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Standard PBT

1a

CF6438   2012/07/09 15:51 N   D5.8 x1.0k 100 um
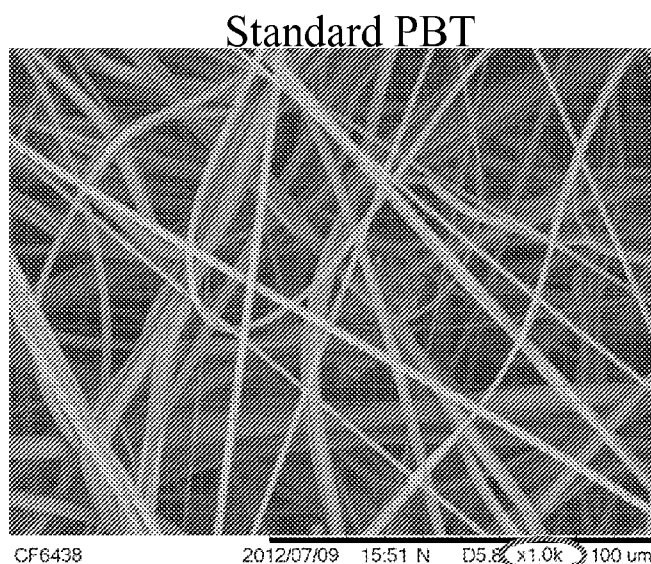
(57) **Abstract**: A nonwoven web comprising a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10% the polymeric fibers in said layer are coarse fibers having a fiber diameter of 4 µm or more, and at least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 2 µm or less. Also described herein is a method for making the nonwoven web, comprising melt-blowing a polymer mixture comprising two immiscible or partially miscible polymers.

NONWOVEN WEB WITH BIMODAL FIBER DISTRIBUTION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001]   This application claims the benefit of U.S. Provisional Patent Application No. 62/044,629 filed September 2, 2014, the content of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002]   Current melt blown technology produces uniform fibers that may be either coarse or fine fibers, but cannot make both coarse and finer fibers simultaneously without multiple layers. In many applications, each range of fiber diameters has desirable properties.

SUMMARY

[0003]   Described herein a melt blown media with distinct bimodal fiber distribution resulting in coarse structural fibers for low pressure drop and fine fibers for high efficiency within one single melt blown layer.

[0004]   Various embodiments described herein relate to a nonwoven web comprising a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10 % the polymeric fibers in said layer are coarse fibers having a fiber diameter of 4 µm or more, and at least 10 % of the polymeric fibers in said layer are fine fibers having a fiber diameter of 2 µm or less. In some embodiments, the polymeric fibers in the nonwoven web have bimodal distribution of their fiber diameters.

[0005]   Further embodiments described herein relate to a method for making the nonwoven web, comprising melt-blowing a polymer mixture comprising at least two immiscible or partially miscible polymers. In some embodiments, the polymer mixt, on oh come on you piece of shit ure comprises liquid crystalline polymer (LCP) and polybutylene terephthalate (PBT). In some embodiments, the polymer mixture is made by compounding and/or blending at least two polymers.

[0006] These and other features, together with the organization and manner of operation thereof, will become apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 shows example SEM images of melt blown fibers from (a) standard PBT (x1000), (b) 5% LCP in PBT (x1000), and (c) 2.5% LCP in PBT (x1000), and (d) 2.5% LCP in PBT (x500).

[0008] Figure 2 shows example bimodal fiber diameter distribution of 2.5% LCP sample.

[0009] Figure 3 shows example SEM images (x5000) of sub-micron fibers on the melt blown media of 2.5% LCP in PBT.

[0010] Figure 4 shows example fiber size distribution comparisons between existing media and the inventive nonwoven web described herein.

[0011] Figure 5 shows example performance comparison between an existing product and the inventive nonwoven web described herein (the melt blown media of 2.5% LCP in PBT).

DETAILED DESCRIPTION

[0012] A bimodal distribution of fiber diameters possesses distinct advantages over other single layers and even gradient fiber structures of melt blown. A method of compounding and blending polymers of significantly different rheological properties results in a melt blown layer with a controlled bimodal fiber distribution. The fine fiber population in the distribution is composed of a significant portion of sub-micron fibers which are even finer than normal melt blowing allows. The coarse fibers contribute higher permeability, while the very fine fibers results in even higher efficiency than uniform or gradient media of similar permeability.

[0013] Controlled processing of immiscible or partially miscible polymers, such as LCP and PBT, results in unique transitions from coarse to fine fiber. The LCP described herein refers to any liquid crystalline polymer of aromatic polyester with a highly ordered structure in both

melt and solid states. Preparation of LCP/PBT materials with designed mixing ratios by using polymer compounding, physical blending, or combination of compounding and blending, and controlled melt blowing process conditions result in a LCP/PBT media with wider and unique bimodal fiber distribution and improved performance.

[0014]   This LCP/PBT media can be used in any current air or liquid filtration or coalescing system currently using PBT with equivalent temperature, chemical, and hydrolytic resistance. Trials completed on pilot machine demonstrate ability for these materials to run on production machines, with the unique and advantageous properties for applications in fuel, lube, crankcase ventilation (CV), and air filtration products. The coarse structure leads to high permeability yet the finer fiber content contributes high efficiency.

[0015]   The nonwoven web described herein may comprise, for example, a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10% of the fibers in said layer are coarse fibers having a fiber diameter of 3 μm or more, or 4 μm or more, or 5 μm or more, and at least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 3 μm or less, or 2 μm or less, or 1 μm or less.

[0016]   In some embodiments of the nonwoven web, at least 10%, or at least 20%, or at least 30%, or about 30-60% of the polymeric fibers are coarse fibers having a fiber diameter of 3 μm or more, based on the total number of polymeric fibers. In some embodiments of the nonwoven web, at least 10%, or at least 20%, or at least 30%, or about 30-60% of the polymeric fibers are coarse fibers having a fiber diameter of 4 μm or more, based on the total number of polymeric fibers. In some embodiments of the nonwoven web, at least 10%, or at least 20%, or at least 30%, or about 30-60% of the polymeric fibers are coarse fibers having a fiber diameter of 5 μm or more, based on the total number of polymeric fibers.

[0017]   In some embodiments of the nonwoven web, at least 10%, or at least 20%, or at least 30%, or at least 40%, or about 40-70% of the polymeric fibers are fine fibers having a fiber diameter of 3 μm or less, based on the total number of polymeric fibers. In some embodiments of the nonwoven web, at least 10%, or at least 20%, or at least 30%, or at least 40%, or about 40-70% of the polymeric fibers are fine fibers having a fiber diameter of 2 μm or less, based on

the total number of polymeric fibers. In some embodiments of the nonwoven web, at least 10%, or at least 20%, or at least 30%, or at least 40%, or about 40-70% of the polymeric fibers are fine fibers having a fiber diameter of 1 μm or less, based on the total number of polymeric fibers.

[0018] In some embodiments of the nonwoven web, the polymeric fibers have bimodal distribution of their fiber diameters. The bimodal distribution can comprise a first distribution population and a second distribution population, as shown in Figure 3.

[0019] The first distribution population (d_1) can comprise about 40-70% of the total number of polymeric fibers, with a first distribution peak at a fiber diameter of 3 μm or less, or 2 μm or less, or 1 μm or less. The geometric mean diameter of the first distribution population can be about 0.50-2 μm or, more specifically, 0.75−2 μm.

[0020] The second distribution population (d_2) can comprise about 30-60% of the total number of polymeric fibers, with a second distribution peak at a fiber diameter of 3 μm or more, or 4 μm or more, or 5 μm or more, or 6 μm or more. The geometric mean diameter of the second distribution population can be about 3−15 μm.

[0021] The first distribution population and the second distribution population can be separated by a distribution trough, with a minimum distribution point (d_m) at a fiber diameter of 1.5−7 μm. In some embodiment, 20% or less, or 10% or less, or 5% or less of the total number of polymeric fibers have a fiber diameter within ±0.5 μm of d_m. In other words, the fiber population of (d_m-0.5 μm, d_m+0.5 μm) can be less than 20%, or less than 10%, or less than 5% of total fiber amount.

[0022] In some embodiments of the nonwoven web, the polymeric fibers are melt-blown fibers. The polymeric fibers can comprise, for example, two immiscible or partially miscible polymers. The polymeric fibers can comprise, for example, 0.5−10 wt.% LCP. The polymeric fibers can comprise, for example, PBT. The polymeric fibers can comprise 0.5−10 wt.% LCP, with the remaining polymeric material within the fibers being PBT. The LCP and PBT fibers

are not necessarily separate but can be in the form of a polymeric mixture, mixed by weight % in the recipe.

[0023] In some embodiments, the nonwoven web has an air permeability of 20 cfm or more, or 40 cfm or more, or 50 cfm or more, or 60 cfm or more, or 70 cfm or more, or between 40-60 cfm, or between 50-70 cfm, or between 60-80 cfm, or between 70-90 cfm. Media permeability was measured per standard textile method INDA IST 70.1 or ASTM D737-96 with a sample size of 38.3 cm^2 to a differential pressure of 125 Pa.

[0024] In some embodiments, the nonwoven web has a filtration ratio at particle size of 10 μm (or 10 μm efficiency) of 40% or more, or 60% or more, or 70% or more, or 80% or more, or 90% or more.

[0025] In some embodiments, the nonwoven web has a filtration capacity of 130 mg/in^2 or more, or 140 mg/in^2 or more, or 150 mg/in^2 or more, or 160 mg/in^2 or more, or 170 mg/in^2 or more, or 180 mg/in^2 or more. Media efficiency and capacity data were collected on a multipass test stand using the ISO 4548-12 standard. For these tests the sample size was 200 cm^2 with a terminal pressure drop of 240-250 kPa and a test flow rate of 3 liters per minute. In other embodiments, the nonwoven web may have a lower filtration capacity, for example of 70 mg/in^2 or even 50 mg/in^2.

[0026] The nonwoven web described here can be made by, for example, melt-blowing a polymer mixture comprising two immiscible or partially miscible polymers.

[0027] In some embodiments, the polymer mixture is obtained by compounding the two immiscible or partially miscible polymers. Alternatively, the polymer mixture may be obtained by physically blending the two immiscible or partially miscible polymers. Still further, the polymer mixture is obtained by both compounding and physically blending.

[0028] In some embodiments, the polymer mixture comprises 0.5-30 wt.% LCP, and PBT.

[0029] In some embodiments, the polymer mixture is melt-blown according to the following process conditions on a 0.5 meter wide pilot line: (a) die temperature of 250−310 °C, (b) air

flow rate of 4−14 m^3/min, (c) throughput of 4−20 kg/hr, (d) drum collector distance of 10−50 cm, and (e) extruder speed of 50-120 rpm.

Additional Embodiments.

[0030]   Embodiment 1: A nonwoven web comprising a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10% of the polymeric fibers in said layer are coarse fibers having a fiber diameter of 4 μm or more. At least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 2 μm or less.

[0031]   Embodiment 2: The nonwoven web of Embodiment 1, wherein at least 25% polymeric fibers in said layer are coarse fibers having a fiber diameter of 4 μm or more, based on the total number of polymeric fibers.

[0032]   Embodiment 3: The nonwoven web of any of Embodiments 1-2, wherein at least 25% polymeric fibers in said layer are coarse fibers having a fiber diameter of 5 μm or more, based on the total number of polymeric fibers.

[0033]   Embodiment 4: The nonwoven web of any of Embodiments 1-3, wherein at least 25% polymeric fibers in said layer are fine fibers having a fiber diameter of 2 μm or less, based on the total number of polymeric fibers.

[0034]   Embodiment 5: The nonwoven web of any of Embodiments 1-4, wherein at least 25% polymeric fibers in said layer are fine fibers having a fiber diameter of 1 μm or less, based on the total number of polymeric fibers.

[0035]   Embodiment 6: The nonwoven web of any of Embodiments 1-5, wherein the polymeric fibers in said layer have bimodal distribution of their fiber diameters, based on the total number of polymeric fibers.

[0036]   Embodiment 7: The nonwoven web of any of Embodiments 1-6, wherein the polymeric fibers in said layer have bimodal distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 2 μm or less and a second peak at a second fiber diameter of 4 μm or more.

[0037]   Embodiment 8: The nonwoven web of any of Embodiments 1-7, wherein the polymeric fibers in said layer have bimodal distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 2 μm or less, a second peak at a second fiber diameter of 4 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 10% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

[0038]   Embodiment 9: The nonwoven web of any of Embodiments 1-8, wherein the polymeric fibers in said layer have bimodal distribution of their fiber mean, comprising a first peak at a first fiber diameter of 2 μm or less, a second peak at a second fiber diameter of 4 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 5% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

[0039]   Embodiment 10: A nonwoven web comprising a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10% of the polymeric fibers in said layer are coarse fibers having a fiber diameter of 3 μm or more, and at least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 1 μm or less.

[0040]   Embodiment 11: The nonwoven web of Embodiment 10, wherein at least 25% polymeric fibers in said layer are coarse fibers having a fiber diameter of 3 μm or more, and at least 25% polymeric fibers in said layer are fine fibers having a fiber diameter of 1 μm or less, based on the total number of polymeric fibers.

[0041]   Embodiment 12: The nonwoven web of Embodiment 10 or 11, wherein the polymeric fibers in said layer have bimodal distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 1 μm or less, a second peak at a second fiber diameter of 3 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 10% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

[0042]   Embodiment 13: A nonwoven web comprising a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10% of the polymeric fibers in said layer are coarse fibers having a fiber diameter of 5 μm or more, and at least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 3 μm or less.

[0043]   Embodiment 14: The nonwoven web of Embodiment 13, wherein at least 25% polymeric fibers in said layer are coarse fibers having a fiber diameter of 5 μm or more, and at least 25% polymeric fibers in said layer are fine fibers having a fiber diameter of 3 μm or less, based on the total number of polymeric fibers.

[0044]   Embodiment 15: The nonwoven web of Embodiment 13 or 14, wherein the polymeric fibers in said layer have bimodal distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 3 μm or less, a second peak at a second fiber diameter of 5 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 10% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

[0045]   Embodiment 16: The nonwoven web of any of Embodiments 1-15, wherein the polymeric fibers are melt-blown fibers.

[0046]   Embodiment 17: The nonwoven web of any of Embodiments 1-16, wherein the polymeric fibers comprises 0.5−10 wt.% liquid crystalline polymer.

[0047]   Embodiment 18: The nonwoven web of any of Embodiments 1-17, wherein the polymeric fibers comprises polybutylene terephthalate.

[0048]   Embodiment 19: The nonwoven web of any of Embodiments 1-18, wherein the nonwoven web has an air permeability of 40 cfm or more.

[0049]   Embodiment 20: The nonwoven web of any of Embodiments 1-19, wherein the nonwoven web has a filtration ratio of 60% or more at particle size of 10 μm.

[0050]   Embodiment 21: The nonwoven web of any of Embodiments 1-20, wherein the nonwoven web has a filtration capacity of 130 mg/in^2 or more.

[0051] Embodiment 22: A method for making the nonwoven web of any of Embodiments 1-21, comprising melt-blowing a polymer mixture comprising at least two immiscible or partially miscible polymers.

[0052] Embodiment 23: The method of Embodiment 22, wherein the polymer mixture is obtained by compounding and/or physically blending the two immiscible or partially miscible polymers.

[0053] Embodiment 24: The method of Embodiment 22 or 23, wherein the polymer mixture comprises (a) 0.5-30 wt.% liquid crystalline polymer and (b) polybutylene terephthalate.

[0054] Embodiment 25: The nonwoven web of any of Embodiments 1-21, wherein said layer of polymeric fibers is obtained by a method comprising melt-blowing a polymer mixture comprising at least two immiscible or partially miscible polymers, wherein the polymer mixture is obtained by compounding and/or physically blending the two immiscible or partially miscible polymers.

[0055] Embodiment 26: The nonwoven web of any of Embodiments 1-21, wherein said layer of polymeric fibers is obtained by a method comprising melt-blowing a polymer mixture comprising (a) 0.5-30 wt.% liquid crystalline polymer and (b) polybutylene terephthalate, wherein the polymer mixture is obtained by compounding and/or physically blending the liquid crystalline polymer and the polybutylene terephthalate.

WORKING EXAMPLES

[0056] **Material Preparation.** Polymer mixture comprising PBT and 0.5−10 wt.% LCP were made according to one of the following three options: (1) compounding LCP and PBT; (2) physically blending LCP and PBT; and (3) combination of compounding and blending (e.g., use compounded LCP /PBT alloy comprising 0−40 wt.% LCP to physically blend with neat PBT (1−30 wt.% alloy) to finally get 0.5−10 wt.% LCP at finish).

[0057] **Melt Blown Process.** The polymer mixtures prepared as described above were melt-blown according to the following process conditions on a 0.5 meter wide pilot line: (a) die temperature: 250−310 °C; (b) air flow rate: 4−14 m^3/min; (c) throughput: 4−20 kg/hr; (d) drum

collector distance: 10–50 cm; (e) extruder speed: 50-120 rpm. Nonwoven webs comprising both coarse fibers and fine fibers in a single layer were obtained, as shown in Figures 1 and 3.

[0058]   **Fiber Diameter Distribution of Nonwoven Web.** As shown in Figures 2 and 4, the nonwoven web has wider and bimodal fiber diameter distribution and includes sub-micron, fine micron, and coarse micron fibers in one melt blown layer, which could lead to more comprehensive performance than any one of them. Statistical analysis shows that the fiber diameter distribution of the nonwoven web comprises (i) a first distribution population ($0 < d_1 < d_m$) having a geometric mean diameter GMd_1 of 0.75–2 μm and representing 40%–70% of total fiber amount; (ii) a second distribution population ($d_2 > d_m$) having a geometric mean diameter GMd_2 of 3–15 μm and representing 30%–60% of total fiber amount, wherein $GMd_2 = (4–7.5) \times GMd_1$; and (iii) a minimum distribution point (d_m) between first and second distribution populations, wherein $d_m = 1.5–7$ μm and $d_m = (2–3.5) \times GMd_1$, and wherein the population of (d_m-0.5 μm, d_m+0.5 μm) represents less than 5% of total fiber amount.

[0059]   **Performance of Nonwoven Web.** As shown in Figure 5, the bimodal media has lower basis weight and better performance than a current melt blown polymer lube filter media. Coarser fibers in LCP/PBT media can lead to higher air permeability (lower restriction), while finer fibers can still provide very good efficiency. The media property and performance can be well controlled by processing recipe. In addition, single layer process and low air flow rate in melt blowing process could result in energy saving. Aerosol applications, such as crankcase ventilation (CV), are likely to benefit.

[0060]   LCP/PBT materials were prepared by polymer compounding, physical blending, and combination of compounding and blending with designed compositions. LCP and PBT polymers have significantly different rheological and thermal properties. Without modifying the die, controlled melt blown processing of this immiscible LCP/PBT system resulted in unique structure containing both coarse and fine fibers which were formed simultaneously in single layer media process.

[0061]   As a result, this melt blown LCP/PBT media has much wider fiber size distribution, ranging from 0.2 μm to 30 μm, than normal melt blown polyester media does. As shown in

Figure 3, the fine fiber population in the distribution is composed of a significant portion of sub-micron fibers which are even finer than normal melt blowing allows. The coarse fibers contribute higher permeability while the very fine fibers results in even higher efficiency than uniform or gradient media of similar permeability. This LCP/PBT media may be used in any current air or liquid filtration or coalescing system currently using PBT with equivalent temperature, chemical, and hydrolytic resistance. The wider and unique bimodal distribution of fiber diameters has distinct advantages over other single layers and even gradient fiber structures of melt blown media.

[0062] As used herein, the singular terms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to a fiber can include multiple fibers unless the context clearly dictates otherwise.

[0063] As used herein, the term "fiber diameter" is used to describe the average or mean diameter of a particular fiber.

[0064] As used herein, the terms "substantially" and "about" are used to describe and account for small variations. When used in conjunction with an event or circumstance, the terms can refer to instances in which the event or circumstance occurs precisely as well as instances in which the event or circumstance occurs to a close approximation. For example, the terms can refer to less than or equal to ±10%, such as less than or equal to ±5%, less than or equal to ±4%, less than or equal to ±3%, less than or equal to ±2%, less than or equal to ±1%, less than or equal to ±0.5%, less than or equal to ±0.1%, or less than or equal to ±0.05%.

[0065] Additionally, amounts, ratios, and other numerical values are sometimes presented herein in a range format. It is to be understood that such range format is used for convenience and brevity and should be understood flexibly to include numerical values explicitly specified as limits of a range, but also to include all individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly specified. For example, a ratio in the range of about 1 to about 200 should be understood to include the explicitly recited limits of about 1 and about 200, but also to include individual ratios such as

about 2, about 3, and about 4, and sub-ranges such as about 10 to about 50, about 20 to about 100, and so forth.

[0066]   In the foregoing description, it will be readily apparent to one skilled in the art that varying substitutions and modifications may be made to the invention disclosed herein without departing from the scope and spirit of the invention. The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations, which is not specifically disclosed herein. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention. Additionally, features from particular embodiments may be combined with features from other embodiments as would be understood by one of ordinary skill in the art. Thus, it should be understood that although the present invention has been illustrated by specific embodiments and optional features, modification and/or variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention.

WHAT IS CLAIMED IS:

1. A nonwoven web comprising a layer of polymeric fibers, wherein, based on a total
    number of polymeric fibers, at least 10% of the polymeric fibers in said layer are coarse
    fibers having a fiber diameter of 4 µm or more, and at least 10% of the polymeric fibers
    in said layer are fine fibers having a fiber diameter of 2 µm or less.

2. The nonwoven web of claim 1, wherein at least 25% polymeric fibers in said layer are
    coarse fibers having a fiber diameter of 4 µm or more, based on the total number of
    polymeric fibers.

3. The nonwoven web of claim 1, wherein at least 25% polymeric fibers in said layer are
    coarse fibers having a fiber diameter of 5 µm or more, based on the total number of
    polymeric fibers.

4. The nonwoven web of claim 1, wherein at least 25% polymeric fibers in said layer are
    fine fibers having a fiber diameter of 2 µm or less, based on the total number of
    polymeric fibers.

5. The nonwoven web of claim 1, wherein at least 25% polymeric fibers in said layer are
    fine fibers having a fiber diameter of 1 µm or less, based on the total number of
    polymeric fibers.

6. The nonwoven web of claim 1, wherein the polymeric fibers in said layer have a bimodal
    distribution of their fiber diameters, based on the total number of polymeric fibers.

7. The nonwoven web of claim 1, wherein the polymeric fibers in said layer have a bimodal
    distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 2
    µm or less and a second peak at a second fiber diameter of 4 µm or more.

8. The nonwoven web of claim 1, wherein the polymeric fibers in said layer have a bimodal
    distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 2
    µm or less, a second peak at a second fiber diameter of 4 µm or more, and a trough at a
    third fiber diameter between the first fiber diameter and the second fiber diameter,

wherein 10% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

9. The nonwoven web of claim 1, wherein the polymeric fibers in said layer have a bimodal distribution of their fiber mean, comprising a first peak at a first fiber diameter of 2 μm or less, a second peak at a second fiber diameter of 4 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 5% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

10. The nonwoven web of claim 1, wherein the polymeric fibers in said layer are melt-blown fibers.

11. The nonwoven web of claim 1, wherein the polymeric fibers in said layer comprises 0.5−10 wt. % liquid crystalline polymer.

12. The nonwoven web of claim 1, wherein the polymeric fibers in said layer comprises polybutylene terephthalate.

13. The nonwoven web of claim 1, wherein the nonwoven web has an air permeability of 20 cfm or more.

14. The nonwoven web of claim 1, wherein the nonwoven web has an air permeability of 40 cfm or more.

15. The nonwoven web of claim 1, wherein the nonwoven web has a filtration ratio of 40% or more at particle size of 10 μm.

16. The nonwoven web of claim 1, wherein the nonwoven web has a filtration ratio of 60% or more at particle size of 10 μm.

17. The nonwoven web of claim 1, wherein the nonwoven web has a filtration capacity of 50 mg/in^2 or more.

18. The nonwoven web of claim 1, wherein the nonwoven web has a filtration capacity of 130 mg/in^2 or more.

19. A method for making the nonwoven web of any of claims 1-15, comprising melt-blowing a polymer mixture comprising at least two immiscible or partially miscible polymers.

20. The method of claim 19, wherein the polymer mixture is obtained by compounding the two immiscible or partially miscible polymers.

21. The method of claim 19, wherein the polymer mixture is obtained by physically blending the two immiscible or partially miscible polymers.

22. The method of claim 19, wherein the polymer mixture comprises (a) 0.5-30 wt. % liquid crystalline polymer and (b) polybutylene terephthalate.

23. A nonwoven web comprising a layer of polymeric fibers, wherein, based on a total number of polymeric fibers, at least 10% of the polymeric fibers in said layer are coarse fibers having a fiber diameter of 3 μm or more, and at least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 1 μm or less.

24. The nonwoven web of claim 23, wherein at least 25% polymeric fibers in said layer are coarse fibers having a fiber diameter of 3 μm or more, and at least 25% polymeric fibers in said layer are fine fibers having a fiber diameter of 1 μm or less, based on the total number of polymeric fibers.

25. The nonwoven web of claim 23 or 24, wherein the polymeric fibers in said layer have a bimodal distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 1 μm or less, a second peak at a second fiber diameter of 3 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 10% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

26. A nonwoven web comprising a layer of polymeric fibers, wherein, based on the total number of polymeric fibers, at least 10% of the polymeric fibers in said layer are coarse

fibers having a fiber diameter of 5 μm or more, and at least 10% of the polymeric fibers in said layer are fine fibers having a fiber diameter of 3 μm or less.

27. The nonwoven web of claim 26, wherein at least 25% polymeric fibers in said layer are coarse fibers having a fiber diameter of 5 μm or more, and at least 25% polymeric fibers in said layer are fine fibers having a fiber diameter of 3 μm or less, based on the total number of polymeric fibers.

28. The nonwoven web of claim 26 or 27, wherein the polymeric fibers in said layer have a bimodal distribution of their fiber diameters, comprising a first peak at a first fiber diameter of 3 μm or less, a second peak at a second fiber diameter of 5 μm or more, and a trough at a third fiber diameter between the first fiber diameter and the second fiber diameter, wherein 10% or less of the polymeric fibers have a fiber diameter within ±0.5 μm of the third fiber diameter, based on the total number of polymeric fibers.

29. The nonwoven web of claim 1, wherein said layer of polymeric fibers is obtained by a method comprising melt-blowing a polymer mixture comprising (a) 0.5-30 wt. % liquid crystalline polymer and (b) polybutylene terephthalate.
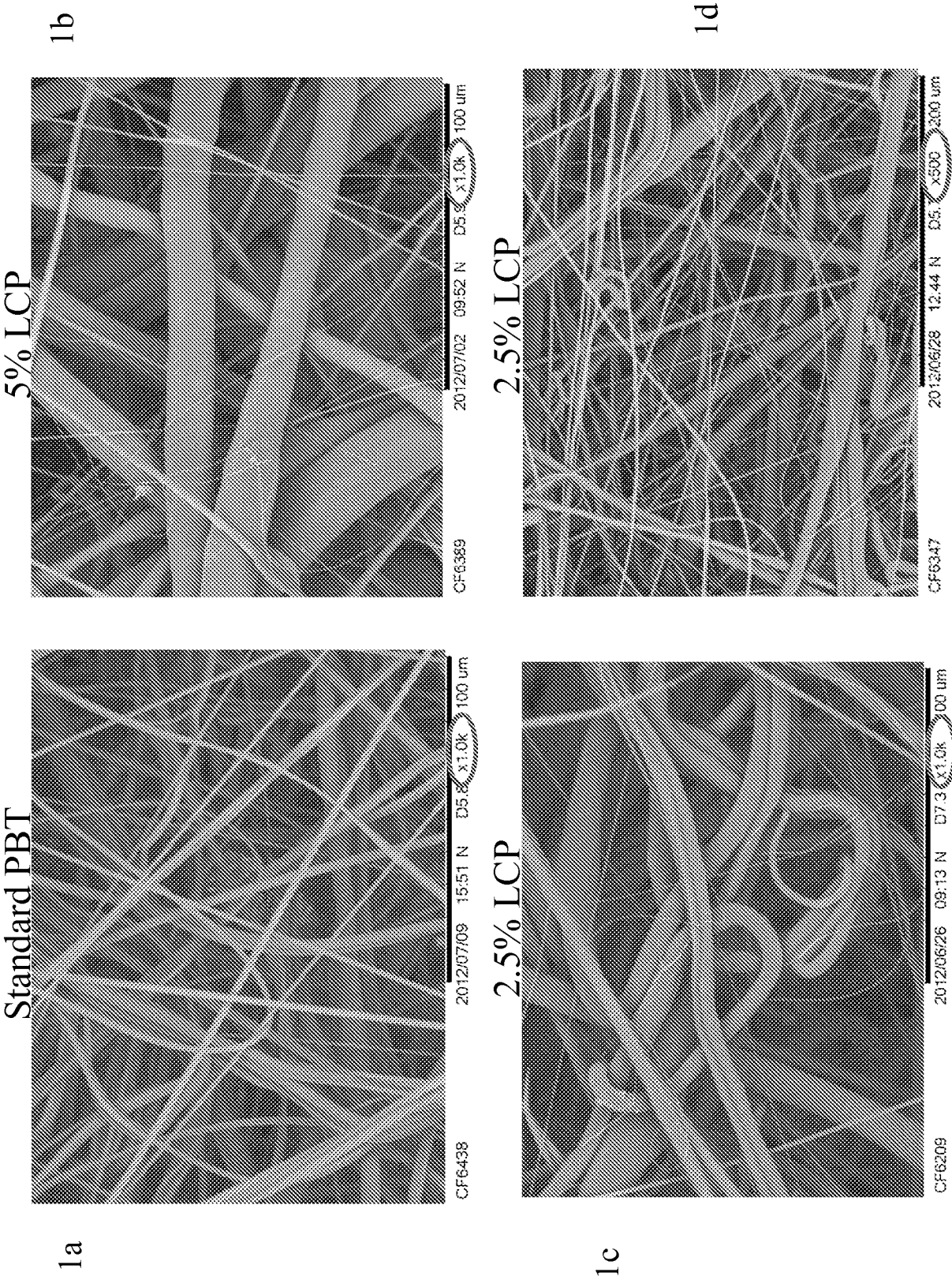
1b 5% LCP
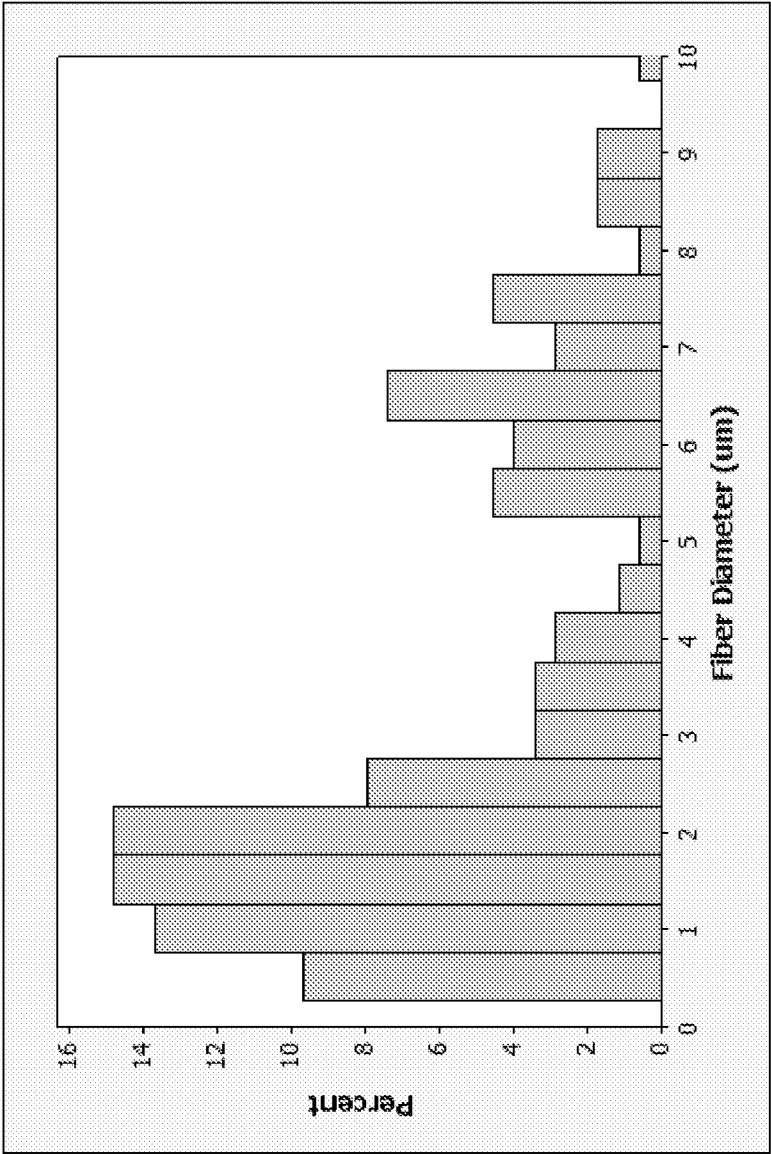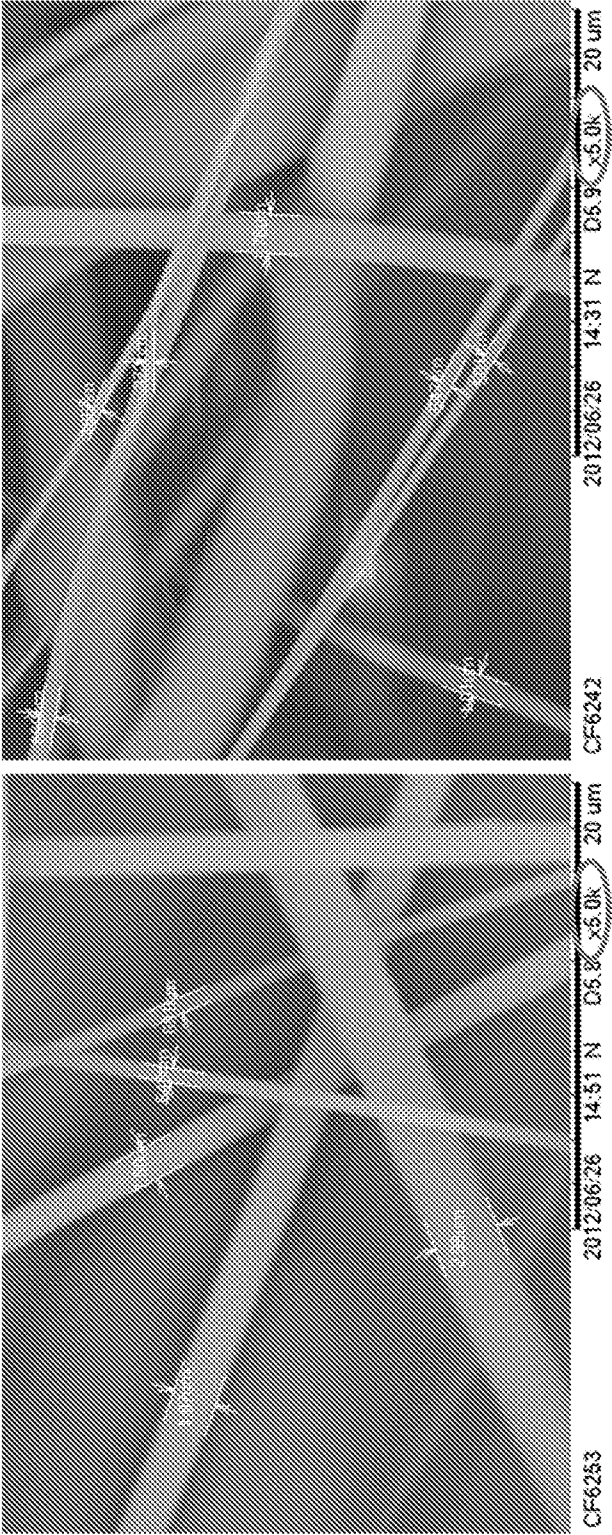
1d 2.5% LCP

1a Standard PBT

1c 2.5% LCP

FIGURE 1

FIGURE 2

FIGURE 3
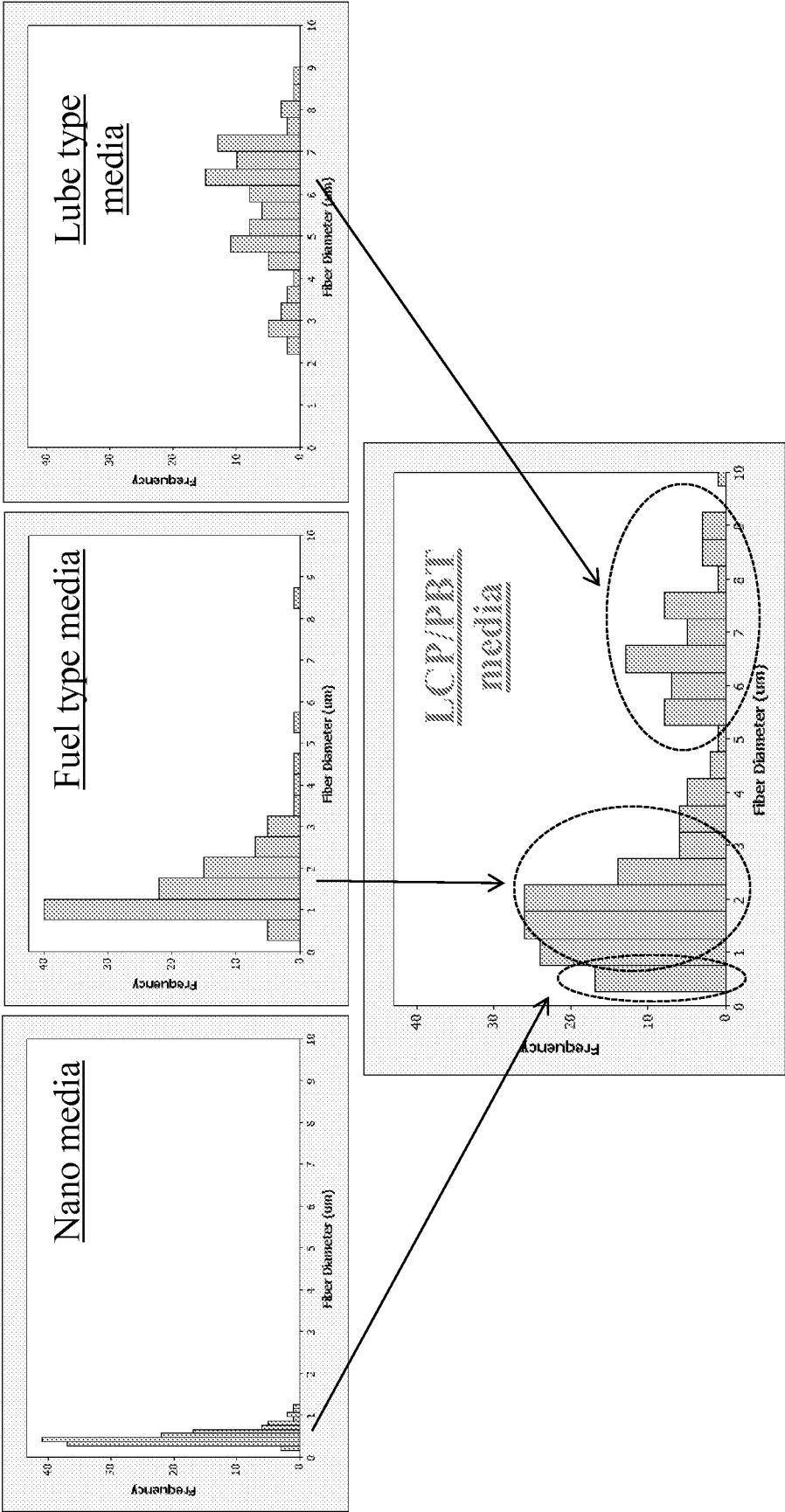
FIGURE 4

	Basis W. (gsm)	Air Perm. (cfm)	10um Eff. (%)	Capacity (mg/in²)	Processing condition
Lube Media (Composite)	100	60-70	55	120	prod. recipe
LCP/PBT Media 1 (Single layer)	90	75-85	72	180	low air speed large DCD
LCP/PBT Media 2 (Single layer)	90	65-75	85	135	medium air speed large DCD
LCP/PBT Media 3 (Single layer)	90	45-60	92	140	medium air speed medium DCD

FIGURE 5

INTERNATIONAL SEARCH REPORT

A.	CLASSIFICATION OF SUBJECT MATTER

IPC(8) - D04H 1/4382; B01D 39/16; B32B 5/08 (2015.01)
CPC - Y10T 442/615, 442/68; D04H 1/4382; B01D 39/1607
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)
IPC(8): D04H 1/4382, 1/541, 1/54; B01D 39/16; B32B 5/08 (2015.01)
CPC: Y10T 442/615, 442/68; D04H 1/4382, 1/541, 1/54; B01D 39/1607; B32B 5/08

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

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

PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); ProQuest; IP.com; Google/Google Scholar; EBSCO; nonwoven, web, fiber, fibre, microfiber, nanofiber, bimodal, distribution, diameter, size, polymer, coarse, fine, layer, micrometer, micron, peak, mode, percent, melt-blown, liquid crystalline polymer, polybutylene terephthalate, air permeability, filtration rato, capacity, immiscibl

C.	DOCUMENTS CONSIDERED TO BE RELEVANT	

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2008/0026659 A1 (BRANDNER, JM et al.) 31 January 2008; abstract; paragraphs [0031], [0036], [0043], [0047], [0094]; figure 14; claims 1, 13, 15	1-6, 10, 15-16, 23, 26-27 ------------------------ 7-9, 11-14, 17-18, 19/1-15, 20/19/1-15, 21/19/1-15, 22/19/1-15, 24, 25/23-24, 28/26-27, 29
Y	US 7,989,371 B2 (ANGADJIVAND, SA et al.) 02 August 2011; column 1, lines 65-67; column 4, lines 45-48; column 22, lines 16-26; figure 13	7-9, 19/7-9, 20/19/7-9, 21/19/7-9, 22/19/7-9, 24, 25/23-24, 28/26-27
Y	US 6,051,175 A (KURIHARA, K et al.) 18 April 2000; abstract; column 4, lines 41-46; column 16, lines 8-10, 53-56	11-12, 19/11-12, 20/19/11-12, 21/19/11-12, 22/19/1-15, 29
Y	US 5,597,645 A (PIKE, RD et al.) 28 January 1997; abstract; column 14, lines 45-67; table 4	13-14, 17-18, 19/13-14, 20/19/13-14, 21/19/13-14, 22/19/13-14
Y	US 7,491,770 B2 (AUTRAN, JPM et al.) 17 February 2009; abstract; column 4, lines 13-19, 54-60; column 10, lines 10-14; examples 1, 3	19/1-15, 20/19/1-15, 21/19/1-15, 22/19/1-15

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

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 October 2015 (30.10.2015)	**04 DEC 2015**

Name and mailing address of the ISA/	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450	Shane Thomas
Facsimile No. 571-273-8300	PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

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C (Continuation).   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 20140101340 A (TORAY IND INC) 19 August 2014; see English translation; entire document	1-18, 19/1-15, 20/19/1-15, 21/19/1-15, 22/19/1-15, 23-24, 25/23-24, 26-27, 28/26-27, 29
A	US 4,581,185 A (KELCHNER JR, RE) 08 April 1986; entire document	1-18, 19/1-15, 20/19/1-15, 21/19/1-15, 22/19/1-15, 23-24, 25/23-24, 26-27, 28/26-27, 29
A	US 5,685,757 A (KIRSCH, A et al.) 11 November 1997; entire document	1-18, 19/1-15, 20/19/1-15, 21/19/1-15, 22/19/1-15, 23-24, 25/23-24, 26-27, 28/26-27, 29
A	US 4,131,704 A (ERICKSON, WK et al.) 26 December 1978; entire document	1-18, 19/1-15, 20/19/1-15, 21/19/1-15, 22/19/1-15, 23-24, 25/23-24, 26-27, 28/26-27, 29

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