven fabrics of Examples 2 and 4 that were excellent in air permeability while also being excellent in strength had an occupancy variation rate of no less than 10%.

EXPLANATION OF REFERENCE NUMERALS

[0079]

- 1: Melt-blown nonwoven fabric manufacturing device
- 2: Melt-blown nonwoven fabric
- 10: Spinning die head
- 11: Nozzle hole
- 12: Conveyor
- 13: Roller
- 14: Winding device
- 100: Hopper
- 101: Extruder
- 102: Gear pump
- 103: Filter
- 104: Kneader

Claims

1. A melt-blown nonwoven fabric manufacturing method comprising:

a resin discharging step of discharging a molten resin from a spinning die head provided with a nozzle having a plurality of holes;
 a fiberization step of forming fibers by blowing hot gas toward the holes of the nozzle, and thus making the discharged molten resin into fibers, the hot gas flowing from the holes of the nozzle toward a conveyor opposed to the spinning die head; and
 a nonwoven fabric formation step of forming a melt-blown nonwoven fabric by depositing the fibers on the conveyor using a flow of the hot gas, wherein
 calendering is not performed after the nonwoven fabric formation step,
 the hot gas has a temperature greater than or equal to a melting point of the resin and less than or equal to (the melting point + 100°C),
 the hot gas has a flow rate of greater than or equal to 1000 NL/min/m and less than or equal to 7000 NL/min/m, the resin is discharged through each of the holes of the nozzle at a discharging rate of greater than or equal to 0.006 cm³/min and less than or equal to 0.3 cm³/min,
 the resin has, at the holes of the nozzle, a temperature greater than or equal to the melting point of the resin and less than or equal to (the melting point + 100°C),
 a minimum distance between the conveyor and the holes of the nozzle is greater than or equal to 10 mm and less than or equal to 75 mm, and
 an atmosphere between the conveyor and the holes of the nozzle has a temperature of greater than or equal to 110°C and less than or equal to 160°C.

2. The melt-blown nonwoven fabric manufacturing method according to claim 1, wherein the resin is a polyester-based resin or a polyolefin-based resin.

3. The melt-blown nonwoven fabric manufacturing method according to claim 1 or 2, wherein the melt-blown nonwoven fabric has two opposite surfaces from which ultrasound is reflected at different reflection intensities,

one of the reflection intensities is 1.2 times or more and 3.0 times or less larger than another of the reflection intensities, and
 the reflection intensities are each an average of values measured at 100 or more points under measurement conditions including:

a distance of 155 mm between an ultrasound transceiver and a surface of the nonwoven fabric;
 a frequency of 360 kHz;

a measurement temperature of 22°C;
 an applied voltage of 500 V;
 a wavenumber of 5 for burst waves;
 a chirp ratio of 100%, and
 100 or more measurement points within an area of 25 mm × 40 mm.

4. A melt-blown nonwoven fabric, having two opposite surfaces from which ultrasound is reflected at different reflection intensities,

one of the reflection intensities being 1.2 times or more and 3.0 times or less larger than another of the reflection intensities, wherein
 the reflection intensities are each an average of values measured at 100 or more points under measurement conditions including:

a distance of 155 mm between an ultrasound transceiver and a surface of the nonwoven fabric;
 a frequency of 360 kHz;
 a measurement temperature of 22°C;
 an applied voltage of 500 V;
 a wavenumber of 5 for burst waves;
 a chirp ratio of 100%; and
 100 or more measurement points within an area of 25 mm × 40 mm.

5. The melt-blown nonwoven fabric according to claim 4, having a thickness of greater than or equal to 0.1 mm and less than or equal to 0.4 mm.

6. The melt-blown nonwoven fabric according to claim 4 or 5, having an apparent density of greater than or equal to 50 kg/m³ and less than or equal to 350 kg/m³.

7. The melt-blown nonwoven fabric according to any one of claims 4 to 6, having an average pore size of greater than or equal to 2.5 μm and less than or equal to 5.0 μm as measured using a permeability porometer.

8. The melt-blown nonwoven fabric according to any one of claims 4 to 7, having an average fiber diameter of greater than or equal to 0.5 μm and less than or equal to 3.0 μm, the average fiber diameter being an average of values of diameter of 100 or more fibers as determined based on an electron microscope image.

9. A melt-blown nonwoven fabric having an occupancy variation rate of greater than or equal to 10%, the occupancy variation rate being calculated from an average fiber occupancy FO1 in a range extending across 15% of thickness of the melt-blown nonwoven fabric from one surface thereof, an average fiber occupancy FO2 in a range extending across 15% of the thickness from an opposite surface, and an average fiber occupancy AFO across the melt-blown nonwoven fabric, based on the following equation:

$$\text{occupancy variation rate (\%)} = (|FO1 - FO2|) / AFO \times 100,$$

the average fiber occupancy FO1, the average fiber occupancy FO2, and the average fiber occupancy AFO being determined based on results of an x-ray computed tomography analysis involving scanning the melt-blown nonwoven fabric in a thickness direction of the melt-blown nonwoven fabric and obtaining data of fiber distributions on planes in the melt-blown nonwoven fabric that are perpendicular to the thickness direction.

10. The melt-blown nonwoven fabric according to any one of claims 4 to 8, having an occupancy variation rate of greater than or equal to 10%, the occupancy variation rate being calculated from an average fiber occupancy FO1 in a range extending across 15% of thickness of the melt-blown nonwoven fabric from one surface thereof, an average fiber occupancy FO2 in a range extending across 15% of the thickness from an opposite surface, and an average fiber occupancy AFO across the melt-blown nonwoven fabric, based on the following equation:

$$\text{occupancy variation rate (\%)} = (|FO1 - FO2|) / AFO \times 100,$$

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the average fiber occupancy FO1, the average fiber occupancy FO2, and the average fiber occupancy AFO being determined based on results of an x-ray computed tomography analysis involving scanning the melt-blown nonwoven fabric in a thickness direction of the melt-blown nonwoven fabric and obtaining data of fiber distributions on planes in the melt-blown nonwoven fabric that are perpendicular to the thickness direction.

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FIG. 1

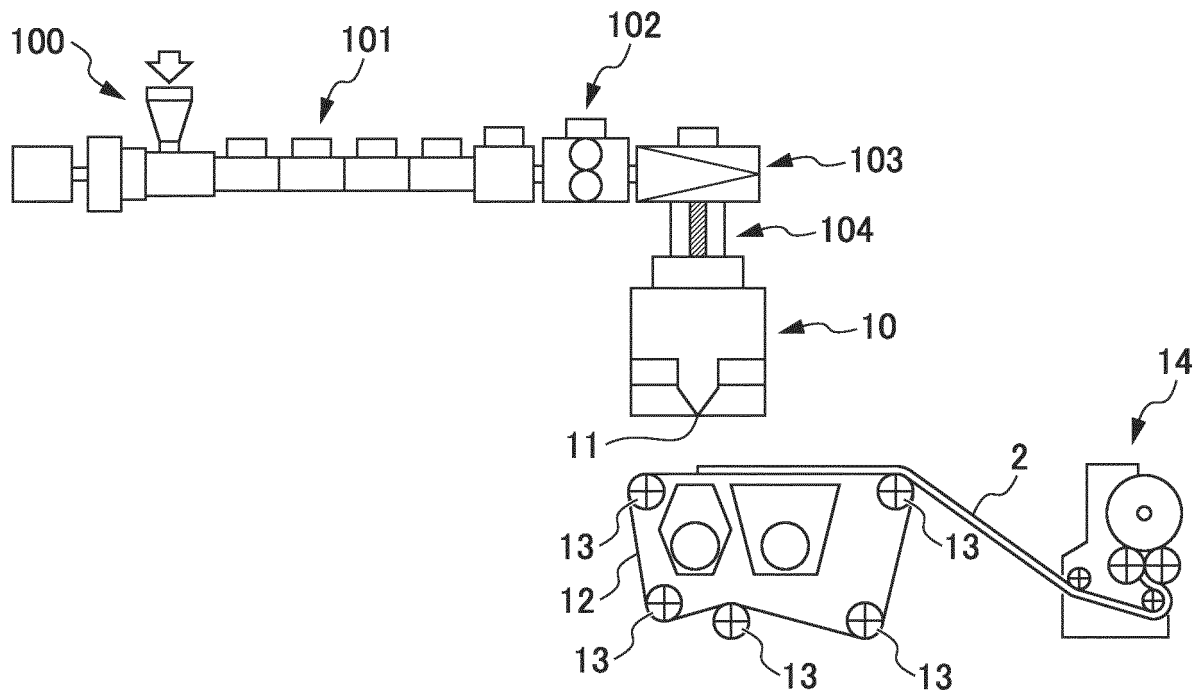


FIG. 2

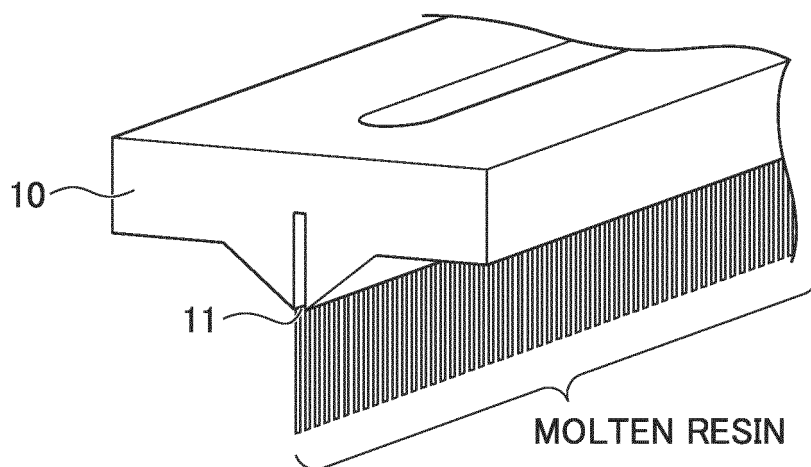


FIG. 3

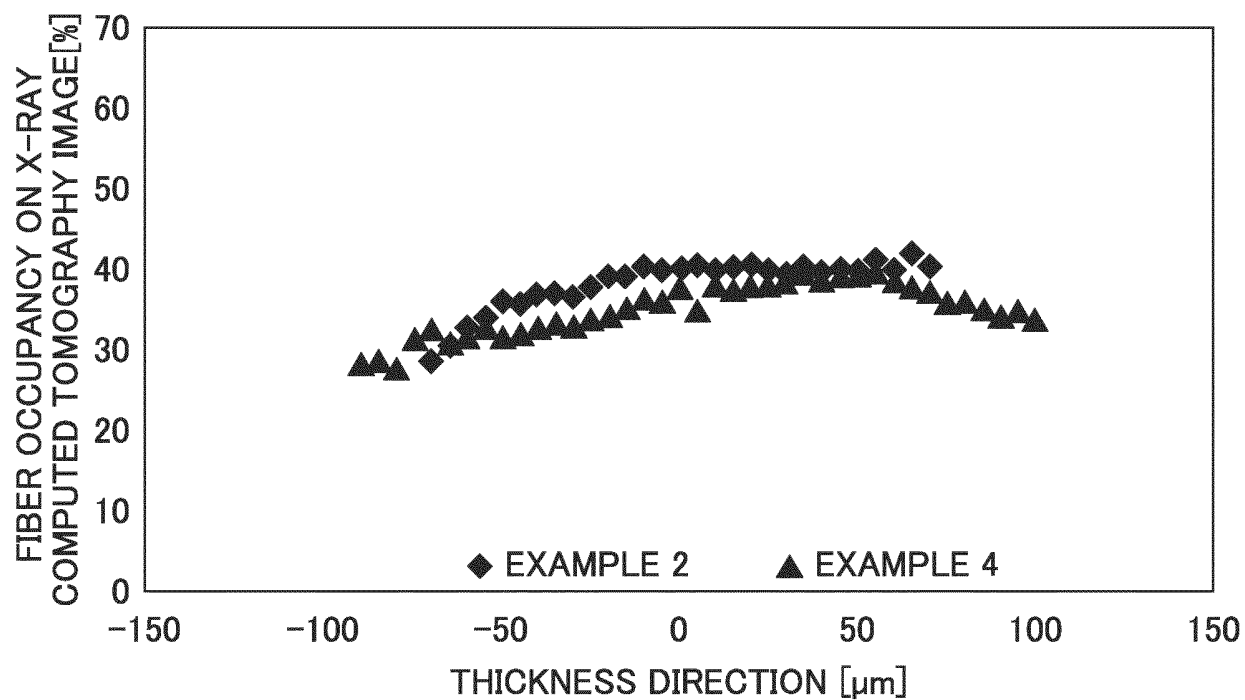


FIG. 4

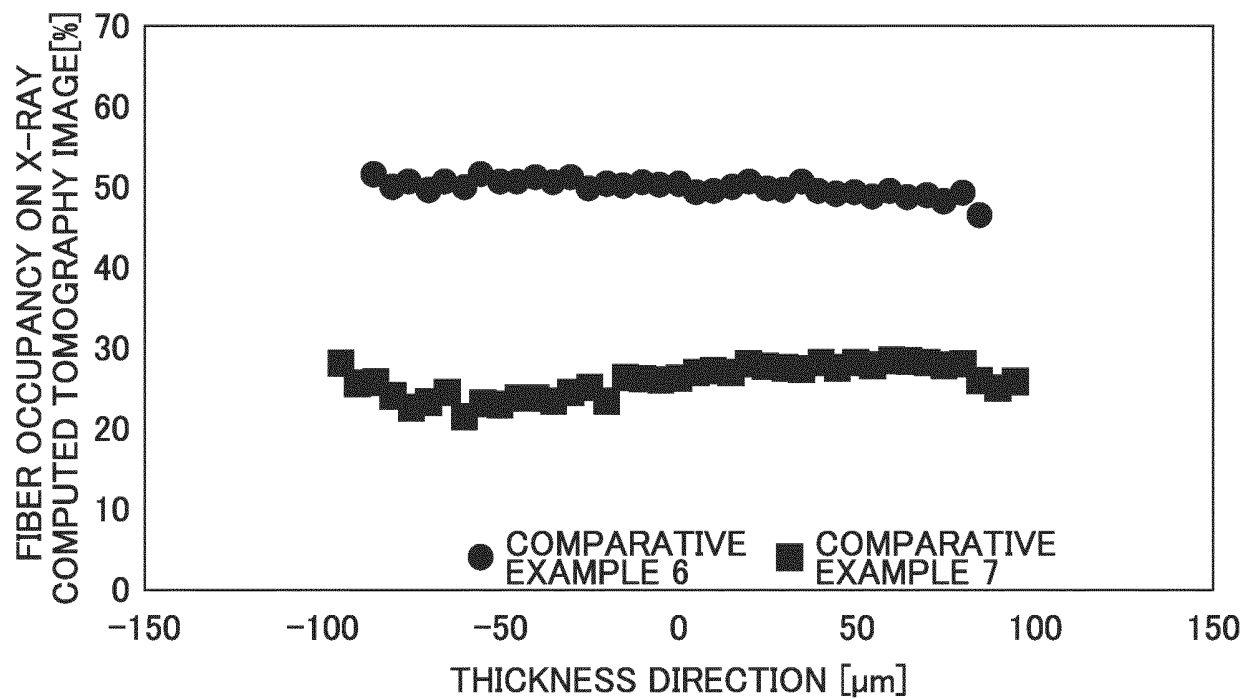
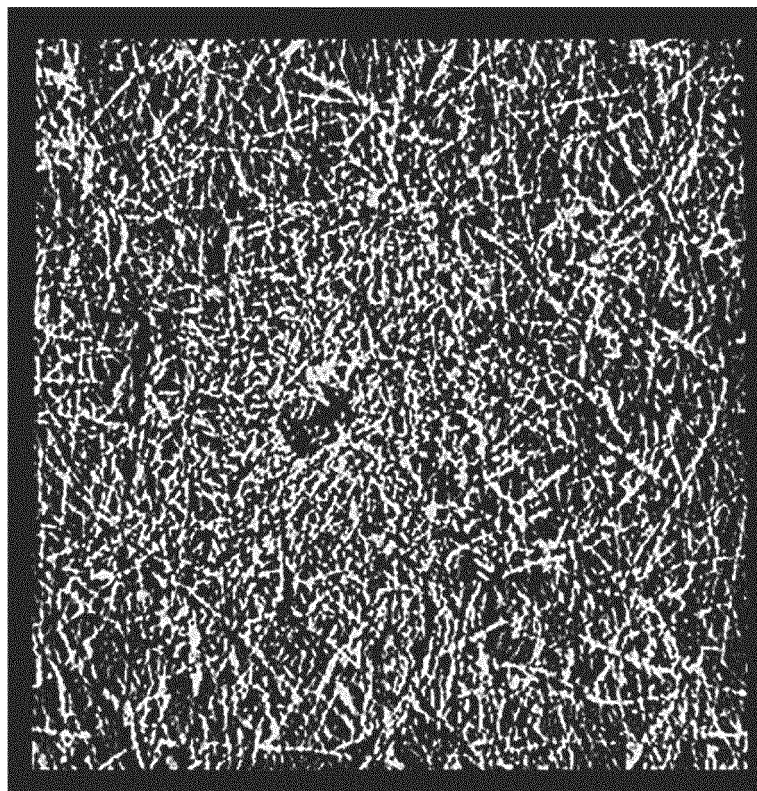


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/014392

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. D04H3/16(2006.01) i, D01D5/08(2006.01) i
 FI: D04H3/16, D01D5/08C

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. D04H3/16, D01D5/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2020

Registered utility model specifications of Japan 1996-2020

Published registered utility model applications of Japan 1994-2020

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2019/031286 A1 (KURARAY CO., LTD.) 14.02.2019 (2019-02-14), claims, example 1, fig. 1, 2	4-10
X	JP 08-144166 A (TOYOBO CO., LTD.) 04.06.1996 (1996-06-04), claims, example 1	4-10
A	JP 03-260153 A (MITSUI PETROCHEMICAL INDUSTRIES, LTD.) 20.11.1991 (1991-11-20), claims	1-10
A	JP 2000-238156 A (TORAY INDUSTRIES, INC.) 05.09.2000 (2000-09-05), claims	1-10

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search
15.06.2020

Date of mailing of the international search report
23.06.2020

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Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/JP2020/014392

WO 2019/031286 A1 14.02.2019 US 2020/171789 A1
claims, example 1, fig. 1, 2
CN 110998006 A

JP 08-144166 A 04.06.1996 (Family: none)

JP 03-260153 A 20.11.1991 (Family: none)

JP 2000-238156 A 05.09.2000 (Family: none)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H06136656 A [0004]