(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 September 2011 (01.09.2011)

PCT

(10) International Publication Number
WO 2011/106535 A2

(51) International Patent Classification:
B01D 69/10 (2006.01) *B01D 69/02* (2006.01)

(21) International Application Number:
PCT/US2011/026091

(22) International Filing Date:
24 February 2011 (24.02.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

61/308,488	26 February 2010 (26.02.2010)	US
61/330,462	3 May 2010 (03.05.2010)	US
61/383,569	16 September 2010 (16.09.2010)	US
61/383,487	16 September 2010 (16.09.2010)	US

(71) Applicant *(for all designated States except US)*: **CLARCOR INC.** [US/US]; 840 Cresent Drive, Suite 600, Franklin, TN 37067 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **LI, Lei** [CN/US]; 8354 Sea Mist Court, West Chester, OH 45069 (US). **GREEN, Thomas, B.** [US/US]; 6770 Stillington Drive, Liberty Township, OH 45011 (US).

(74) Agent: **HEINISCH, Andrew, J.**; Reinhart Boerner Van Dueren P.C., 2215 Perrygreen Way, Rockford, IL 61107 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO,

[Continued on next page]

(54) Title: FINE FIBER LIQUID PARTICULATE FILTER MEDIA

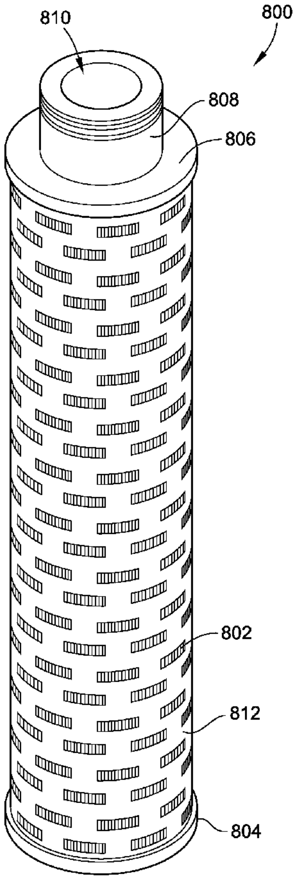

FIG. 23

(57) Abstract: A filter media for liquid particulate filtration applications is provided. The filter media includes a substrate and fine fibers, which are compressed together.

WO 2011/106535 A2

DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

FINE FIBER LIQUID PARTICULATE FILTER MEDIA

FIELD OF THE INVENTION

[0001] This invention generally relates to a filter media, and particularly to a composite filter media including fine fibers for liquid particulate filtration applications and methods of making the same.

BACKGROUND OF THE INVENTION

[0002] Fluid streams such as liquid flows and gaseous flows (e.g. air flows) often carry particulates that are often undesirable contaminants entrained in the fluid stream. Filters are commonly employed to remove some or all of the particulates from the fluid stream.

[0003] Filter media including fine fibers formed using an electrostatic spinning process is also known. Such prior art includes Filter Material Construction and Method, U.S. Patent No. 5,672,399; Cellulosic/Polyamide Composite, U.S. Patent Publication No. 2007/0163217; Filtration Medias, Fine Fibers Under 100 Nanometers, And Methods, U.S. Patent Publication No. 2009/0199717; Integrated Nanofiber Filter Media, U.S. Patent Publication No. 2009/0266759; Filter Media Having Bi-Component Nanofiber Layer, U.S. Provisional Patent Application No. 61,047,455; Expanded Composite Filter Media Including Nanofiber Matrix and Method, U.S. Provisional Patent Application No. 61/308,488; and Compressed Nanofiber Composite Media, U.S. Provisional Patent Application No. 61/330,462, the entire disclosures of which are incorporated herein by reference thereto.

[0004] The invention provides improved filter medias for various liquid particulate filtration applications. These and other advantages of the invention, as well as additional inventive features, will be apparent from the description of the invention provided herein.

BRIEF SUMMARY OF THE INVENTION

[0005] A liquid is generally much more viscous than a gas, and thus results in a higher drag force. Therefore, liquid filtration applications pose unique challenges when compared to gas or air filtration applications, and particularly relative to fine fiber filter medias. For example, a liquid has a much greater tendency to pull particulates with it than a gas. Thus, the interception capability of a filter media for liquid filtration applications is significantly worse than gas or air filtration applications. In fact, higher the viscosity of a liquid, the lower the interception by a filter media. For example, a filtration efficiency of a filter media can drop from about 90% for an air filtration application to about 20% for a diesel fuel filtration application. Therefore, a filter media designed for air or gas filtration applications generally cannot meet filtration requirements of liquid filtration applications.

[0006] Filter medias including nanofibers have been known in air/gas filtration applications. However, the Applicants do not believe nanofibers have typically been used in liquid filters due to fluid characteristics of liquids. In fact, preliminary testings of fine fiber air filter medias for liquid applications for particulates/contaminants showed that nanofibers made little or no differences, as if fine fibers were non-existent. This was believed to be due to particulate momentum and viscosity posed by liquid. A composite filter media according to various embodiments of the present invention provides a filter media including nanofibers that is particularly well suited for liquid particulate filtration applications, such as particulate filtration of various hydrocarbon fuels. Various fine fiber coverage, fine fiber parameters, substrates and arrangements are discussed herein that have beneficially application to liquid filters.

[0007] In one aspect, the invention provides a filter media for a liquid particulate filtration application. The filter media includes a substrate and fine fibers carried on the substrate. The substrate includes coarse fibers having an average fiber diameter that is at least 4 times larger than an average fiber diameter of the fine fibers. The fine fibers have a basis weight of at least $0.03 g/m^2$ and a linear coverage of at least about $5000\ km/m^2$.

[0008] In another aspect, the invention provides a filter element for a liquid particulate filtration application. The filter element includes a filter media, a top cap and a bottom cap.

The filter media includes a substrate and fine fibers carried on the substrate. The substrate includes coarse fibers having an average fiber diameter that is at least 4 times larger than an average fiber diameter of the fine fibers. The fine fibers have a basis weight of at least $0.03 g/m^2$ and a linear coverage of at least about 5000 km/m^2. Further, the top cap includes a fluid inlet. The filter media is sealingly attached to the top cap and the bottom cap.

[0009] In yet another aspect, the invention provides a method of forming a filter media. The method includes electrostatically spinning fine fibers having an average fiber diameter of less than 1 micron; applying the fine fibers on a substrate to provide a fine fiber basis weight of at least $0.03 g/m^2$ and a linear coverage of the fine fibers of at least about 5000 km/m^2, wherein the substrate comprising coarse fibers having an average fiber diameter of at least 4 times larger than the fine fibers; and processing the substrate with the applied fine fibers to rearrange the fine fibers on the substrate.

[0010] In another aspect, the invention provides a method of filtering a liquid. The method includes a step of providing the filter media according to any of the embodiments described herein, and a step of flowing a liquid stream through a filter media to capture particulates in the liquid stream.

[0011] Other aspects, objectives and advantages of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The accompanying drawings incorporated in and forming a part of the specification illustrate several aspects of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

[0013] FIG. 1 is a schematic cross-sectional view (e.g. relative illustrated thickness not to scale) of a filter media including tightly compacted multiple scrim layers carrying fine fibers according to an embodiment of the present invention;

[0014] FIG. 2 is a schematic cross-sectional view of the filter media of FIG. 1 in a pre-compressed state being compressed to a compressed state by a set of rollers;

[0015] FIG. 3 is a schematic illustration of a concentric sheath/core type bi-component fiber of a substrate according to an embodiment of the present invention;

[0016] FIG. 4 is a schematic illustration of an eccentric sheath/core type bi-component fiber of a substrate according to an embodiment of the present invention;

[0017] FIG. 5 is a schematic illustration of a side-by-side type bi-component fiber of a substrate according to an embodiment of the present invention;

[0018] FIG. 6 is a schematic illustration of a pie wedge type bi-component fiber of a substrate according to an embodiment of the present invention;

[0019] FIG. 7 is a schematic illustration of a hollow pie wedge type bi-component fiber of a substrate according to an embodiment of the present invention;

[0020] FIG. 8 is a schematic illustration of an islands/sea type bi-component fiber of a substrate according to an embodiment of the present invention;

[0021] FIG. 9 is a schematic illustration of a trilobal type bi-component fiber of a substrate according to an embodiment of the present invention;

[0022] FIG. 10 is a schematic illustration of tipped typed bi-component fiber of a substrate according to an embodiment of the present invention;

[0023] FIG. 11 is a schematic illustration of a system for making a filter media according to an embodiment of the present invention;

[0024] FIG. 12(A) is a Scanning Electron Microscopic image showing bi-component fibers and the fine fibers of a composite media produced using the system of FIG. 11 taken at a magnification level x300;

[0025] FIG. 12(B) is a Scanning Electron Microscopic image showing bi-component fibers and the fine fibers of a composite media produced using the system of FIG. 11 taken at a magnification level x1,000;

[0026] FIG. 12(C) is a Scanning Electron Microscopic image showing bonding between bi-component fibers and the fine fibers of a composite media produced using the system of FIG. 11 taken at a magnification level x2,000;

[0027] FIG. 12(D) is a Scanning Electron Microscopic image showing bonding between bi-component fibers and the fine fibers of a composite media produced using the system of FIG. 11 at a magnification level x10,000;

[0028] FIG. 13 is a schematic illustration of a system for making a filter media according to a different embodiment of the present invention;

[0029] FIG. 14 is a schematic illustration of a system for making a filter media according to yet another embodiment of the present invention;

[0030] FIG. 15 is a schematic cross-sectional view of a filter media including tightly compressed multiple scrim layers and fine fibers according to an embodiment of the present invention;

[0031] FIG. 16 is efficiency test results of first test samples;

[0032] FIG. 17 is efficiency test results of second test samples;

[0033] FIG. 18 is efficiency test results of third test samples;

[0034] FIG. 19 is a schematic cross-sectional view of a filter media according to a different embodiment of the present invention;

[0035] FIG. 20 is efficiency test results of fourth test samples;

[0036] FIG. 21 is a schematic cross sectional view of a filter media according to yet another embodiment of the present invention;

[0037] FIG. 22 is efficiency test results of fifth test samples;

[0038] FIG. 23 is a perspective view of a filter element for a liquid particulate filtration application including a pleated filter media according to an embodiment of the present invention; and

[0039] FIG. 24 is a perspective view of the pleated filter media in the filter element of FIG. 23.

[0040] While the invention will be described in connection with certain preferred embodiments, there is no intent to limit it to those embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents as included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Prior to turning to the details, some lexicography will be developed to assist in understanding the present invention. As used herein, the term "substrate" is meant to be broad in nature and meant to include any structure upon which fine fibers are carried or deposited. "Substrate" may include conventional formed filter medias such as scrims and the like that may be unwound from media rolls. Such filter medias have a fiber entanglement that typically bonded or secured together mechanically, chemically, adhesively and/or otherwise and thereby have strength such that they cannot be easily torn manually (e.g. a 1 square foot sheet typically holds up to application of tension of 5 lbs force) and have filtrations properties. "Substrate" may also include looser fiber entanglements that may not be bonded together or secured together (e.g. a 1 square foot sheet may fall apart upon application of tension of 5 lbs force). A "scrim" used as herein refers to woven or non-woven fiber entanglement, wherein the fibers are bonded and compressed into a planar formed media.

[0042] There are a few ways that nanofiber coverage can be characterized. A first way to characterize nanofiber coverage is basis weight. However, basis weight is dependent in part upon the specific gravity of the material of the nanofiber, as well as the selected size (e.g. also interchangeably referred to as fiber diameter and/or thickness) of the nanofiber. Another useful measure for characterizing nanofiber coverage is calculated lineal distance of nanofiber coverage that can be expressed in terms of kilometer per square meter (km/m2), which is useful as this measure of coverage eliminate variability due to diameter of the fine fiber and variability due to specific gravity differences among different materials that may be employed.

[0043] In many exemplary embodiments discussed herein, fine fibers having an average fiber diameter of 0.08 micron (80 nanometer) were employed. However, it will be appreciated that a double sized fiber (e.g. a 160 nanometer sized fine fiber) based on a simple area calculation (Π*R2) will have 4 times the weight; and a quadruple sized fiber will thus have 16 times the weight. An overapplication of fine fibers can lead to a plastic film that is not very pervious or porous, thus not suitable for a filter media. Using smaller fine fibers is desirable as a higher linear coverage level can be obtained. Considering that larger diameters of fine fibers will have a tendency to occupy greater void space, generally or as a rule of thumb, it is desirable that the application rate of fine fibers on a kilometer basis be lower as the fine fiber diameter increases. However, coverage on a basis weight may nevertheless increase as fine fiber diameter increases, due to the quadrupling of mass for doubling of diameter. As a rule of thumb, basis weight may increase 2-2.5 times for a doubling in fiber diameter (about 4-6 times for a quadrupling of fiber diameter); and for purposes of ease a doubling will be employed. Thus, if a 0 .15 g/m^2 is employed for an 80 nm average diameter, then for a 160 nm fiber, a coverage of 0.30 g/m^2 would be used, and a 320 nm fiber, a coverage of 0.6 g/m^2. Embodiments herein are useable for a range of fine fibers less than 1 micron, typically less than 500 nm, and more preferably smaller fibers under 150 nm. However, coverage adjustments can be made according to principles above to embodiments herein.

[0044] Herein, the terms "first", "second" or third" in reference to a filter media composite or layers is not meant to refer to a specific location. "First layer" is not intended to mean the very first layer, nor meant to be indicative of upstream or downstream location relative to another layer ("upstream" or "downstream") can be used for that purpose. Instead, such terms as "first" and "second" are used for antecedent basis purposes.

[0045] MULTILAYER COMPOSITE FILTER MEDIA

[0046] FIG. 1 is a schematic cross-sectional view of a filter media 100 according to an embodiment of the present invention. It is schematic in the sense that in reality the fine fiber layer has virtually no thickness, but for illustration and understanding, thickness is illustrated in FIG. 1 and other schematic illustrations. The filter media 100 is configured to capture solids in a liquid stream, such as hydrocarbon fuels, water and lube. In preferred embodiments, the filter media 100 includes at least two different fibers, for example, electrospun nanofibers and a substrate of coarser fibers carrying the nanofibers. As such, the filter media 100 is also referred to as a composite filter media, a composite media, or other like terms in this application. Although, the filter media 100 is particularly well suited for liquid particulate filtration applications with examples/embodiments having a significant particulate filtration impact now to liquid applications, the filter media 100 may be used in other fluid filtration applications.

[0047] In the embodiment shown in FIG. 1, the filter media 100 comprises 10 layers of substrate 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, each of which carrying fine fibers 124, 126, 128, 130, 132, 134, 136, 138, 140, 142, and a media 122 on top of the fine fibers 142. The substrate, 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 and the media 122 are formed of fibers having an average fiber diameter typically larger than that of the fine fibers. The substrate layers 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, the fine fibers 124, 126, 128, 130, 132, 134, 136, 138, 140, 142, and the media 122 are laminated and tightly compressed together to increase fiber surface area per volume and to provide a sufficient rigidity/structural integrity to filter particulates from a stream of liquid such as diesel fuel. Although this embodiment is shown with the media layer 122, this media layer is optional, and thus, the filter media 100 according to other embodiments may not include this media layer 122.

[0048] The filter media of FIG. 1 may be formed using the process shown in FIG. 2. FIG. 2 illustrates the filter media 100 in a pre-compressed state 144 and a compressed state

146. As shown, the filter media 100 in the pre-compressed state 144 has an initial thickness t' (also referred herein as an original thickness.) The filter media 100 in the pre-compressed state 144 is compressed into the compressed state 146 using a set of rollers 148, 150, wherein the initial thickness t' is reduced to a final thickness t.

[0049] In some embodiments, the filter media 100 in the pre-compressed state 144 is heated before compressing. In certain preferred embodiments, fibers of the substrate relax and reorient to increase an average distance between the fibers during heating (such as a scrim that has been at least partially compressed during the scrim production process.) As such, the substrate layers expand and loft, wherein the thickness of each of the substrate layer increases. Further, as the fibers proximate the surface of the substrate relax and reorient, the fine fibers which are carried by these fibers move and reorient with the fibers. Thus, fine fibers are extended, pushed and pulled with the larger fibers. It is believed this may created a 3-dimensional matrix for fine fibers as opposed to being merely flat or planar (such 3-dimensional matrix of fine fibers can still be considered to be and may be referred herein as a "layer" even if integrated into surface of substrate.)

[0050] In such embodiments, the initial thickness t' of the pre-compressed state 144 can increase by at least 1.5 times, 2 times, 3 times or even more via heating. In such embodiments, the final thickness t of the filter media 100 after subsequent compression of the lofted filter media 100 can be either less than, or equal to, or greater than the initial thickness t', depending on the amount of expansion during heating and the amount of reduction during compression. In other embodiments, the filter media 100 in the pre-compressed state 144 can be heated and compressed simultaneously via a set of heated calendering rollers. In such embodiments, there may not be any expansion or a very slight increase in the initial thickness t' prior to the thickness reduction to the final thickness t. In yet different embodiments, the compressed filter media 100 having the final thickness t can be heated post compression, wherein the thickness t may be increased. In some embodiments, the filter media 100 can be heated more than once. For example, the filter media 100 can be compressed by a set of rollers arranged in an oven, such that the filter media 100 is heated immediately before being compressed, while being compressed, and immediately after being compressed. In any event, it has been realized that processing of the media after deposition of the fine fibers to rearrange fine fibers into more of a 3-

dimensional matrix is advantageous. Expansion and/or compression are examples of such processing. Such processing can afford a greater porosity and may be used for better flow and/or to facilitate heavier coverage of fine fiber deposition.

[0051] In one embodiment, the final thickness t can be between about 50% and 300% of the initial thickness t', preferably between about 70% and 200% of the initial thickness t', and more preferably between 80% and 150% of the initial thickness t'. As the filter media 100 in the pre-compressed state 144 is pressed down to the final compressed state 144, the fine fibers 124, 126, 128, 130, 132, 134, 136, 138, 140, 142 become more integrated with the coarse fibers of the adjacent substrate layers 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 and form 3 dimensional fine fiber matrix within the filter media 100. Although, the filter media 100 in this embodiment includes 10 layers of substrate carrying fine fibers, other embodiments can include more or less substrate layers carrying fine fibers. For example, a filter media can include a single substrate layer carrying a sufficiently heavy coverage of fine fibers (e.g. at least about $0.3 g/m^2$.)

[0052] The substrate layers 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 can be formed of any suitable porous material. Each of the substrate layer can be formed of a same type of porous material or different types of porous material. In one embodiment, each layer of the substrate 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 comprises a formed filter media. The formed filter media comprises fibers that are bonded together. For example, the fibers of the formed filter media may be bonded together by solvent bonding, thermal bonding, and/or pressure bonding. The formed filter media can carry fine fibers and provide a structural support. The formed filter media is also referred to as a substrate filter media, a filter media substrate, a substrate, a filter media, or other like terms in the present application.

[0053] Alternatively, the substrate may comprise one or more webs of fibers which are loosely tangled together in a highly fluffed thick state and may not be bonded together as in the case of a formed filter media. Thus, the web of coarse fibers can easily be pulled apart with very little manual effort and has little structural integrity such that it is not considered a formed filter media in the conventional sense. The fibers of the web of fibers typically have a larger average fiber diameter than an average fiber diameter of the fine fibers. As such, the web of fibers is also referred to as a web of coarse fibers or other like terms in this application. A composite filter media including fine fibers integrated with such web of coarse fibers is described in Integrated Nanofiber Filter Media, US Patent Application Publication No. 2009/0266759, which is assigned to the assignee of the present application, the entire disclosures of which are incorporated herein by reference thereto.

[0054] Preferably, the substrate is formed of a multi-component filter media. As used herein, the term "multi-component filter media", "multi-component media", "multi-component fiber media" and other similar terms can be used interchangeably to refer to filter medias including at least two different materials. For example, a multi-component filter media can comprise fibers formed of a first material and fibers formed of a second material, wherein the first material and the second material are different materials. Alternatively, a multi-component filter media can be formed of fibers including at least two different materials, such as fibers including a core formed of the first material and a sheath formed of the second material, as described in detail below. A multi-component filter media including two different materials is refer to herein as "bi-component filter media", "bi-component media", and like terms.

[0055] In one preferred embodiment, each of the substrate layers 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 comprises a scrim formed of bi-component fibers including two different materials having different melting points. A composite filter media comprising fine fibers and a substrate formed of such multi-component fibers are described in Multi-Component Filter Media with Nanofiber Attachment, PCT Patent Application No. PCT/US09/50392, which is assigned to the assignee of the present application, the entire disclosure of which are incorporated herein by reference thereto.

[0056] In this embodiment, one component of the bi-component fibers of the scrim has a lower melting point than the other component. The low melt component can be any suitable polymer such as polypropylene, polyethylene, or polyester. The other component may be a polymer having a higher melting point than the low melt component, or other suitable fiber materials such as glass and/or cellulose. The bi-component fibers are bonded together and/or compressed together to form a scrim or a substrate filter media having a certain thickness.

[0057] The bi-component fibers of the scrim used as the substrate 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 can include a high melt polymer component and a low melt polymer component. For example the bi-component may comprise a high-melt polyester and a low-melt polyester, in which one has a higher melting temperature than the other. FIG. 3 schematically illustrates a bi-component fiber 22 according to one embodiment. As shown, the bi-component 22 is a concentric sheath/core type, wherein a core 24 is formed of a high melt polymeric component and a sheath 26 is formed of a low melt polymeric component.

[0058] The high melt polymer component is formed of a polymer having a higher melting temperature than the low melt polymer component. Suitable high melt polymers include, but are not limited to, polyester and polyamide. Suitable low melt polymers include polypropylene, polyethylene, co-polyester, or any other suitable polymers having a lower melting temperature than the selected high melt polymer. For example, bi-component fibers may be formed of a polyester core and a polypropylene sheath. In this embodiment, the bi-component fibers are formed of two different types of polyesters, one having a higher melting point than the other.

[0059] Other types of bi-component fibers may be used to form the substrate in other embodiments. Some examples of different types of bi-component fibers are schematically illustrated in FIGS. 4-10. An eccentric sheath/core type bi-component fiber 28 comprising a core 30 and a sheath 32 is shown in FIG. 4. This fiber is similar to the concentric sheath core fiber 22, but with the core 30 shifted off-center. The different shrinkage rates of the two polymer components can cause the fiber to curl into a helix when heated. This allows an otherwise flat fiber to develop crimp and bulk, and can result in different fiber reorientation, expansion and/or undulation of surface under heat.

[0060] FIG. 5 schematically illustrates a side-by-side type bi-component fiber 34 including a first polymer component 36 and a second polymer component 38. Depending on an application, the first polymer component may be a higher or lower melt polymer than the second polymer component. This is a further extension of the eccentric sheath/core fiber, in which both polymers occupy a part of the fiber surface. With proper polymer selection, this fiber can develop higher levels of latent crimp than the eccentric sheath/core fiber 28.

[0061] A pie wedge type bi-component fiber 40 is schematically illustrated in FIG. 6. The pie wedge fiber 40 comprises a plurality of adjacent wedges formed of a first polymer component 42 and a second polymer component 44. Each of the first polymer component 42 has a second polymer component 44 on either side. The first polymer component 42 may be a higher or lower melt polymer than the second polymer component 44. These fibers are designed to be split into the component wedges by mechanical agitation (typically hydroentangling), yielding microfibers of 0.1 to 0.2 denier in the filter media.

[0062] FIG. 7 is a schematic illustration of a hollow pie wedge type bi-component fiber 46 comprising first polymer wedges 48 and second polymer wedges 50. Again, depending on an application, the first polymer wedges 48 may be formed of a higher or lower melt polymer than the second polymer wedges 50. The hollow pie wedge fiber 46 is similar to the pie wedge fiber 40 but with a hollow center 52 core that prevents the inner tips of the wedges from joining, thus making splitting easier.

[0063] FIG. 8 is a schematic illustration of a islands/sea type bi-component fiber 54. This fiber is also known as the "pepperoni pizza" configuration where a first polymer component 56 is the pepperoni and a second polymer component 58 is the cheese. In some embodiments, the first polymer component 56 is formed of a higher melt polymer than the second polymer component 58, or the second polymer component 58 is formed of a soluble polymer. In such embodiments, this fiber allows the placement of many fine strands of high melt polymer 56 within a matrix of low melt or soluble polymer 58 that is subsequently melted or dissolved away. This allows the production of a media made of fine microfiber because the fibers are easier to process in the "pizza" form rather than as individual "pepperonis." Staple fibers can be made of 37 pepperonis on each pizza, producing fibers about 0.04 denier (about 2 microns diameter), or even finer.

[0064] The bi-component fibers may be formed into different shapes. For example, some bi-component fibers may not have a cylindrical shape with a circular cross section as the bi-component fibers described above. FIGS. 9 and 10 illustrate some examples of bi-component fibers with irregular shapes. Although, these fibers do not have a circular cross section, each has a diameter in context of the present invention. The diameter of the fibers having a non-circular cross section is measured from the outer perimeter of the fiber. FIG. 9 is a schematic illustration of a trilobal type bi-component fibers 60, 62. Each of the trilobal fibers 60, 62 comprises a first polymer component 64, 66 and a second polymer component 68, 70. Each of the trilobal fibers 60, 62 are measured by its diameter 72, 74. In some embodiments, the first polymer component 64, 66 is formed of a higher melt or lower melt polymer than the second polymer component 68, 70.

[0065] FIG. 10 is a schematic illustration of a tipped type bi-component fibers 78, 80. The fiber 78 is a tipped trilobal bi-component fiber with a first polymer center 82 and second polymer tips 84. The fiber 80 is a tipped cross bi-component fiber with a first polymer center 86 and second polymer tips 88. Preferably, the first polymer center 82, 86 is formed of a higher melt polymer than the second polymer tips 84, 88.

[0066] Now referring back to FIG. 1, the fibers of the substrates are formed to have a larger average fiber diameter than that of the fine fibers. In one embodiment, the fibers of the substrates have an average fiber diameter that is at least 4 times as that of the fine fibers. In another embodiment, the fibers of the substrates can have an average fiber diameter of greater than about 0.6 micron, preferably greater than about 3 micron, and more preferably, greater than 5 micron. In one embodiment, an average diameter of the bi-component fibers of the substrate are between about 1 micron and about 40 micron, and more typically between about 10-40 microns.

[0067] The coarse fibers are compressed and/or heated, for example via a set of calendering rollers and/or an oven, to form the substrate 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, wherein any of the substrate layers has a thickness between about 0.05 and 1.0 mm, preferably between about 0.1 and 0.5 mm. Such substrate can provide a structural support necessary for the fine fibers. Bi-component scrims of various thicknesses suitable for use as any of the substrate layers are commercially available through various suppliers, such as HDK Industries, Inc. of Rogersville, TN, or other filter media suppliers. Thus, the substrate can be selected from such off the shelf bi-component medias.

[0068] In one embodiment, each layer of the substrate 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 and the media 122 comprise a scrim formed of bi-component staple fibers having a high melt polyester core and a low melt polyester sheath. The bi-component staple fibers are compressed together to form the scrim, wherein the bi-component staple fibers are bonded together chemically, mechanically and/or thermally. For example, the bi-component staple fibers are heated to or near the melting temperature of the low melt polyester and compressed together, wherein the sheath formed of the low melt polyester melts or softens and acts as a bonding agent to bond fibers together.

[0069] The fine fibers 124, 126, 128, 130, 132, 134, 136, 138, 140, 142 can be deposited directly on the corresponding substrate 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 as they are formed. Alternatively, the fine fibers may be separately prepared as a web of fine fibers, then laminated with the substrate. Although, the fine fibers may comprise fibers having various fiber diameters, preferably, the fine are nanofibers having very fine fiber diameter. Such fine fibers can be formed by electrospinning or other suitable processes. In one embodiment, the fine fibers are electrospun nanofibers having an average fiber diameter less than about 1 micron, preferably less than 0.5 micron, and more preferably between 0.01 and 0.3 microns. Examples herein have employed a smaller average diameter of 0.08 micron (80nm). Such small diameter fine fibers can afford the ability to pack more fibers together in a given volume to provide an increased fiber surface area, which can increase filtration efficiency while decreasing pressure drop of a filter media.

[0070] The fine fibers may be formed by various suitable polymeric materials. To avoid destruction of the fine fibers during heating and/or compressing of the filter media 100, the fine fibers are typically formed of a material having a higher melt temperature than at least the low-melt component of the bi-component fibers of the substrate. In preferred embodiments, the fine fibers are formed of a polyamide. Other suitable polymers include, but not limited to, polyvinyl chloride (PVC), polyolefin, polyacetal, polyester, cellulous ether, polyalkylene sulfide, polyarylene oxide, polysulfone, modified polysulfone polymers and polyvinyl alcohol, polyamide, polystyrene, polyacrylonitrile, polyvinylidene chloride, polymethyl methacrylate, polyvinylidene fluoride. Solvents for making polymeric solution for electrostatic spinning may include acetic acid, formic acid, m-cresol, tri-fluoro ethanol, hexafluoro isopropanol chlorinated solvents, alcohols, water, ethanol, isopropanol, acetone, and N-methyl pyrrolidone, and methanol..

[0071] In one embodiment, the fine fibers are formed of nylon-6 (polyamide-6, also referred to as "PA-6" herein) via electrospinning, wherein the electrospun fine fibers are deposited directly on the substrate. In this embodiment, the fine fibers 124 are generated electrostatically from a solution containing nylon-6 and deposited on a surface of the substrate 102. The fine fibers 126 can be similarly generated and deposited on the substrate layer 104, and so on. The substrate layers 102, 104, 106, 108, 110, 112, 114, 116, 118, 120 coated with the electrospun nanofibers 124, 126, 128, 130, 132, 134, 136, 138, 140, 142 are then laminated together with the media 122, such that each layer of the fine fibers is sandwiched between the adjacent substrate and/or the media 122 to create the filter media 100 in the pre-compressed state 144 as shown in FIG. 2. As discussed above, the filter media 100 in the pre-compressed state 144 is then compressed to form the filter media 100 in its final compressed state 146 as shown in FIGS. 1 and 2. In preferred embodiments, the filter media 100 is heated before, during, and/or after the compression. For example, the filter media 100 in the pre-compressed state 144 is heated prior to passing through the set of rollers 148, 150. Further, the set of rollers 148, 150 can be heated to further heat the filter media 100 during the compression.

[0072] The bonding between the fine fibers and adjacent coarser fibers of the substrates and/or media 122 may involve solvent bonding, pressure bonding, and/or thermal bonding. For example, as the fine fibers are electrostatically generated from a polymer solution containing a solvent, the solvent remaining on the surface of the fine fibers can effectuate a solvent bonding as the fiber fibers come in contact with the coarse fibers of the substrate. Further, the low melt component of the bi-component fibers of the substrate can be used to enhance bonding between the fine fibers and the adjacent coarse fibers of the substrate. In such embodiment, the filter media 100 is heated to or near the melting point of the low melt component and compressed, wherein the low melt component of the bi-component coarse fibers melts or softens, which allows the adjacent fine fibers to embed into the low melt component as they are compressed together, thereby enhancing the bonding between the coarse fibers and the fine fibers (via pressure bonding and thermal bonding.) In a preferred embodiment, the adhesion between the fine fibers and the substrate on which the fine fibers were deposited are greater than that of between the fine fibers and the other adjacent substrate. For example, the adhesion between the fine fibers 124 and the substrate 102 is greater than the adhesion between the fine fibers 124 and the substrate 104. As such, when a delamination is forced, the fine fibers 124 will delaminate from the substrate 104 and remain on the substrate 102. Thus, when forced, the filter media 100 of such embodiment can be separated into ten layers of substrates carrying fine fibers (102/124, 104/126, 106/128, 108/130, 110/132, 112/134, 114/136, 116/138, 118/140, 120/142) and the media 122.

[0073] In one embodiment, each of the substrate layers is formed of a bi-component fiber scrim having an average fiber diameter between about 1 and 40 microns and a basis weight between about 0.5 and 15 oz/yd^2. The bi-component fibers comprise a high-melt polyester core and a low melt polyester sheath. The fine are electrospun nanofibers formed of nylon-6. The fine fibers have an average fiber diameter between about 0.01 and 0.5 microns, wherein each layer of the fine fibers 124, 126, 128, 130, 132, 134, 136, 138, 140, 142 has a basis weight between about 0.03 g/m^2 and 0.5 g/m^2, providing total fine fiber basis coverage between 0.3 g/m^2 and 5 g/m^2. The fine fiber coverage of the filter media 100 for liquid particulate filtration applications is significantly greater that the fine fiber coverage of gas or air filtration medias. A target basis weight of fine fibers on each substrate layer is selected according to an average diameter of the fine fibers and a desired efficiency and capacity of the filter media. A desired efficiency and capacity of the filter media 100 can be obtained by adjusting fine fiber diameter, fine fiber coverage on each substrate, number of fine fiber layers, amount of lofting and compression.

[0074] Although, the fine fiber coverage can be characterized in terms of a basis weight, the basis weight depends upon a specific weight of a polymer(s) and a diameter of the fine fibers. Thus, it is most useful to characterize the fine fiber coverage in terms of linear coverage per area (km/m^2) as this takes out the variability associated with the specific weight and fine diameter. Thus, the linear coverage truly measures how much fiber is laid down as the quantity of fiber. In this regard, preferred fine fiber linear coverage ranges are greater than 5,000 km/ m^2 for the heaviest coverage fine fibers, more preferably greater than 10,000 km/ m^2, and most preferably between 20,000 km/ m^2 and 60,000 km/ m^2. The fine fiber coverages in various terms including the basis weight and linear coverage for fine fibers having an average fiber diameter of about 0.08 micron (80 nm) according to embodiments of the present invention are shown below in Table 1. The fine fibers of these embodiments are formed of PA-6 having a density of 1.084 g/cm^3 via a electrospinning process. As shown, Table 1 includes fine fiber mass coverage form 0.03 – 0.225 g/m^2.

[0075] **Table 1**: **Nanofiber Coverage**

ID	1	2	3	4	5	6	7
NF coverage g/m^2	0.225	0.15	0.09	0.075	0.05	0.0375	0.03
cm^3 PA6/m^2	0.208	0.138	0.083	0.069	0.046	0.035	0.028
Linear cm of NF/m^2	4.129E+09	2.753E+09	1.652E+09	1.376E+09	9.176E+08	6.882E+08	5.506E+08
Linear Meters of NF / m^2	4.129E+07	2.753E+07	1.652E+07	1.376E+07	9.176E+06	6.882E+06	5.506E+06
Linear Miles of NF / m^2	25658.691	17105.794	10263.476	8552.897	5701.931	4276.448	3421.159
2d area of NF cm^2	33034.928	22023.285	13213.971	11011.643	7341.095	5505.821	4404.657
2d area of NF m^2	3.303	2.202	1.321	1.101	0.734	0.551	0.440
surface area of NF m^2	10.378	6.919	4.151	3.459	2.306	1.730	1.384

[0076] Table 2 shows filter medias including multilayer substrates coated with fine fibers according to various embodiments of the present invention. The fine fibers were applied on a substrate layer at one of the line speeds according to embodiments shown in Table 1.

[0077] **Table 2**: **Filter Medias**

ID of fine fiber application on each substrate layer	Total Basis Weight (g/m^2)	Linear Coverage (km/m^2)	Efficiency Beta Ratio (%efficiency = 1-(1/ß))
5-2-1-1-1-1	1.1	201,866	
5-5-4-3-2-1	0.64	117,452	ß33-522 (H2O pleated element)
5-5-4-3-2-1	0.64	117,452	ß300-10000 (Hydraulic pleated element 15 min)
5-5-4-3-2-1	0.64	117,452	ß40-10000 (Hydraulic pleated element full test)
5-4-3-2-1	0.59	108,276	
5-5-4-3-2	0.415	76,162	ß39-22 (H2O pleated element)
5-5-4-3-2	0.415	76,162	ß55-10000 (Hydraulic pleated element full test)
5-5-4-3-2	0.415	76,162	ß100-10000 (Hydraulic pleated element 15 min)
5-4-3-2	0.365	66,986	ß40-15 (H2O pleated element)

4-4-2-1-1	0.75	137,630	
5x(4)+5x(3)+5X(2)	1.575	289,050	ß10,000+ (Hydraulic Flat)

[0078] While fine fiber coverage may vary based on fiber diameter, based on examples using 80 nm fibers and other calculations, typically embodiments that employ fine fibers having less than 500 nm average diameter will have similar coverage ranges for purpose of broad characterization and claiming purposes.

[0079] **METHOD OF MAKING MULTILAYER COMPOSITE FILTER MEDIA**

[0080] FIG. 11 schematically illustrates a representative process of making a filter media according to a processing embodiment of the present invention. Although this embodiment includes process steps for making the filter media 100 of FIG. 1, the process can produce filter medias according to other embodiments of the present invention with minor modifications. A system 200 shown in FIG. 11 includes an upstream system 201 for making a composite media including a substrate and fine fibers deposited thereon, and a downstream system 203 for laminating, lofting and compressing multiple layers of composite media to make a multilayer composite filter media for liquid particulate filtration applications.

[0081] The upstream system 201 includes an unwinding station 202, an electrospinning station 204, an optional oven 206, an optional set of rollers 207 and a rewinding station 208. In this embodiment, a roll of scrim 210, which is used here as a substrate layer, is unwound from the unwinding station 202. The scrim 212 unwound from the roll of scrim 210 travels in a machine direction 214 toward the electrospinning station 204. In the electrospinning station 204, fine fibers 216 are formed and deposited on one surface of the scrim 212 to form a composite media 218 comprising the scrim carrying the fine fibers 216. The composite media 218 may be heated and compressed in the optional oven 206 and the optional set of rollers 207 before being wound into a roll of composite media 230 on the rewound station 208 for improved adhesion between the fine fibers and the substrate.

[0082] The scrim may be formed in an upstream process of the system 200 (either part of a continuous line process or interrupted line process) or may be purchased in a roll form from a supplier such as HDK or other suitable media supplier such as H&V or Ahlstrom or the like. The scrim can be formed of various suitable materials, such as bi-component fibers of FIGS. 3-10 as discussed above. For example, the scrim can be formed of high melt polyester core/low melt polyester sheath bi-component staple fibers, which are compressed and/or heated to form the roll of scrim 210 having a desired thickness and solidity. Alternatively, the substrate layer may be other single component media that may be compressed and held in place via a solvent bond, heat bond or the like.

[0083] In the case of bi-component fibers, for example, the concentric sheath/core type bi-component fibers may be coextruded using a high melt polyester as the core and a low melt polyester as the sheath. Such bi-component fibers can then be used to form a scrim or a filter media. In one embodiment, the bi-component fibers are used as staple fibers to form a multi-component filter media or a scrim via conventional dry laying or air laying process. The staple fibers used in this process are relatively short and discontinuous but long enough to be handled by conventional equipment. Bales of the bi-component fibers can be fed through a chute feed and separated into individual fibers in a carding device, which are then air laid into a web of fibers (which itself for purposes of the present disclosure may be used as a substrate.) The web of fibers is then compressed using a set of calendering rollers to form the roll of scrim 210 (which can also be used as a substrate.) The web of the fibers may optionally be heated before entering the set of calendering rollers. Since the scrim 210 of this embodiment comprises bi-component fibers, including a high melt component and a low melt component, it is also referred to as a bi-component filter media. In some embodiments, the web of fibers are folded before being calendered to form a thicker bi-component filter media.

[0084] In a different embodiment, a web comprising high melt polymer fibers such as polyester fibers and a web comprising low melt polymer fibers such as polypropylene fibers can be formed, separated and laminated together to form the roll of bi-component filter media or scrim. In such embodiment, the fine fibers 216 are deposited on the low melt side of the scrim 212. In this embodiment, the low melt web is substantially thinner than the high melt web, such that the low melt component does not clog the surface of the high melt web when heated and melted.

[0085] In another embodiment, the bi-component fiber scrim can be formed via a melt blowing process. For example, molten polyester and molten polypropylene can be extruded and drawn with heated, high velocity air to form coarse fibers. The fibers can be collected as a web on a moving screen to form a bi-component scrim 210.

[0086] The multi-component fiber filter media or scrim may also be spun-bounded using at least two different polymeric materials. In a typical spun-bounding process, a molten polymeric material passes through a plurality of extrusion orifices to form a multifilamentary spinline. The multifilamentary spinline is drawn in order to increase its tenacity and passed through a quench zone wherein solidification occurs which is collected on a support such as a moving screen. The spun-bounding process is similar to the melt blowing process, but melt blown fibers are usually finer than spun-bounded fibers.

[0087] In yet another embodiment, the multi-component filter media is wet-laid. In a wet laying process, high melt fibers and low melt fibers are dispersed on a conveying belt, and the fibers are spread in a uniform web while still wet. Wet-laid operations typically use ¼" to ¾" long fibers, but sometimes longer if the fiber is stiff or thick. The above discussed fibers, according to various embodiments, are compressed to form a scrim 210 or a filter media having a desired thickness.

[0088] Referring back to FIG. 11, the scrim 212 enters the electrospinning station 204, wherein the fine fibers 216 are formed and deposited on one surface of the scrim 212. In the electrospinning station 204, the fine fibers 216 are electrospun from electrospinning cells 222 and deposited on the web of scrim 212. The electrospinning process of the system 200 can be substantially similar to the electrospinning process disclosed in Fine Fibers Under 100 Nanometers, And Methods, U.S. Patent Application Publication No. U.S. 2009/0199717, assigned to the assignee of the present application, the entire disclosure of which has been incorporated herein by reference thereto. Alternatively, nozzle banks or other electrospinning equipment can be utilized to form the fine fibers. Such alternative electrospinning devices or rerouting of chain electrodes of the cells 222 can permit the fibers to be deposited in any orientation desired (e.g. upwardly is shown although fibers can also be spun downwardly, horizontally or diagonally onto a conveyor carrying coarser fibers).

[0089] The electrospinning process produces synthetic fibers of small diameter, which are also known as nanofibers. The basic process of electrostatic spinning involves the introduction or electrostatic charge to a stream of polymer melt or solution in the presence of a strong electric field, such as a high voltage gradient. Introduction of electrostatic charge to polymeric fluid in the electrospinning cells 222 results in formation of a jet of charged fluid. The charged jet accelerates and thins in the electrostatic field, attracted toward a ground collector. In such process, viscoelastic forces of polymeric fluids stabilize the jet, forming small diameter filaments. An average diameter of fibers may be controlled by the design of eletrospinning cells 222 and formulation of polymeric solutions.

[0090] The polymeric solutions used to form the fine fibers can comprise various polymeric materials and solvents. Examples of polymeric materials include polyvinyl chloride (PVC), polyolefin, polyacetal, polyester, cellulous ether, polyalkylene sulfide, polyarylene oxide, polysulfone, modified polysulfone polymers and polyvinyl alcohol, polyamide, polystyrene, polyacrylonitrile, polyvinylidene chloride, polymethyl methacrylate, polyvinylidene fluoride. Solvents for making polymeric solution for electrostatic spinning may include acetic acid, formic acid, m-cresol, tri-fluoro ethanol, hexafluoro isopropanol chlorinated solvents, alcohols, water, ethanol, isopropanol, acetone, and N-methyl pyrrolidone, and methanol. The solvent and the polymer can be matched for appropriated use based on sufficient solubility of the polymer in a given solvent and/or solvent mixture (both of which may be referred to as "solvent".) For example, formic acid may be chosen for nylon-6. Reference can be had to the aforementioned patents for further details on electrospinning of fine fibers.

[0091] In the electrospinning station 204, an electrostatic field is generated between electrodes in the electrospinning cells 222 and a vacuum collector conveyor 224, provided by a high voltage supply generating a high voltage differential. As shown in FIG. 11, there may be multiple electrospinning cells 222, wherein fine fibers 216 are formed. The fine fibers 216 formed at the electrodes of the electrospinning cells 222 are drawn toward the vacuum collector conveyor 224 by the force provided by the electrostatic field. The vacuum collector conveyor 224 also holds and transfers the scrim 212 in the machine direction 214. As configured, the scrim 212 is positioned between the electrospinning cells 222 and the vacuum collector conveyor 224, such that the fine fibers 216 are deposited on the scrim 212. In embodiments, wherein the scrim 212 is a multi-component filter media including a low melt component on one surface and a high melt component on the other surface, the multi-component scrim 212 is positioned between the electrospinning cells 222 and the vacuum collector conveyor 224, such that the low melt component surface of the multi-component scrim faces the electrospinning cells 222.

[0092] In one preferred embodiment, the electrospinning cells 222 contain a polymeric solution comprising polyamide-6 (PA-6) and a suitable solvent consisting of 2/3 acetic acid and 1/3 formic acid. In such a solvent, both acetic acid and formic acid act as a dissolving agent to dissolve PA-6, and acetic acid controls conductivity and surface tension of the polymeric solution. The electrospinning cells 222 generate fine fibers formed of PA-6, which are deposited onto a surface of the scrim 212. As the fine fibers 216 are deposited on the surface of the scrim 212, some fine fibers 216 entangle with coarse fibers of the scrim proximate the surface facing the electrospinning cells 222. When some fine fibers 216 entangle with some coarse fibers, solvent remaining in the fine fibers 216 from the electrospinning process can effectuate a solvent bonding between the fine fibers 216 and the coarse fibers of the scrim 212.

[0093] In other embodiments, the fine fibers can be formed by other suitable processes such as a melt blowing process. For example, the fine fibers having an average fiber diameter of about 0.6 - 0.7 micron can be formed via a melt blowing under an influence electrical fields. In such embodiments, the coarse fibers for a substrate are prepared to have an average fiber diameter at least 4 times larger than the fine fibers. For purposes of differentiation, melt blown fibers and electrospun nanofibers are thus meant to be more specific terms than fine fibers, which is intended to be generic.

[0094] The bonding between bi-component fibers of the scrim 212 and the fine fibers 216 may be enhanced via thermal bonding and pressure bonding by the optional oven 206 and the optional set of calendering rollers 207. As the composite media 218 is heated in the oven 206, the low melt polymer component of the bi-component fibers softens or melts and allowing the fine fibers 216 to embed into the low melt polymer component. Thus, during the heat treatment, the composite filter media 218 is heated to at least above the glass transition temperature of the low melt component, and more preferably to or near the melting temperature of the low melt component. For example, the composite media 218 is heated to or near the melt point of low melt polyester, such that the outer low melt polyester layer of the bi-component fibers melts and bonds with the fine fibers 216 formed of PA-6. In such embodiments, PA-6 fine fibers 216 and the high melt polyester core of the bi-component fibers do not melt, since PA-6 and the high melt polyester have a significantly higher melting temperature than that of the low melt polyester. The low melt polyester, which has the lowest melting temperature, melts or softens, and adjacent PA-6 fine fibers 216 are embedded in the softened or melted low melt polyester, thereby bonding the fine fibers 216 and the scrim 212 together. Thus, the low melt polyester acts as a bonding agent between the bi-component fiber scrim 212 and the fine fibers 216. The bonding between the fine fibers 216 and the scrim 212 can further be enhanced through pressure bonding via the set of rollers 207. As the composite media passes through the rollers 207, the fine fibers 216 and the scrim 212 are compressed together, wherein the fine fibers are further embedded into the fibers of the scrim 212. Further, the compression reduces voids in the composite media to form a composite media 220 with an increased solidity.

[0095] FIGS. 12(A)-12(D) are Scanning Electron Microscopic (SEM) images of the bi-component fibers of the scrim 212 and the fine fibers 216 proximate the surface of the scrim 212 taken at various magnification levels. As shown in the SEM images taken at magnification levels x300 and x1000 of FIGS. 12(A) and 12(B), the fine fibers 216 deposited on the web of scrim 212 form a spider web like fiber structure between the coarser bi-component fibers that are located proximate the surface of the scrim 212. The SEM images taken at higher magnifications (FIG. 12(C) at x2,000 and FIG. 12(D) at x10,000) show the bonding between the fine fibers 216 and the bi-component fibers. As shown clearly in FIG. 12(D), the fine fibers 216 are embedded on the low melt polyester surface of the bi-component fibers.

[0096] The roll of composite media 230 including the bi-component scrim 212 and the fine fibers 216 is laminated with other composite medias 232, 234, 236, 238, 240, 242, 244, 246, 248, and a media 250 in the downstream system 203. Each of the composite media rolls 230, 232, 234, 236, 238, 240, 242, 244, 246, 248, and a roll of the media 250 are unwound from unwind stations 252, 254, 256, 258, 260, 262, 264, 266, 268, 270, 272, and laminated together by a set of rollers 274. The set of rollers may be a calendering rollers to apply a significant pressure to laminate and significantly reduce a thickness of the layers of composite medias. Alternatively, the set of rollers 274 may apply a small pressure to laminate and reduce the thickness of the laminated layers just enough to fit through an oven 276. In such embodiment, the laminated layers 280 is heated in the oven 276 and compressed via a set of calendering rollers 282, wherein the laminated layers 280 is compressed together into a compressed state having a desired thickness and solidity.

[0097] In this embodiment, each roll of the composite media 232, 234, 236, 238, 240, 242, 244, 246, 248 is prepared similarly as the roll of the composite media 230. Therefore, each of the roll of the composite media 232, 234, 236, 238, 240, 242, 244, 246, 248 includes a substrate formed of a bi-component fiber scrim 284, 286, 288, 290, 292, 294, 296, 298, 300, and electrospun nanofibers 302, 304, 306, 308, 310, 312, 314, 316, 318, carried by the bi-component fiber scrim 284, 286, 288, 290, 292, 294, 296, 298, 300.

[0098] In one embodiment, each of the substrates 212, 284, 286, 288, 290, 292, 294, 296, 298, 300 and the media 250 are formed of a same bi-component fiber scrim having a thickness between about 0.05 mm and 1.0 mm. Each layer of the fine fibers 216, 302, 304, 306, 308, 310, 312, 314, 316, 318, is formed by electrospinning PA-6 polymer solution to produce a fine fiber coverage between about 0.03 g/m^2 and 0.5 g/m^2. In other embodiments, the substrates may be formed of different types of filter media or scrim, and each of the fine fibers layer may have different fine fiber coverage.

[0100] The composite media 280 is heated in the oven 276 to or near a melting temperature of the low melt polyester component of the bi-component fiber scrim. During heating the substrates can relax and expand in thicknesses. Thus, the lofted composite media 281 can have a thickness that is at least 1.5 times, 2 times, 3 times or even greater than the thickness of the composite media 280 before being heated in the oven 276. The lofted composite media 281 is then compressed via the set of calendering rollers 282 into the compressed state 320. The composite media is compressed, such that the thickness of the composite media 280 is reduced between about 50% and 300%, preferably between about 70% and 200%, and more preferably between about 80% and 150% of the original thickness of the composite media 280 prior to heating ((total thickness of 10 scrim layers carrying 10 fine fiber layers + thickness of media - thickness of the composite media in the compressed state 320)/(total thickness of 10 scrim layers carrying 10 fine fiber layers + thickness of media).) The thickness reduction can depend on the amount of lofting during heating. Thus, when the lofting from heating is large, the final thickness of the composite media after compression may be greater than the initial thickness of the composite media before heating. The composite media in the compressed state 320 is then wound into a roll of filter media 324.

[0101] In this embodiment, the rolls of the composite media 230, 232, 234, 236, 238, 240, 242, 244, 246, 248. and the media 250 are laminated together, such that each of the fine fiber layers 216, 302, 304, 306, 308, 310, 312, 314, 316, 318 is sandwiched between adjacent substrate layer and/or media. However, in other embodiments, the composite media layers may be laminated such that some of the fine fiber layers face each other to form fine fiber to fine fiber or substrate to substrate bonding within the final composite media 320. For example, the system 200 can be used to make the filter media 500 of FIG. 15. In this embodiment, each of the first five unwind stations 252, 254, 256, 258, 260 unwinds a roll of composite media such that the nanofibers are facing upward as shown in FIG. 11. However, the unwind station 262 unwinds a composite media such that the nanofibers are facing downward. As such, the fine fibers on the first four substrate layers 514, 516, 518, 520 are sandwiched between the substrates 502, 504, 506, 508, 510 as shown in FIG. 15. However, the fine fibers 522 on the substrate 510 and the fine fibers 524 of the substrate 512 face each other forming the fine fiber-fiber fiber.

[0102] FIG. 13 schematically illustrates a system and a process of making a filter media according to a different embodiment of the present invention. A system 400 generally includes an unwinding station 402, an electrospinning station 404, a folding station 406, a set of rollers 408, an oven 410, and a set of calendering rollers 412 and a rewinding station 414.

[0103] In this embodiment a roll of substrate 416 is unwound from the unwinding station 402 and transferred to the electrospinning station 404, wherein fine fibers are formed and deposited on a surface of the substrate 416. The electrospinning station 404 and the process are similar to the electrospinning station 204 and the process described above. In this embodiment, the substrate 416 is a scrim formed of bi-component fibers including a high melt polyester core and a low melt polyester sheath. The fine fibers 418 are formed of PA-6.

[0104] The composite media 420 comprising the substrate 416 and fine fibers 418 is folded in the folding station 406. The composite media 420 can be folded to 2-20 folds thick depending on desired characteristics of the final media. As shown, the folding creates fine fiber to fine fiber laminated surfaces and substrate to substrate laminated surfaces. The folding station 406 in this embodiment is shown as folding the composite media 420 in a line direction, such that the folds are pointing toward the set of the rollers 408. However, in other embodiments, the composite media 402 may be folded such that the folds are pointing toward the electrospinning station 404, or folded in cross-line directions. The folded composite media 422 is then compressed to a thickness appropriate to pass through an oven 410. As the composite media 424 is heated, the low melt polyester sheath melts or softens to effectuate thermal bonding between layers. After exiting the oven 410, the composite media 424 passes through the set of calendering rollers 412. The calendering rollers 412 are spaced apart from each other according to a desired final thickness of the media. The composite media 424 is pressed down into a compressed state having a desired thickness as it passes through the set of calendering rollers 412.

[0105] Further, media layers 426, 428 are laminated on each surface of the media 430 and wound into a roll in the rewinding station 414. A expanded cross sectional view of a filter media 432 including the media 430, the media layers 426, 428 is shown in FIG. 13. As shown, the media 430 includes multiple layers of substrate 416 and multiple layers of fine fibers 418 in a slanted orientation from the folding process. The media layers 426, 428 can be formed of any suitable media, but in this embodiment, the media layers 426, 428 are formed of the same bi-component fiber scrim used for the substrate 416.

[0106] FIG. 14 shows yet a different embodiment of a system and a process of making a media. A system 600 is similar to the system 400 but the fine fibers in this embodiment are not deposited on a substrate. Rather, the fine fibers are formed and deposited onto a web of loosely entangled coarse fibers. The system 600 generally includes a chute 602, a carding device 603, an electrospinning station 604, a folding station 606, a set of rollers 608, an oven 610, and a set of calendering rollers 612 and a rewinding station 614.

[0107] In the system 600, the web of coarse fibers 616 is formed from staple fibers using a dry laying or air laying process. The staple fibers of this embodiment are bi-component fibers comprising a high melt polyester core and a low-melt polyester sheath. The bi-component staple fibers are relatively short and discontinuous, but long enough to be handled by conventional equipment. Bales of staple fibers are fed through the chute feed 602. In the carding device 603, the bi-component staple fibers are separated into individual fibers and air laid to form the web of coarse fiber 616. At this point, the web of coarse fiber 616 can be loosely tangled together in a highly fluffed thick state and may not be bonded together. The web of coarse fiber 616 can be easily pulled apart with very little manual effort and has little structural integrity at this point such that it is not considered a filter media or substrate in the conventional sense.

[0108] The web of coarse fiber 616 is transferred via a conveyor belt 617 toward the electrospinning station 604, wherein the fine fibers 618 are formed and deposited on a surface of the web of coarse fiber 616. As the fine fibers 618 are deposited on the web of coarse fiber 616, the fibers 618 are integrated with the coarse fibers of the web of coarse fiber 616 much more than in the previous embodiment with the substrate 416, as the web of coarse fiber 616 are much more porous and less dense to allow deeper integration of the fine fibers 616.

[0109] The web of coarse fiber 616 integrated with the fine fibers 618 are then folded into 10-30 folds in the folding station 606 and compressed via the set of rollers 608, which is heated in the oven 610 and compressed again via the set of calendering rollers 612 as it was with the system 400. The media 630 is then laminated with a media layer 626 and a porous layer 628 to from a filter media 632. The coarse bi-component fibers and the fine fibers of the media 630 of this embodiment are much more integrated. Thus, a cross sectional view of the media 630 does not show multiple layers, but rather appears more like a single integrated media 630. The media 630 has a sufficient fine fiber coverage and structural integrity to capture particulate matters from a liquid stream, such as a hydrocarbon fuel stream.

[0110] The media according to various embodiments of the present invention can be configured into various shapes and sizes for various applications. For example, the media can be used in spin-on filter applications, large fuel filtration vessels, aviation filter systems, hydraulic filter elements, bio-fuel systems, diesel fuel filters, lube filters, and water filtration systems. The media can be pleated or gathered into a fluted filter, a pleated filter, or other such typical filter element arrangements.

[0111] **EXAMPLES AND TEST RESULTS**

[0112] FIG. 15 is a schematic cross-sectional view of a filter media 500 according to a different embodiment of the present invention. The filter media 500 is similarly constructed as the filter media 100, but includes six layers of substrate 502, 504, 506, 508, 510, 512, each of which carrying fine fibers 514, 516, 518, 520, 522, 524, instead of ten layers of substrate carrying fine fibers. Further, the most upstream composite media layer comprising the substrate layer 512 and fine fibers 524 is reversed such that the fine fibers 524 face the fine fibers 522 forming a fine fiber-fine fiber interface. As shown, the substrate 512 provides an upstream surface 526 of the filter media 500, thus fine fibers are not exposed and protected.

[0113] The test samples of the filter media 500 were prepared in a laboratory. Test samples of all embodiments described herein are prepared to have a sample area of 0.1 ft^2. A bi-component fiber scrim comprising a high melt polyester core and a low melt polyester sheath having a basis weight of 35.0 GSY was used for the each of the substrate layers 502, 504, 506, 508, 510, 512. The fine fibers were formed via an electrospinning process from a polymeric solution comprising PA-6 and deposited on each of the substrate layers. On the substrate 512, about 0.05 g/m^2 of the PA-6 nanofibers 524 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 9176 km/m^2 (5,702 $miles/m^2$.) On the substrate 510, about 0.15 g/m^2 of the PA-6 nanofibers 522 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 27,530 km/m^2 (17,106 $miles/m^2$.) On each of the substrate layers 502, 504, 506, 508, about 0.225 g/m^2 of the PA-6 nanofibers 514, 516, 518, 520 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 41,290 km/ m^2 (25,659 $miles/m^2$) on each substrate. Thus, the filter media 500 includes a total fine fiber basis weight of about 1.1 g/m^2, which provides about 201,866 km/ m^2 (125,444 $miles/m^2$) of linear fiber coverage.

[0114] The six substrate layers carrying the fine fibers were arranged as shown in FIG. 15 such that the substrate layer 512 forms the upstream surface 526 and the substrate layer 502 forms the downstream surface 528. The six composite media layers were heated and compressed via a calendering roller as described in the previous embodiments to form the composite filter media 500.

[0115] Test samples of the filter media 500 were prepared and tested for efficiency and dust holding capacity according to the ISO 16889 international standard for multi-pass method for evaluating filtration performance. All tests were performed using a hydraulic fluid Mil-H-5606 having a viscosity at the test temperature of 15 mm^2/s loaded with ISOMTD test dust.

[0116] In the first test, the test fluid having a base upstream contaminant concentration of 5.00 mg/L was used at a flow rate of 0.26 GPM. FIG. 16 shows particle counts per mL and filtration ratio at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% time intervals during the 6-hour test period. When the test results were converted to a fluid cleanliness rating according to ISO 4406:99 cleanliness code (R4/R6/R14), the cleanliness rating at 10% time interval is 7/5/0, at 100% is 13/11/7, and average is 6/4/0.

[0117] In the second test, the test fluid having a base upstream contaminant concentration of 15.00 mg/L was used at a flow rate of 0.26 GPM. FIG. 17 shows particle counts per mL and filtration ratio test results. The cleanliness rating at 10% time interval is 7/6/0, at 100% is 19/18/14, and average is 12/11/7.

[0118] Test samples of the filter media 500 for the third test were prepared in a laboratory similarly as the test samples for the first test and the second test. However, the fine fiber basis weight of each substrate layer was changed. On each of the substrates 510 and 512, about 0.05 g/m^2 of the PA-6 nanofibers 522, 524 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 9176 km/m^2 (5,702 $miles/m^2$) on the each substrate. On the substrate 508, about 0.075 g/m^2 of the PA-6 nanofibers 520 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 13,760 km/m^2 (8,553 $miles/m^2$.) On the substrate 506, about 0.09 g/m^2 of the PA-6 nanofibers 518 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 16,520 km/m^2 (10,263 $miles/m^2$.) On the substrate 504, about 0.15 g/m^2 of the PA-6 nanofibers 516 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 27,530 km/m^2 (17,106 $miles/m^2$.) On the substrate 502, about 0.225 g/m^2 of the PA-6 nanofibers 514 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 41,290 km/m^2 (25,659 $miles/m^2$.) Thus, the filter media 500 includes a total fine fiber basis weight of about 0.64 g/m^2, which provides about 117,452 km/m^2 (72,985 $miles/m^2$) of linear fiber coverage.

[0119] In the third test, the test fluid having a base upstream contaminant concentration of 15.00 mg/L was used at a flow rate of 0.26 GPM. FIG. 18 shows particle counts per mL and filtration ratio test results. The cleanliness rating at 10% time interval is 11/9/4, at 100% is 17/16/11, and average is 16/15/10.

[0120] FIG. 19 is a schematic cross-sectional view of a filter media 600 according to a different embodiment of the present invention. The filter media 600 is similarly constructed as the filter media 500 of FIG. 15, however the filter media 600 include five substrate layers 602, 604, 606, 608, 610 and five fine fiber layers 612, 614, 616, 618, 620. Test samples of the filter media 600 for the fourth test were prepared in a laboratory similarly as the previous test samples. For these test samples, about 0.15 g/m^2 of the PA-6 nanofibers 612, 614, 616, 618, 620 having an average fiber diameter of 0.08 micron were formed and deposited on each of the substrate layers 602, 604, 606, 608, 610. This level of fine fiber basis weight provides a linear fine fiber coverage of about 27,530 km/m^2 (17,106 miles/m^2) on each substrate. Thus, the filter media 600 includes a total fine fiber basis weight of about 0.75 g/m^2, which provides about 137,650 km/m^2 (85,530 miles/m^2) of linear fiber coverage.

[0121] In the fourth test, the test fluid having a base upstream contaminant concentration of 15.00 mg/L was used at a flow rate of 0.26 GPM. FIG. 20 shows particle counts per mL and filtration ratio test results. The cleanliness rating at 10% time interval is 10/8/0, at 100% is 16/13/11, and average is 14/12/8.

[0122] FIG. 21 is a schematic cross-sectional view of a filter media 700 according to yet another embodiment of the present invention. The filter media 700 is similarly constructed as the filter media 500 of FIG. 15, however the filter media 700 include three substrate layers 702, 704, 706 and three fine fiber layers 708, 710, 712. Test samples of the filter media 700 for the fifth test were prepared in a laboratory similarly as the previous test samples. For these test samples, about 0.075 g/m^2 of the PA-6 nanofibers 712 having an average fiber diameter of 0.08 micron were formed and deposited on the substrate 706. This level of fine fiber basis weight provides a linear fine fiber coverage of about 13,760 km/m^2 (8,553 miles/m^2.) On the substrate 704, about 0.09 g/m^2 of the PA-6 nanofibers 710 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 16,520 km/m^2 (10,263 miles/m^2.) . On the substrate 702, about 0.15 g/m^2 of the PA-6 nanofibers 708 having an average fiber diameter of 0.08 micron were formed and deposited. This level of fine fiber basis weight provides a linear fine fiber coverage of about 27,530 km/m^2 (17,106 miles/m^2.) Thus, the filter media 700 includes a total fine fiber basis weight of about 0.315 g/m^2, which provides about 57,810 km/m^2 (35,922 miles/m^2) of linear fiber coverage.

[0123] In the fifth test, the test fluid having a base upstream contaminant concentration of 5.00 mg/L was used at a flow rate of 0.26 GPM. FIG. 22 shows particle counts per mL and filtration ratio test results. The cleanliness rating at 10% time interval is 11/10/5, at 100% is 11/9/4, and average is 9/8/0.

[0124] FILTER ELEMENT

[0125] The filter media according various embodiment of the present invention can be pleated, gathered, or formed into different shapes according to various liquid filtration applications. FIG. 22 shows a filter element 800 for a locomotive diesel fuel system according to an embodiment of the present invention. The filter element 800 includes a pleated filter media 802, a bottom cap 804, a top cap 806, and an outer protective layer 812. The pleated filter media 802 can be formed of a filter media of various embodiments of the present invention, such as the filter media 500 of FIG. 15. FIG. 23 shows a pleated filter media 801 formed of the filter media 500. The pleated filter media 801 can be pleated to have various pleat depths. The pleated filter media 801 formed of the compressed filter media 500 including six layers of substrate and six layers of fine fibers has a greater rigidity and structural integrity compared to pleated filter medias formed of other multilayer or single layer medias. Thus, the pleated filter media 801 is well suited to filter particulates in viscous liquid streams such as the diesel fuel. The pleated filter media 801 is then rolled into the pleated filter media 802 having a cylindrical shape.

[0126] The bottom end cap 804 and the top end cap 806 are then placed on each end of the cylindrical pleated filter media 802. The pleated filter media 802 is then thermally welded to the bottom end cap 804 and the top end cap 806 to prevent a liquid stream form flowing between ends of the pleated filter media 802 and the top and bottom end caps 804, 806. The top and bottom end caps 804, 806 can be formed of various suitable polymeric materials. In this embodiment, the top and bottom end caps 804, 806 were formed of a polyester. The bottom end cap 804 forms a closed end without a fluid path. The top cap 808 includes a hollow cylindrical piece 808 extending from its top surface, which provides a fluid flow path 810. The outer protective layer 812 includes large openings and forms an outer periphery of the filter element 800 to protect the pleated filter media 802.

[0127] All references, including publications, patent applications, and patents cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0128] The use of the terms “a” and “an” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) is to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0129] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

WHAT IS CLAIMED IS:

1. A filter media for a liquid particulate filtration application, comprising:

a substrate including coarse fibers;

fine fibers carried on the substrate, wherein the fine fibers have an average fiber diameter that is at least 4 times as small as the coarse fibers; and

wherein a basis weight of the fine fibers is at least $0.03 g/m^2$ and a linear coverage of the fine fibers is at least about 5000 km/m^2.

2. The filter media of claim 1, wherein the filter media comprises at least two substrate layers, each substrate layer carrying the fine fibers; wherein the basis weight of the fine fibers on at least one of the substrate layer is at least $0.03 g/m^2$ and the linear coverage of the fine fibers is at least about 5000 km/m^2, and other substrate layers have a same or a different fine fiber basis weight and linear coverage than the at least one of the substrate layer.

3. The filter media of claim 1, wherein the fine fibers are electrospun fine fibers formed by an electrospinning process, the fine fibers having an average fiber diameter of less than 0.1 micron.

4. The filter media of claim 3, wherein the electrospun fine fibers are deposited on the substrate, wherein the fine fibers are rearranged and partially integrated with the coarse fibers by lofting and compression.

5. The filter media of claim 1, wherein the fine fibers are at least partially integrated with the coarse fibers of the substrate; wherein the at least some fine fibers are attached to adjacent coarse fibers.

6. The filter media of claim 1, wherein the substrate is a scrim comprising bi-component fibers, the bi-component fibers having a high melt component and a low melt component.

7. The filter media of claim 6, wherein the bi-component fibers comprise a high melt polyester core and a low melt polyester sheath, wherein the at least one substrate and the fine fibers are heated and compressed together to form a filter media, wherein the low melt polyester sheath melts or softens to bon the coarse fibers and the fine fibers.

8. The filter media of claim 7, wherein the fine fibers are formed of a polyamide.

9. The filter media of claim 1, wherein the filter media comprises at least three substrate layers, each substrate layer formed of a scrim formed of bi-component coarse fibers; wherein each substrate layer carries the fine fibers; wherein each substrate layer carries the fine fibers at a basis weight of between about 0.05g/m^2 and about 0.225g/m^2 and a linear coverage of between about 9,000 km/m^2 and about 41,300 km/m^2; wherein the filter media has a total basis weight of between 0.3 g/m^2 and about 4.8 g/m^2 and a total linear coverage of between about 60,000 km/m^2 and about 300,000 km/m^2; wherein the substrate layers and the fine fibers are lofted by heating and compressed to form a compacted filter media configured for a liquid filtration.

10. The filter media of claim 9, wherein the fine fibers carried on each of the substrate layers is sandwiched between two substrate layers.

11. The filter media of claim 9, wherein the compacted filter media includes a fine fibers to fine fibers interface.

12. The filter media of claim 9, wherein the filter media has a ISO 4406:09 cleaness code at 10% time interval of a filtration efficiency test according to ISO 16889 international standard for multi-pass method of between about 11/10/5 and 7/5/0.

13. A filter element for a liquid particulate filtration application, comprising:

a filter media, comprising:

a substrate including coarse fibers;

fine fibers carried on the substrate, wherein the fine fibers have an average fiber diameter that is at least 4 times as small as the coarse fibers; and wherein a basis weight of the fine fibers is at least 0.03g/m^2 and a linear coverage of the fine fibers is at least about 5000 km/m^2;

a top cap including a fluid inlet; and

a bottom cap; wherein the filter media is sealingly attached to the top cap and the bottom cap.

14. The filter element of claim 13, wherein the filter media comprises at least three substrate layers, each substrate layer formed of a scrim formed of bi-component coarse fibers; wherein each substrate layer carries the fine fibers; wherein each substrate layer carries the fine fibers at a basis weight of between about 0.05g/m^2 and about 0.225g/m^2 and a linear coverage of between about 9,000 km/m^2 and about 41,300 km/m^2; wherein the filter media has a total basis weight of between 0.3 g/m^2 and about 4.8 g/m^2 and a total linear coverage of between about 60,000 km/m^2 and about 300,000 km/m^2; wherein the substrate layers and the fine fibers are lofted by heating and compressed to form a compacted filter media configured for a liquid filtration.

15. The filter element of claim 14, wherein the fine fibers are formed of a polyamide and have an average fiber diameter of less than 0.1 micron; wherein the bi-component coarse fibers include a high melt polyester core and a low melt polyester sheath; wherein the compacted filter media includes at least some fine fibers embedded in the low melt polyester sheath.

16. The filter element of claim 13, wherein the filter media is pleated, and the pleated filter media is sealingly attached to the top cap and the bottom cap by thermal plastic welding.

17. The filter element of claim 16, wherein the thermal plastic welding attachment of the pleated filter media to the top and bottom caps prevents a liquid stream from bypassing the pleated filter media.

18. A method of forming a filter media, comprising:

electrostatically spinning fine fibers having an average fiber diameter of less than 1 micron;

applying the fine fibers on a substrate to provide a fine fiber basis weight of at least 0.03g/m^2 and a linear coverage of the fine fibers of at least about 5000 km/m^2, wherein the substrate comprising coarse fibers having an average fiber diameter that is at least 4 times larger than the fine fibers; and

processing the substrate with the applied fine fibers to rearrange the fine fibers on the substrate.

19. The method of claim 18, wherein rearrangement of the fine fibers on the substrate includes lofting the substrate and the fine fibers by heating, and compacting the substrate and the fine fibers via a set of rollers.

20. The method of claim 18, further comprising:

providing at least two substrate layers, wherein each substrate layer is formed of a scrim comprising bi-component coarse fibers;

applying the fine fibers on a first substrate layer to provide a fine fiber basis weight of between about 0.05g/m^2 and about 0.225g/m^2 and a linear coverage of between about 9,000 km/m^2 and about 41,300 km/m^2;

applying the fine fibers on a second substrate layer to provide a fine fiber basis weight of between about 0.05g/m^2 and about 0.225g/m^2 and a linear coverage of between about 9,000 km/m^2 and about 41,300 km/m^2;

laminating the first substrate layer carrying the fine fibers and the second substrate layer carrying the fine fibers; and

compressing the first and second substrate layers and the fine fibers to form a compressed filter media configured for a liquid filtration.

21. The method of claim 20 further including lofting the first and second substrate layers and the fine fibers prior to compressing to rearrange the fine fibers and to at least partially integrate the fine fibers with the coarse fibers of the substrate.

22. The method of claim 20, wherein applying the fine fibers such that the basis weight and the linear coverage of the fine fibers on the first substrate is greater than that of the second substrate layer.

23. The method of claim 20, wherein applying the fine fibers such that the basis weight and the linear coverage of the fine fibers on the first substrate layer is equal to that of the second substrate layer.

24. The method of claim 18, wherein electrostatically spinning fine fibers include forming the fine fibers from a solution including a polyamide.

25. The method of claim 18, further including pleating the filter media.

26. A method of filtering a liquid, comprising:

providing the filter media of claim 1; and

flowing a liquid stream through a filter media to capture particulates in the liquid stream.

27. A filter media for a liquid particulate filtration application, comprising:

a substrate including bi-component coarse fibers having an average fiber diameter of greater than 0.6 micron;

fine fibers carried on the substrate, the fine fibers having an average fiber diameter of less than 0.6 micron, wherein the average diameter of the coarse fibers is at least 4 times larger than the average fiber diameter of the fine fibers; and

wherein a basis weight of the fine fibers is at least $0.03 g/m^2$ and a linear coverage of the fine fibers is at least about 5000 km/m^2.

28. A filter media for a liquid particulate filtration application, comprising:

at least two layers of substrate, each of the substrate layers formed of coarse fibers;

fine fibers carried on each of the substrate layers, wherein an average fiber diameter of the coarse fibers is at least 4 times larger than an average fiber diameter of the fine fibers; and

wherein a basis weight of the fine fibers on at least one substrate layer is at least $0.03 g/m^2$ which provides a linear fiber coverage of at least about 5000 km/m^2.

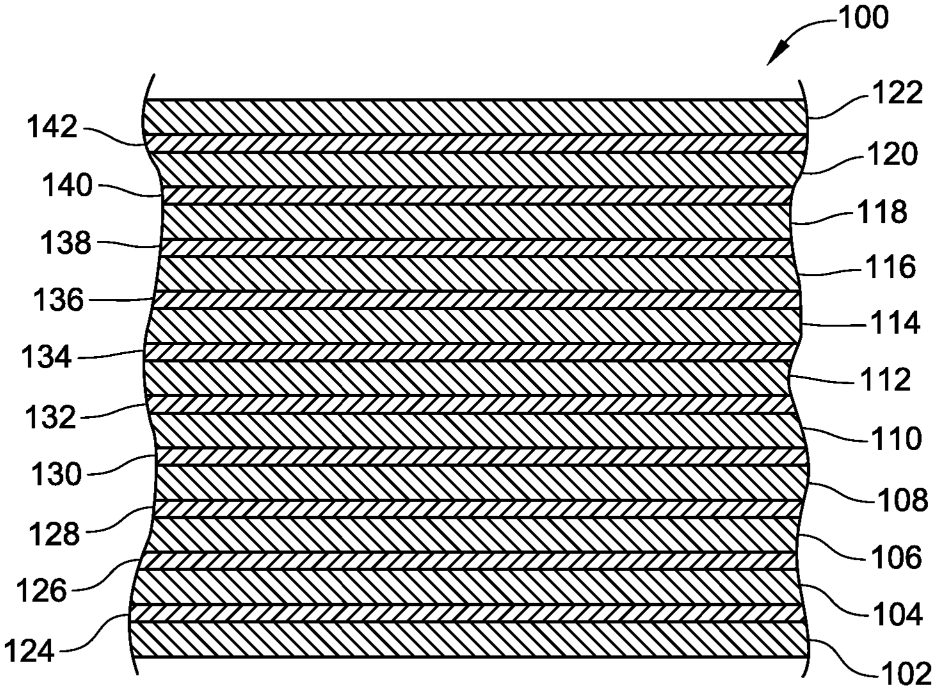
100
122
142
120
140
118
138
116
136
114
134
112
132
110
130
108
128
106
126
104
124
102

FIG. 1

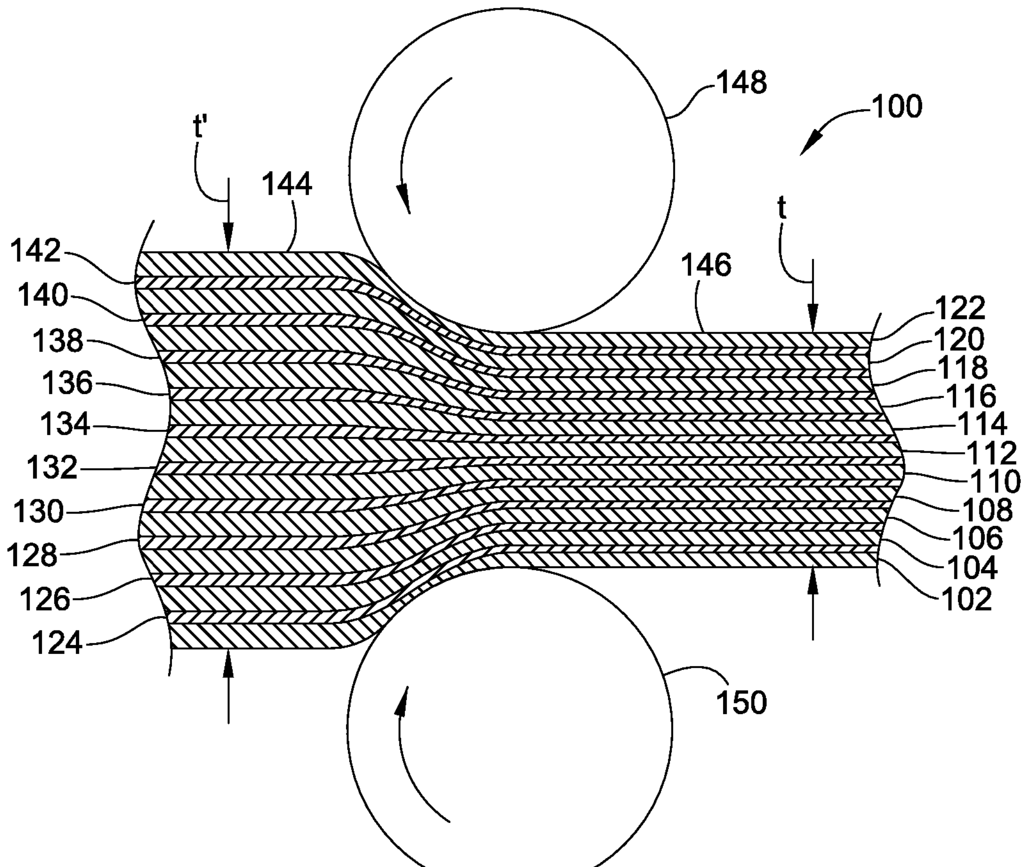
148
100
t'
144
t
146
142
140
138
136
134
132
130
128
126
124
122
120
118
116
114
112
110
108
106
104
102
150

FIG. 2

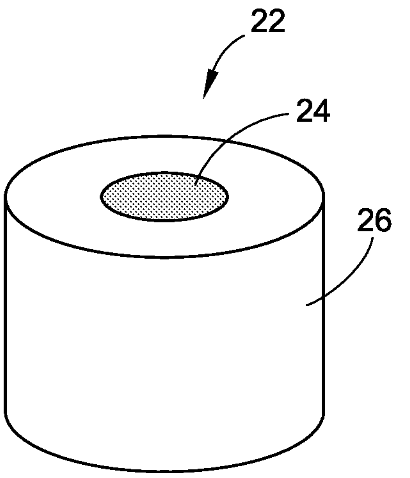

FIG. 3

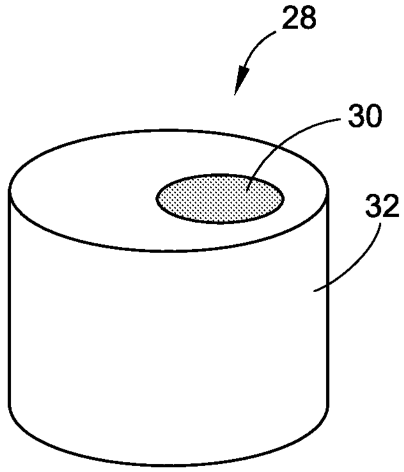

FIG. 4

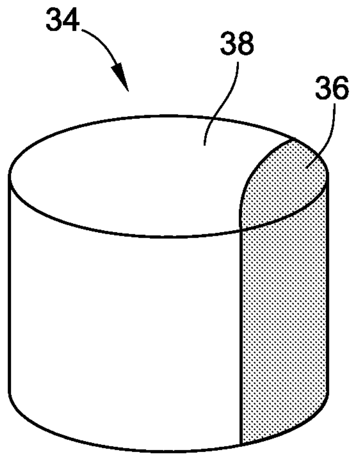

FIG. 5

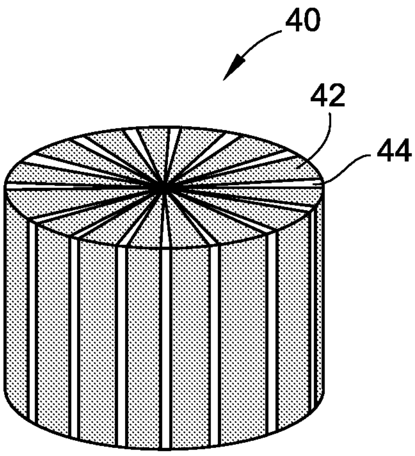

FIG. 6

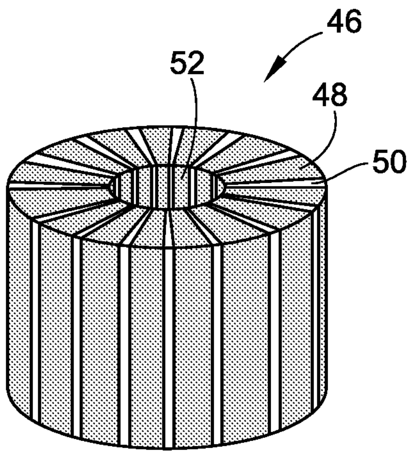

FIG. 7

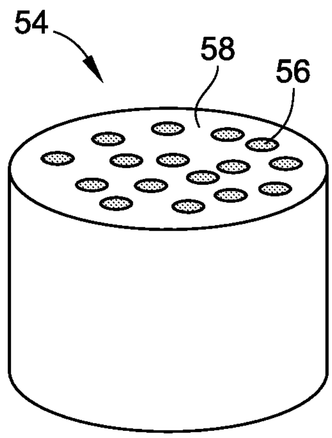

FIG. 8

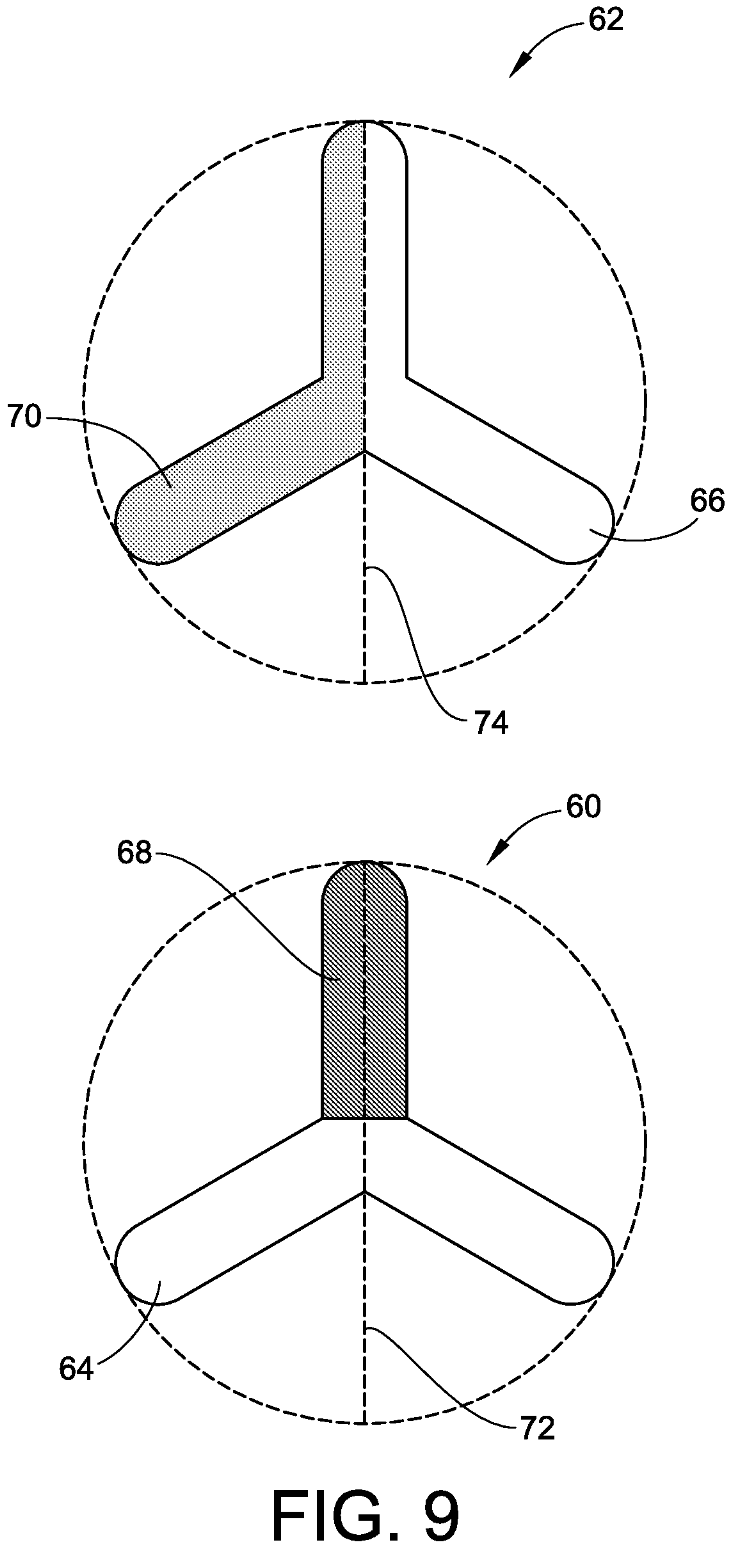

FIG. 9

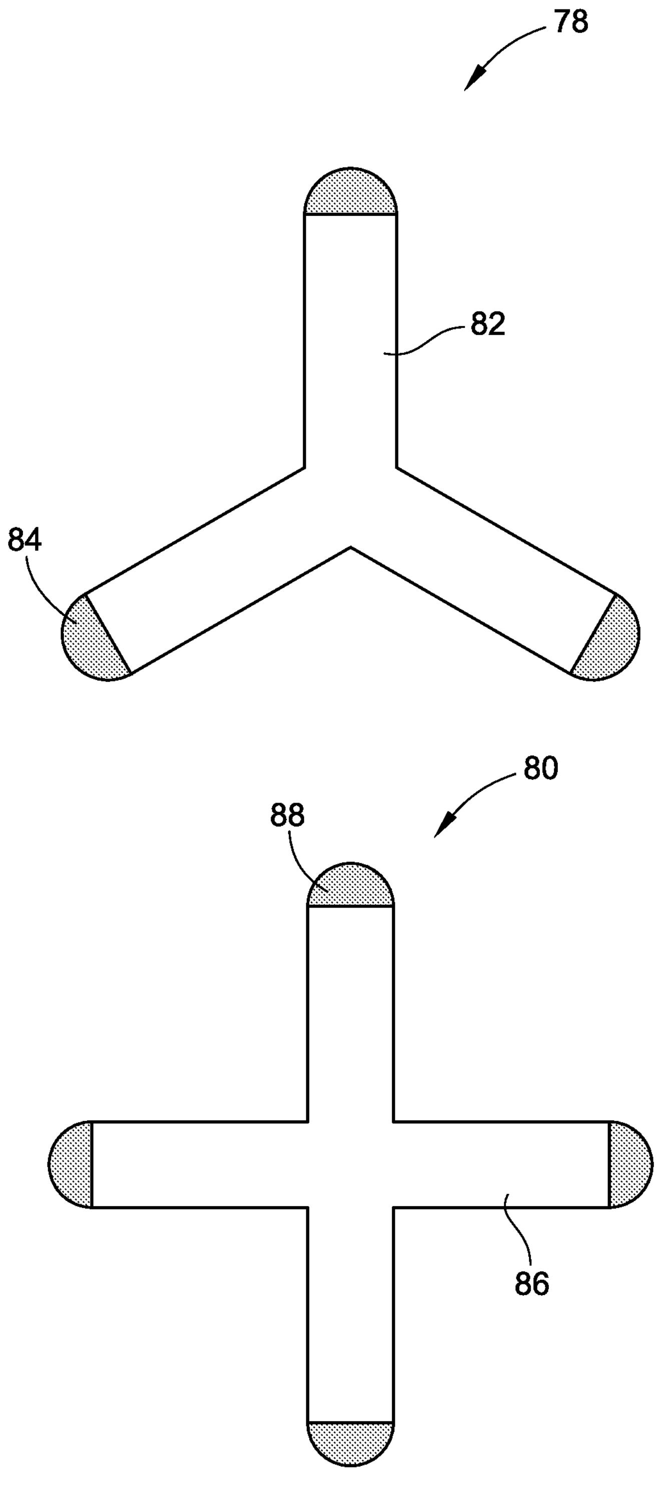

FIG. 10

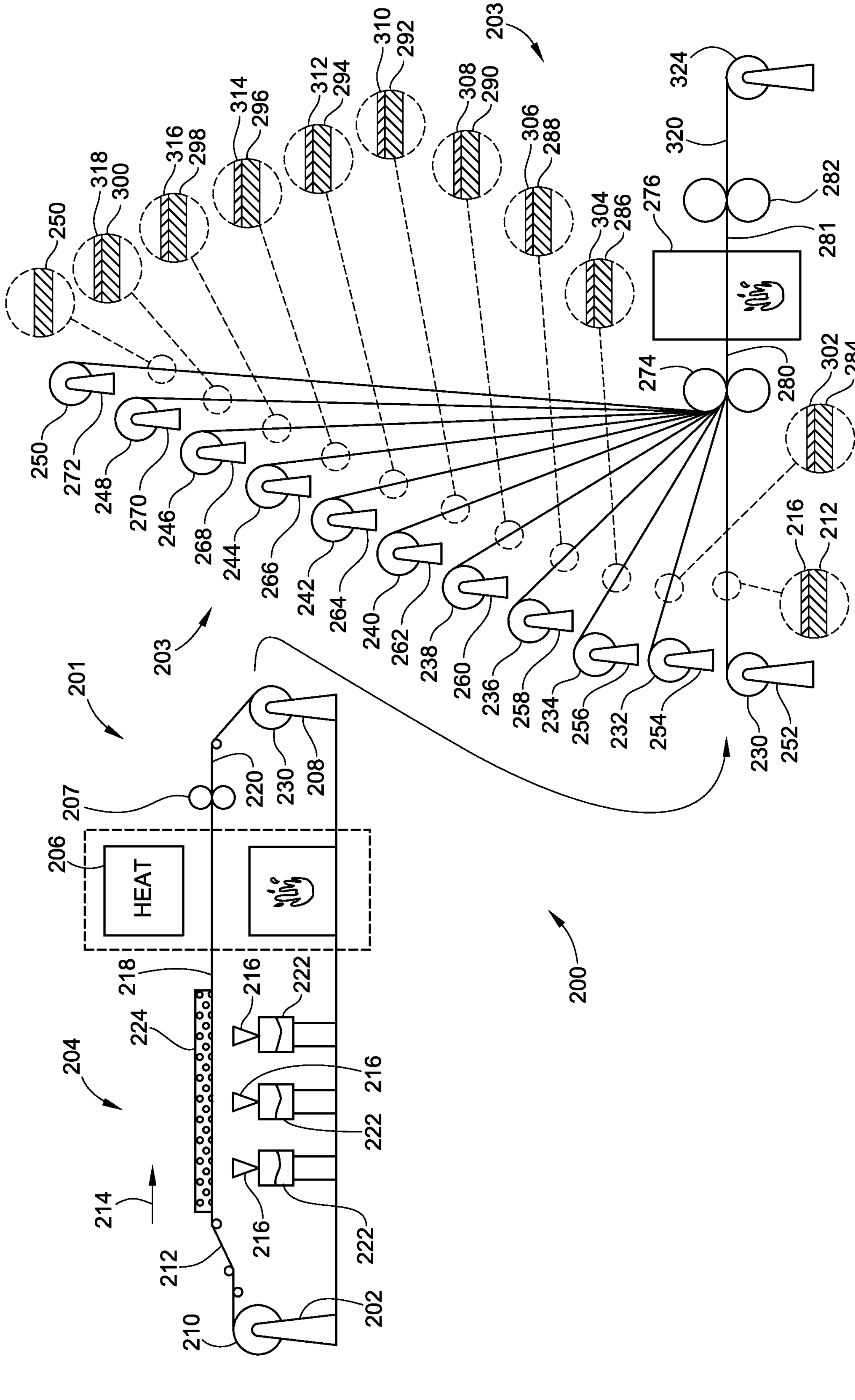
HEAT
200
201
203
204
206
207
208
210
212
214
216
218
220
222
224
230
232
234
236
238
240
242
244
246
248
250
252
254
256
258
260
262
264
266
268
270
272
274
276
280
281
282
284
286
288
290
292
294
296
298
300
302
304
306
308
310
312
314
316
318
320
324

FIG. 11

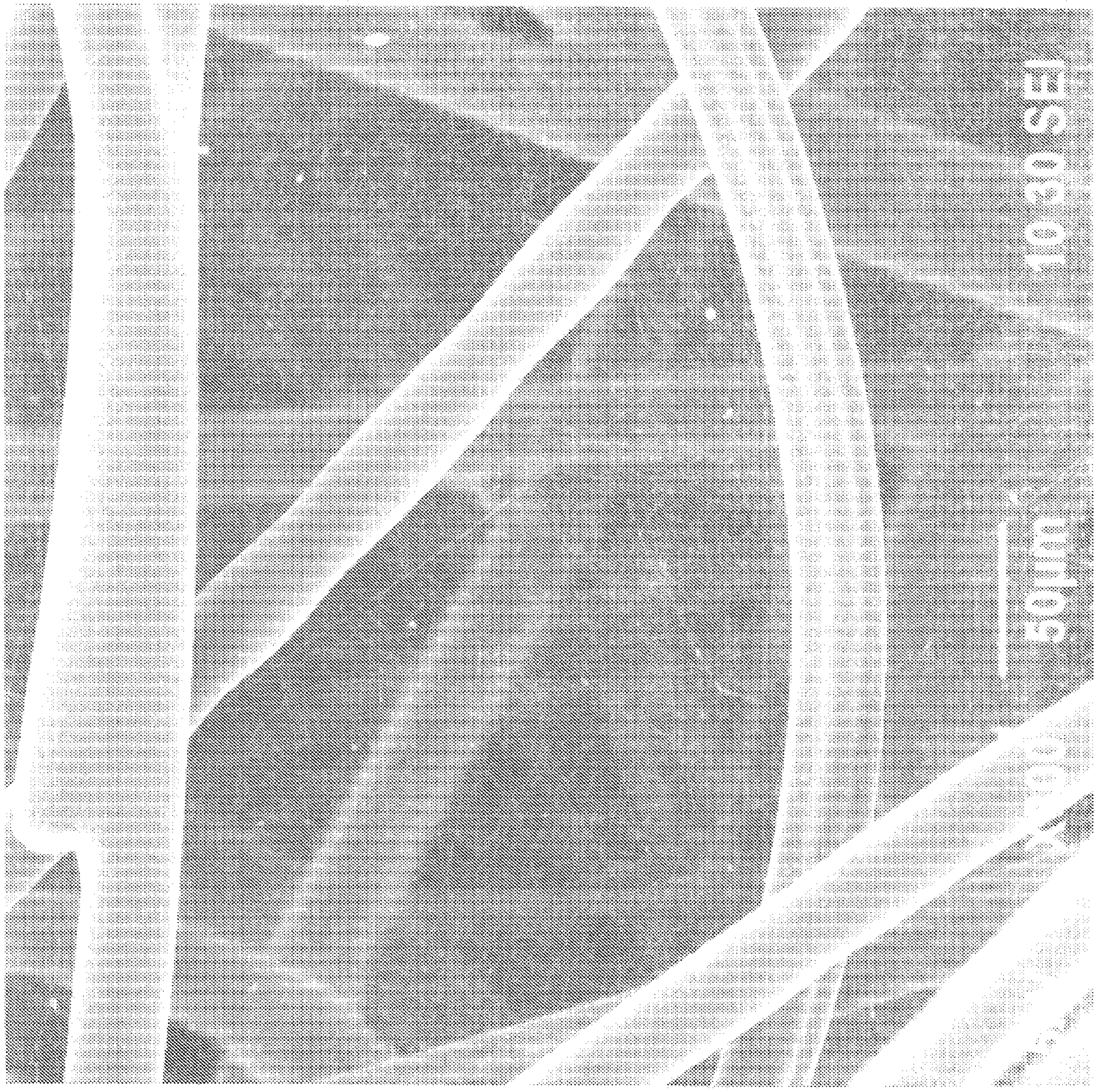

FIG. 12(A)

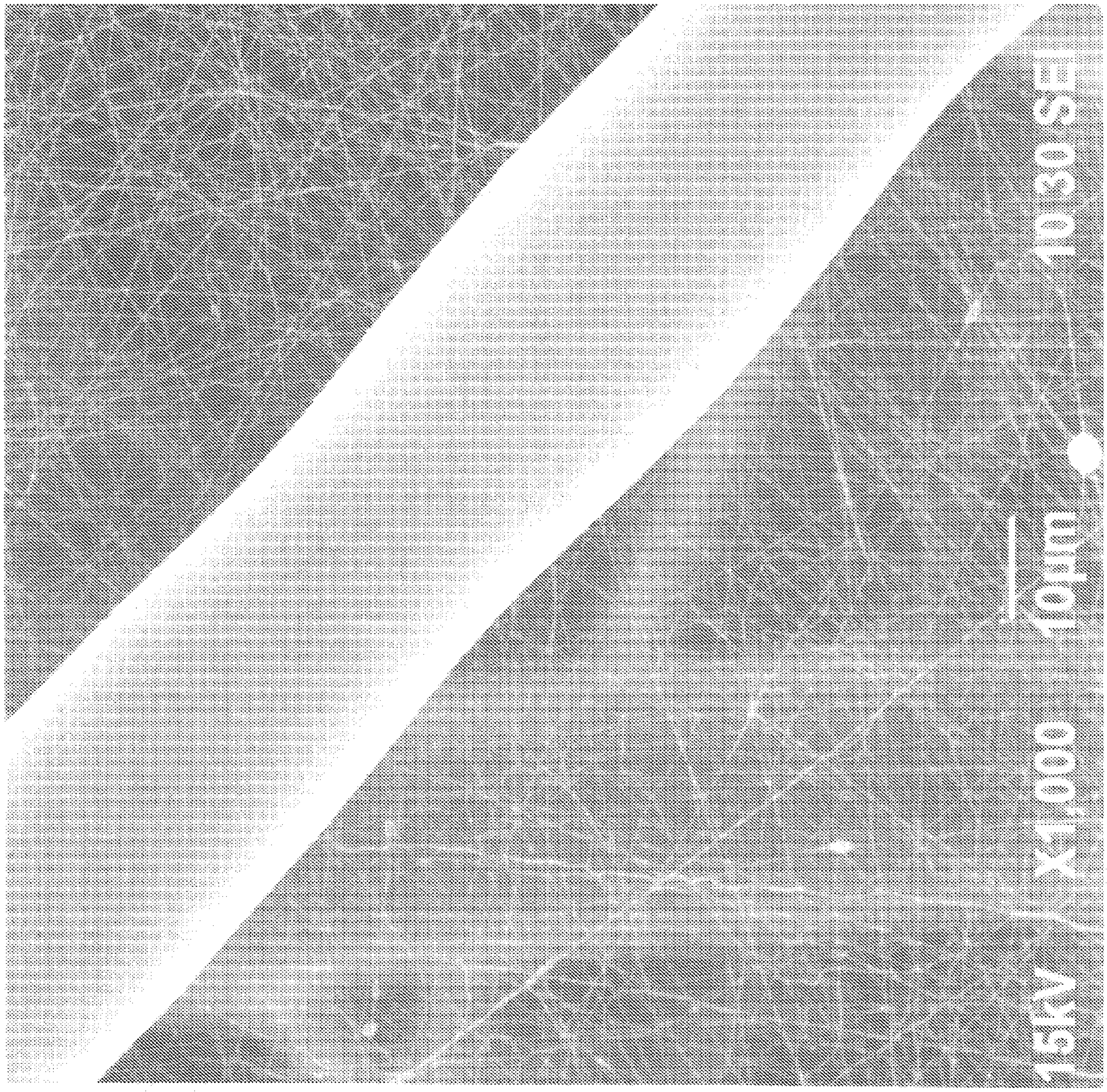

FIG. 12(B)

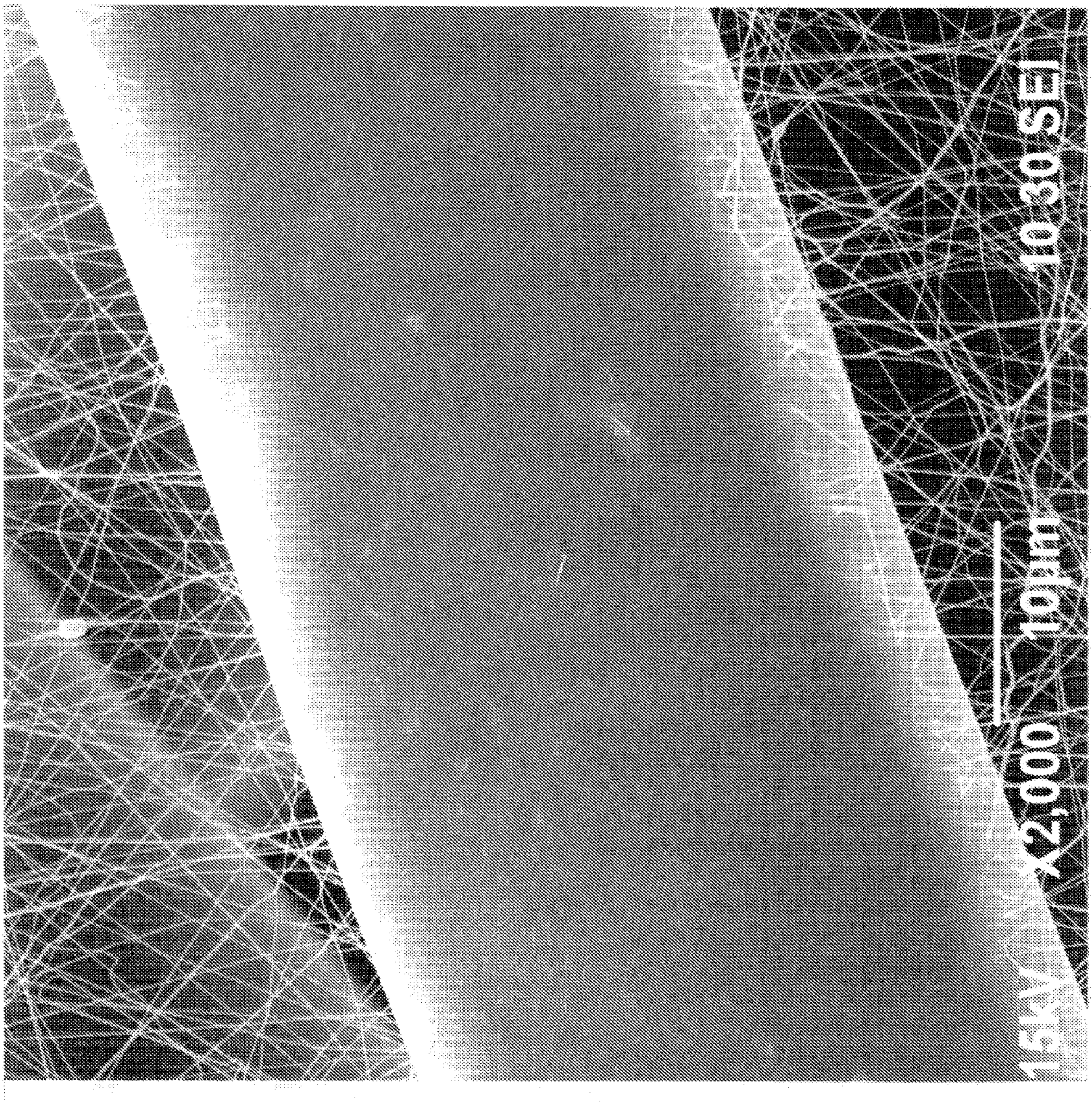

FIG. 12(C)

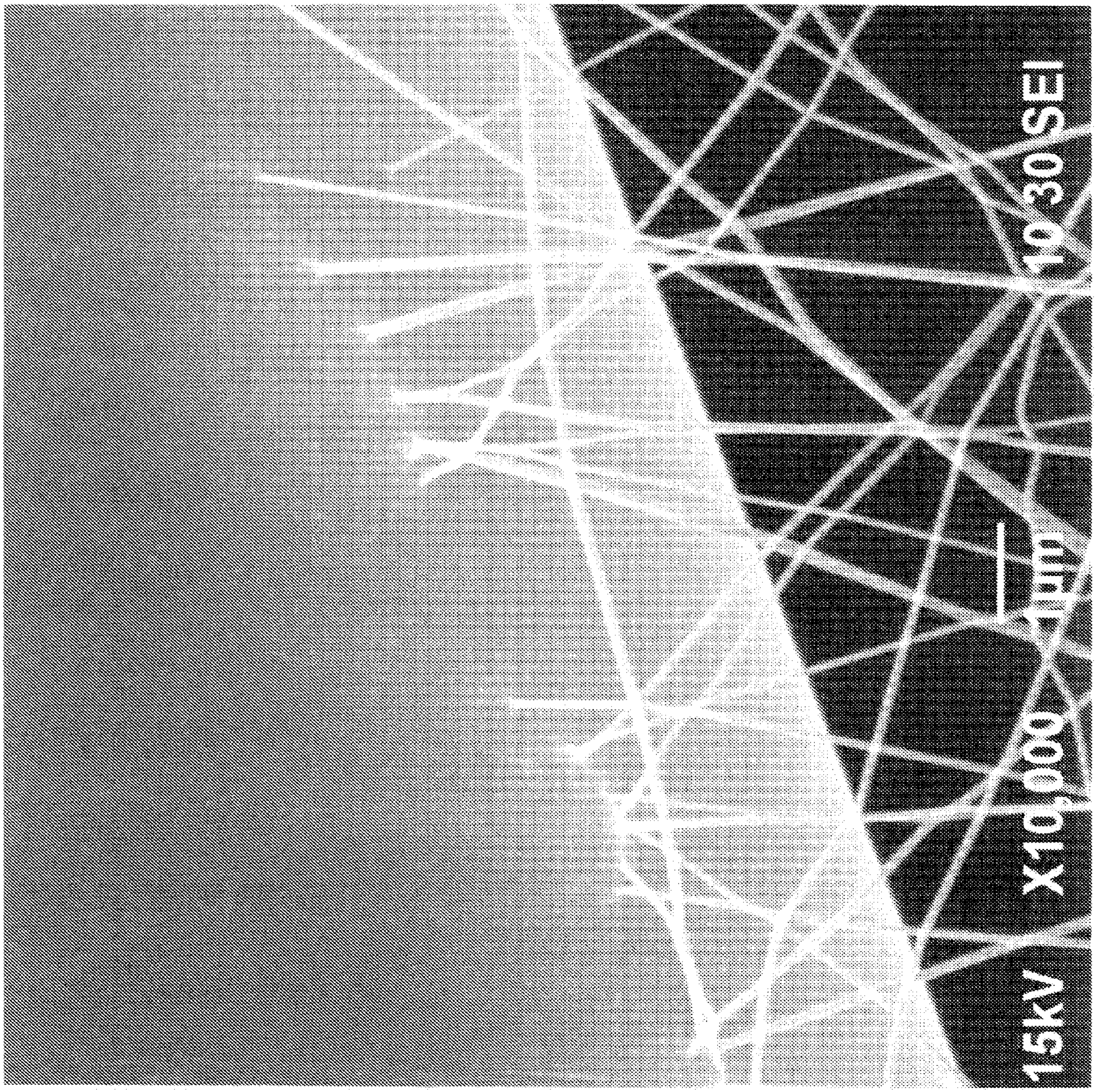

FIG. 12(D)

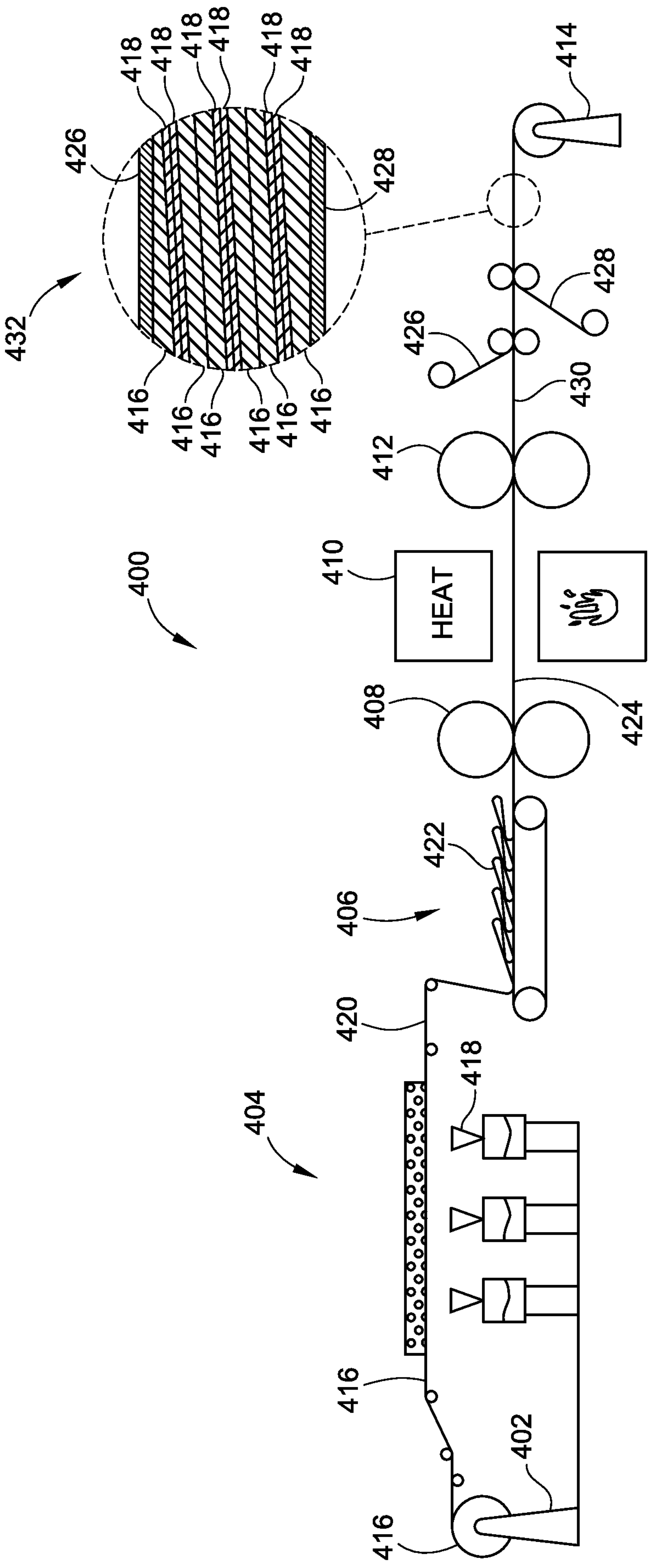
432
426
418
418
418
418
418
418
428
416
416
416
416
416
416
414
400
410
HEAT
412
426
428
430
408
424
406
422
420
404
418
416
402
416

FIG. 13

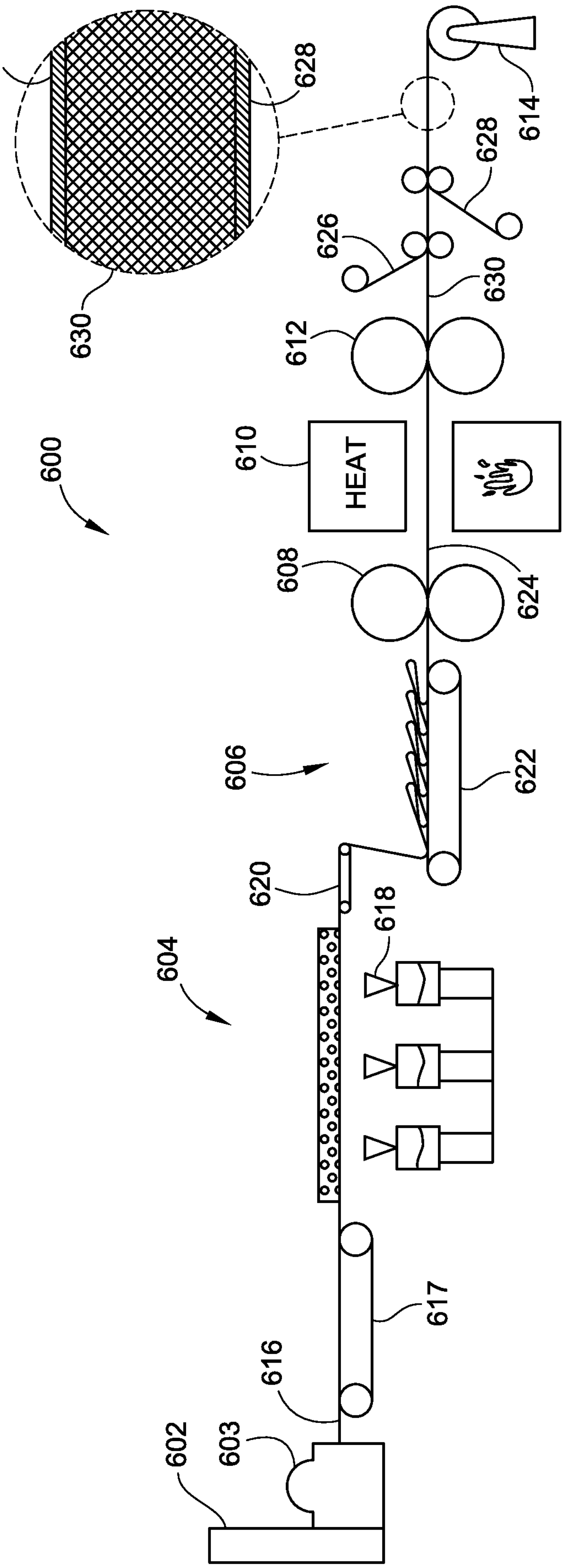
626
628
630
614
628
626
630
612
600
610
HEAT
608
624
606
622
620
618
604
617
616
603
602

FIG. 14

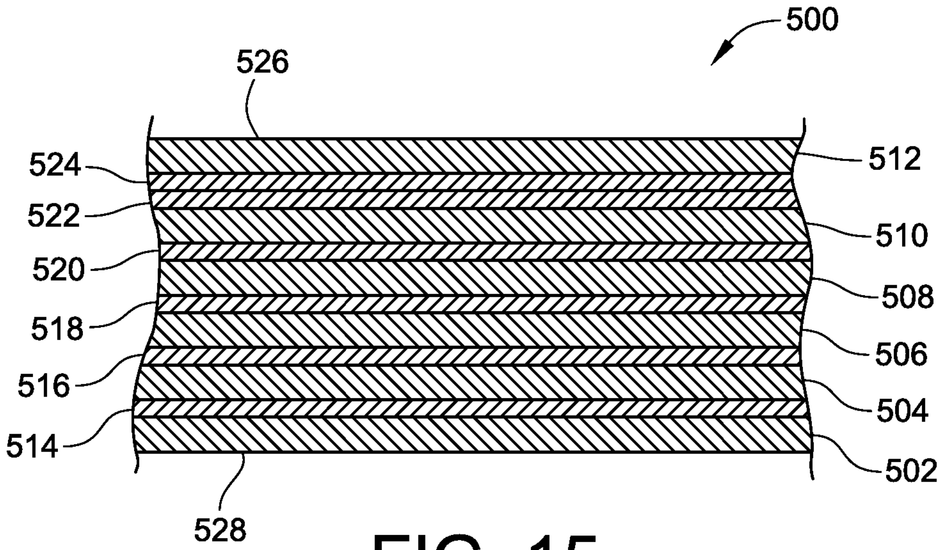

FIG. 15

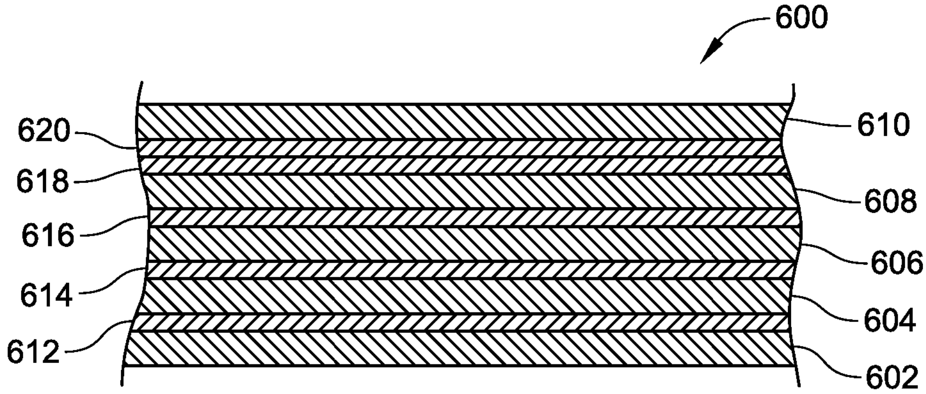

FIG. 19

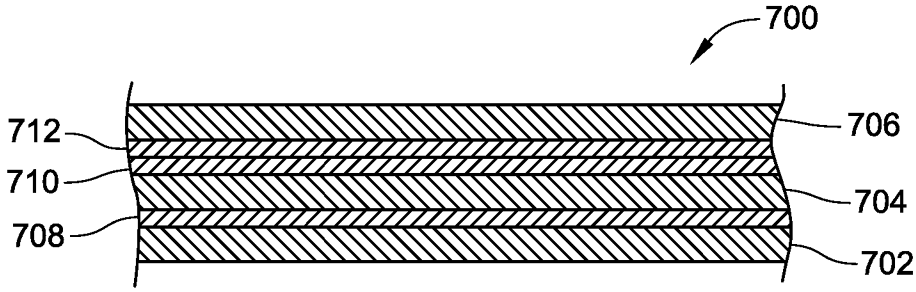

FIG. 21

ISO 16889 - FILTER ELEMENT MULTIPASS REPORT SHEET

Test File Name: 100826-00-1-2

TEST RESULTS II

Particle counts (per mL) and filtration ratio

Time interval		d > 4 µm(c)	d > 5 µm(c)	d > 6 µm(c)	d > 7 µm(c)	d > 8 µm(c)	d > 10 µm(c)	d > 12 µm(c)	d > 14 µm(c)	d > 15 µm(c)	d > 17 µm(c)	d > 20 µm(c)	d > 25 µm(c)	d > 30 µm(c)	d > 35 µm(c)	d > 40 µm(c)	d > 50 µm(c)
	Initial	98.8	64.5	37.3	31.3	27.2	18.1	11.1	8.1	8.1	4.0	1.0	1.0	1.0	1.0	1.0	1.0
10%	Up	9020.0	5489.2	3473.8	3280.9	1687.7	802.6	455.8	275.3	220.0	144.8	80.9	32.9	15.1	7.7	6.0	2.2
	Down	0.8	0.5	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	10846.2	10368.7	12756.5	18139.0	12080.6	8798.4	28851.4	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
20%	Up	9980.6	6074.2	3844.9	2647.7	1743.2	892.6	603.7	311.3	251.8	165.1	93.1	37.1	16.7	9.1	5.6	3.3
	Down	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	87747.0	90198.3	93530.1	82494.9	124138.1	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
30%	Up	9913.7	8023.9	3811.2	2617.3	1714.7	870.2	498.8	302.7	243.4	168.4	87.8	35.0	15.9	8.8	5.1	2.4
	Down	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	73488.9	64498.2	82063.4	80898.1	131136.1	67238.2	37882.6	23145.2	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
40%	Up	9930.8	6014.1	3801.7	2608.1	1706.0	883.8	493.5	238.0	238.1	165.3	83.4	32.9	14.7	7.7	8.0	3.0
	Down	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	102987.9	139386.7	246864.7	100000.0	186000.0	100000.0	100000.0	100280.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
50%	Up	9894.0	8027.4	3820.1	2614.8	1717.8	879.8	490.1	302.7	248.4	181.2	89.8	36.8	15.9	8.6	6.3	2.4
	Down	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	82198.2	115749.2	145174.9	85847.2	69480.8	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
60%	Up	9915.3	5985.7	3786.9	2494.8	1704.9	872.8	497.2	301.2	241.9	188.3	88.8	35.6	18.2	8.6	6.2	2.7
	Down	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	38754.8	44931.1	35132.9	46853.4	31884.8	18323.7	12386.8	7484.8	8013.6	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
70%	Up	9908.2	6990.5	3704.0	2501.3	1708.2	872.6	488.3	293.8	238.5	168.1	88.4	33.6	18.6	8.8	5.3	2.8
	Down	1.3	0.8	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	7514.5	7898.2	9436.2	7781.1	7884.3	12882.1	37148.2	22429.8	18081.6	11821.8	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
80%	Up	9927.0	6016.8	3808.7	2616.7	1711.6	881.8	503.7	303.2	244.5	158.8	87.7	35.6	18.7	9.6	6.7	2.9
	Down	8.3	3.6	2.2	1.4	1.0	0.5	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	β	1589.0	1677.0	1729.4	1812.9	1691.4	1619.8	1806.6	2313.0	3146.7	3096.7	3370.8	100000.0	100000.0	100000.0	100000.0	100000.0
90%	Up	9943.0	6029.8	3814.4	2619.3	1723.6	885.7	497.5	298.7	241.9	158.1	83.7	33.5	18.7	8.4	5.1	2.0
	Down	30.9	18.3	11.3	7.4	5.0	3.4	1.2	0.7	0.5	0.3	0.1	0.1	0.0	0.0	0.0	0.0
	β	321.8	329.2	339.0	340.9	346.7	374.1	412.8	414.9	442.2	494.8	818.0	418.6	881.1	621.4	100000.0	100000.0
100%	Up	9922.8	6010.1	3823.0	3581.7	1797.1	875.6	488.2	297.8	238.9	155.0	84.8	33.4	15.2	8.4	5.3	2.8
	Down	52.7	31.4	19.7	12.8	8.4	4.0	2.2	1.2	0.8	0.4	0.2	0.1	0.0	0.0	0.0	0.0
	β	188.3	191.2	192.8	198.0	203.5	218.1	230.8	253.0	293.8	382.8	382.5	625.2	1110.8	100000.0	100000.0	100000.0
Average	Up	5800.3	5945.3	3760.3	2483.4	1684.9	869.0	481.3	297.8	238.7	157.0	88.8	34.7	15.9	8.4	5.3	2.8
	Down	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	23454.0	24679.3	28639.0	27946.8	28836.7	27034.3	42113.7	31394.4	31486.1	83908.2	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0

FIG. 16

ISO 16889 - FILTER ELEMENT MULTIPASS REPORT SHEET

Test File Name: 100828-00-1

TEST RESULTS II

Particle counts (per mL) and filtration ratio

Time interval		d > 4 µm(c)	d > 5 µm(c)	d > 6 µm(c)	d > 7 µm(c)	d > 8 µm(c)	d > 10 µm(c)	d > 12 µm(c)	d > 14 µm(c)	d > 15 µm(c)	d > 17 µm(c)	d > 20 µm(c)	d > 25 µm(c)	d > 30 µm(c)	d > 35 µm(c)	d > 40 µm(c)	d > 50 µm(c)
	Initial	83.2	83.1	38.1	18.6	11.0	3.8	1.2	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0
10%	Up	28112.1	14028.9	8851.1	4832.0	3978.5	2031.3	1138.2	887.8	548.0	288.7	180.2	71.3	32.3	18.9	9.8	8.7
	Down	1.1	0.7	0.4	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	21124.1	20873.3	19908.1	23380.6	28398.7	32779.3	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
20%	Up	28812.8	17619.0	11143.2	7363.7	6227.4	2574.0	1448.6	883.7	886.8	444.8	243.0	83.6	41.9	21.0	12.7	5.1
	Down	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	67286.3	58580.3	68524.2	88286.7	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
30%	Up	28284.7	17783.9	11328.8	7444.3	5083.8	2818.1	1473.6	880.0	718.9	456.0	352.6	89.8	48.2	24.5	14.8	7.3
	Down	0.8	0.3	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β	33838.0	58109.7	64682.1	72164.2	84443.8	48662.1	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
40%	Up	28328.7	17738.1	11243.8	7434.1	5088.5	3586.3	1481.3	881.3	704.7	488.1	248.1	98.1	41.3	22.8	14.1	7.1
	Down	7.3	4.7	3.0	1.9	1.3	0.8	0.3	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0
	β	3895.2	3773.7	3804.8	3898.8	3850.7	3470.5	4570.8	3985.3	2818.9	2881.4	2321.0	100000.0	100000.0	100000.0	100000.0	100000.0
50%	Up	29300.0	17789.6	11247.3	7437.4	5088.0	2810.5	1478.3	888.9	712.8	484.3	264.7	101.6	48.0	24.8	14.9	7.3
	Down	28.4	15.9	10.2	6.9	4.6	2.1	1.2	0.6	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0
	β	1107.8	1118.6	1100.7	1074.8	1116.1	1285.4	1201.9	1427.3	1680.1	2080.8	3421.3	4298.1	100000.0	100000.0	100000.0	100000.0
60%	Up	28369.7	17826.4	11317.7	7473.7	5098.8	2801.1	1482.7	877.3	704.2	487.5	247.7	93.9	43.2	23.5	14.5	8.4
	Down	68.7	34.8	21.6	14.4	10.0	5.1	2.8	1.6	1.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0
	β	418.4	515.8	524.4	519.8	509.8	549.4	528.7	587.8	644.3	864.9	1858.8	100000.0	100000.0	100000.0	100000.0	100000.0
70%	Up	29346.9	17820.8	11208.9	7483.8	5111.6	2628.2	1472.8	882.4	713.7	485.3	284.4	90.0	41.2	21.7	12.9	8.8
	Down	180.6	107.9	68.2	43.3	29.1	14.2	7.5	4.3	3.3	1.6	0.7	0.2	0.1	0.0	0.0	0.0
	β	162.6	165.3	166.8	172.7	175.4	185.0	197.2	209.0	221.6	293.4	349.5	608.5	610.5	100000.0	100000.0	100000.0
80%	Up	29636.6	17968.3	11376.4	7506.7	5132.3	3838.0	1484.6	883.9	713.6	485.9	263.5	87.8	42.5	22.7	14.7	7.6
	Down	687.6	417.6	263.8	176.5	119.2	59.7	31.7	18.0	13.7	7.6	3.4	0.7	0.2	0.1	0.0	0.0
	β	42.6	43.0	43.1	42.8	43.0	44.2	46.8	49.6	52.0	62.0	74.4	148.8	241.8	289.7	294.6	100000.0
90%	Up	30387.8	18484.4	11897.7	7748.0	5280.7	2704.9	1528.8	921.1	737.8	477.8	258.5	88.1	41.7	22.1	13.1	6.7
	Down	1594.9	1186.8	728.3	482.6	328.1	162.4	87.8	49.8	37.8	21.7	9.1	1.3	0.3	0.0	0.0	0.0
	β	18.8	18.0	16.1	16.1	16.1	16.7	17.4	18.6	19.8	22.0	28.1	74.3	141.8	810.8	478.5	100000.0
100%	Up	32091.6	19468.4	12380.8	8173.4	5580.8	2882.8	1608.8	957.8	783.9	491.3	266.0	102.2	46.8	24.8	15.9	7.6
	Down	4234.7	2539.2	1626.8	1061.8	730.9	356.1	190.5	105.4	81.8	47.8	20.1	3.6	0.7	0.3	0.1	0.0
	β	7.6	7.7	7.7	7.7	7.7	8.1	8.4	9.1	9.4	10.3	13.2	28.8	64.8	109.0	213.3	100000.0
Average	Up	28339.8	17215.4	10906.7	7311.2	4921.8	2620.8	1418.8	864.9	684.1	444.3	241.5	83.2	41.4	21.8	13.4	8.5
	Down	38.1	23.6	14.8	9.6	6.6	3.2	1.7	1.0	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0
	β	724.3	731.5	736.5	763.3	781.4	782.8	841.6	889.1	958.9	1241.0	1821.8	3871.1	3392.8	100000.0	100000.0	100000.0

FIG. 17

ISO 16889 - FILTER ELEMENT MULTIPASS REPORT SHEET

Test File Name: 100812-00-1

TEST RESULTS II

Particle counts (per mL) and filtration ratio

Time interval		d > 4 µm(c)	d > 5 µm(c)	d > 6 µm(c)	d > 7 µm(c)	d > 8 µm(c)	d > 10 µm(c)	d > 12 µm(c)	d > 14 µm(c)	d > 15 µm(c)	d > 17 µm(c)	d > 20 µm(c)	d > 25 µm(c)	d > 30 µm(c)	d > 35 µm(c)	d > 40 µm(c)	d > 50 µm(c)
	Initial	334.8	185.7	128.8	81.2	62.3	39.7	31.1	21.5	19.3	17.2	11.8	8.8	5.4	4.3	2.1	2.1
10%	Up	22885.2	13702.3	8596.1	5573.3	3766.1	1920.8	1096.9	685.9	532.8	352.9	197.7	84.6	41.0	21.4	14.1	7.3
	Down	18.2	8.6	4.4	2.9	1.8	0.4	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	β	1248.9	1589.4	1941.2	1895.8	2104.6	4886.7	6758.7	8328.4	6881.8	4413.1	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
20%	Up	27481.3	16713.1	10568.2	6842.5	4730.0	2419.8	1381.6	844.5	672.8	446.8	244.5	98.7	48.4	25.1	13.9	7.8
	Down	64.9	34.3	19.4	10.7	6.2	1.9	0.9	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	β	423.4	487.0	543.6	850.8	763.6	1284.8	1612.8	2820.7	4167.0	8493.4	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
30%	Up	28681.6	17437.1	11035.7	7274.7	4933.2	2519.1	1435.6	872.4	704.3	464.2	263.4	104.3	47.7	27.1	17.0	9.0
	Down	209.7	117.4	69.3	42.2	26.2	12.3	4.7	1.9	0.9	0.4	0.1	0.0	0.0	0.0	0.0	0.0
	β	136.7	148.6	159.2	172.5	188.4	205.5	303.1	459.3	779.6	1098.5	2708.5	2214.6	100000.0	100000.0	100000.0	100000.0
40%	Up	29016.3	17660.0	11126.4	7318.3	4977.7	2523.7	1435.6	862.9	697.1	454.5	258.4	104.8	51.3	27.9	17.8	8.7
	Down	451.8	251.7	150.6	91.7	55.2	21.6	9.2	3.3	2.3	1.2	0.3	0.0	0.0	0.0	0.0	0.0
	β	64.2	70.2	73.9	79.8	90.2	116.9	155.9	261.2	303.4	385.9	944.8	100000.0	100000.0	100000.0	100000.0	100000.0
50%	Up	29105.4	17674.2	11184.8	7353.2	5018.6	2560.1	1436.8	873.9	696.8	453.4	249.2	101.5	47.6	27.5	15.2	7.7
	Down	702.9	402.3	237.3	147.6	91.8	38.1	18.0	8.3	5.5	2.4	0.8	0.1	0.0	0.0	0.0	0.0
	β	41.4	43.8	47.1	49.8	54.7	65.9	79.7	104.9	126.8	190.3	427.5	1879.9	100000.0	100000.0	100000.0	100000.0
60%	Up	29390.5	17818.7	11303.9	7432.6	5046.8	2680.3	1481.3	883.0	714.5	457.8	248.6	101.3	44.6	24.1	14.9	7.1
	Down	832.1	533.2	317.0	198.8	128.3	63.8	24.2	10.7	7.0	3.0	0.6	0.1	0.0	0.0	0.0	0.0
	β	31.5	33.6	35.7	37.4	39.3	47.9	60.3	83.5	102.0	151.8	397.6	1024.4	100000.0	100000.0	100000.0	100000.0
70%	Up	29503.0	17906.8	11328.0	7436.1	5049.0	2570.3	1459.1	888.6	714.8	465.8	255.2	102.6	46.9	26.4	16.1	8.2
	Down	1098.2	831.1	383.6	240.5	151.0	62.0	26.8	12.8	8.8	3.7	1.2	0.1	0.0	0.0	0.0	0.0
	β	26.9	28.4	29.6	30.9	33.4	41.6	54.2	69.7	81.4	125.0	218.3	1920.0	100000.0	100000.0	100000.0	100000.0
80%	Up	29669.6	18058.0	11420.0	7509.1	5104.7	2615.8	1486.4	898.3	722.5	472.6	258.4	108.5	48.1	26.8	14.7	8.0
	Down	1165.4	669.6	407.1	255.6	162.4	66.6	31.2	14.0	9.1	3.7	0.0	0.0	0.0	0.0	0.0	0.0
	β	25.5	27.0	28.0	29.4	31.4	39.3	47.6	63.8	79.7	126.4	279.2	100000.0	100000.0	100000.0	100000.0	100000.0
90%	Up	29586.0	17369.9	11322.6	7446.3	5062.8	2682.3	1460.1	868.9	694.8	444.7	240.4	97.4	44.0	24.3	14.7	7.4
	Down	1181.8	683.1	408.4	255.3	158.0	68.9	30.7	14.8	10.1	5.1	1.1	0.1	0.0	0.0	0.0	0.0
	β	35.0	25.3	27.7	29.2	32.0	38.6	47.2	58.8	68.8	87.6	216.2	1898.5	100000.0	100000.0	100000.0	100000.0
100%	Up	29801.4	18066.2	11456.8	7544.0	5127.5	2624.6	1488.6	898.7	720.0	472.4	263.2	108.4	48.7	27.2	17.8	8.9
	Down	1087.0	630.3	377.6	238.9	151.9	65.1	30.0	13.3	9.1	4.7	1.7	0.3	0.0	0.0	0.0	0.0
	β	27.4	28.7	30.3	31.6	33.7	40.3	48.6	67.6	73.6	100.7	164.6	405.3	100000.0	100000.0	100000.0	100000.0
Average	Up	27978.9	17001.2	10730.3	7047.0	4763.8	2440.6	1386.5	841.2	676.1	442.0	243.4	99.7	48.4	25.8	16.5	8.1
	Down	495.8	282.6	168.7	104.9	65.8	27.1	12.0	6.3	3.5	1.6	0.4	0.0	0.0	0.0	0.0	0.0
	β	56.3	60.2	63.6	67.2	72.6	89.9	116.2	167.7	191.1	284.9	621.8	2763.2	100000.0	100000.0	100000.0	100000.0

FIG. 18

ISO 16889 - FILTER ELEMENT MULTIPASS REPORT SHEET

Test File Name: 100714-00-7

TEST RESULTS II

Particle counts (per mL) and filtration ratio

Time Interval		d > 4 µm(c)	d > 5 µm(c)	d > 6 µm(c)	d > 7 µm(c)	d > 8 µm(c)	d > 10 µm(c)	d > 12 µm(c)	d > 14 µm(c)	d > 15 µm(c)	d > 17 µm(c)	d > 20 µm(c)	d > 25 µm(c)	d > 30 µm(c)	d > 35 µm(c)	d > 40 µm(c)	d > 50 µm(c)
	Initial	164.0	111.7	70.7	52.3	42.0	21.5	17.4	13.3	9.2	8.2	2.1	1.0	1.0	0.0	0.0	0.0
10%	Up	14808.5	8968.3	5670.8	3711.4	2517.7	1253.6	720.4	419.3	331.0	315.3	111.0	36.2	18.9	5.3	4.3	2.4
	Down	6.5	2.6	1.7	1.2	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	2278.8	3385.2	3398.2	3034.0	2518.8	2518.1	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
20%	Up	22208.2	13480.3	8477.8	5665.4	3788.3	1891.4	1046.0	636.3	503.5	325.8	171.4	84.8	27.3	13.3	8.2	3.5
	Down	12.8	7.7	4.1	2.3	0.9	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	1729.4	1757.5	2058.8	2460.8	4241.2	4738.4	12840.1	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
30%	Up	26633.8	18186.1	10179.8	6680.2	4504.8	2289.8	1297.8	778.4	618.3	393.6	214.8	85.8	42.5	19.5	11.0	8.7
	Down	30.0	23.0	14.9	9.5	5.5	3.0	1.5	1.2	0.9	0.7	0.3	0.0	0.0	0.0	0.0	0.0
	ß	883.1	702.8	683.2	726.8	815.4	765.8	883.8	642.7	690.7	548.6	689.2	100000.0	100000.0	100000.0	100000.0	100000.0
40%	Up	28127.8	17100.8	10781.2	7048.3	4773.0	2423.2	1389.3	818.8	680.8	429.5	240.3	93.2	41.8	21.8	13.6	8.2
	Down	77.9	45.2	28.2	17.6	10.9	5.4	2.5	1.1	0.9	0.7	0.2	0.1	0.0	0.0	0.0	0.0
	ß	361.2	377.8	380.8	401.1	437.2	462.3	550.0	776.2	739.2	595.0	978.8	1123.3	100000.0	100000.0	100000.0	100000.0
50%	Up	28578.0	17324.1	10887.0	7158.4	4881.8	2501.3	1402.7	940.4	578.6	451.8	244.8	82.8	38.1	21.8	14.0	8.8
	Down	141.8	82.9	54.2	33.9	23.2	10.7	5.8	3.0	2.5	1.8	1.0	0.2	0.0	0.0	0.0	0.0
	ß	201.5	208.9	200.8	210.8	208.5	233.5	239.8	278.8	258.4	248.7	237.5	368.1	100000.0	100000.0	100000.0	100000.0
60%	Up	26730.1	17404.8	10960.2	7198.6	4891.2	2473.8	1367.1	847.8	683.5	439.8	239.0	82.7	40.6	24.5	16.1	8.8
	Down	163.2	114.3	71.8	44.4	30.6	18.0	8.3	4.6	3.1	1.8	0.6	0.3	0.0	0.0	0.0	0.0
	ß	148.7	152.3	152.4	162.2	159.8	164.4	180.2	183.0	218.2	260.8	515.4	304.8	100000.0	100000.0	100000.0	100000.0
70%	Up	28808.2	17812.1	11085.4	7232.9	4882.5	2502.4	1401.8	853.4	678.8	436.8	240.4	87.9	38.8	19.1	11.4	6.2
	Down	256.1	152.4	95.7	60.9	43.2	20.2	10.9	6.5	4.7	2.7	1.4	0.2	0.0	0.0	0.0	0.0
	ß	112.8	114.9	115.6	118.7	113.2	123.8	128.6	131.8	143.3	161.3	176.4	350.5	100000.0	100000.0	100000.0	100000.0
80%	Up	28789.3	17402.5	10971.8	7188.2	4886.4	2484.7	1377.7	828.7	667.8	432.8	232.6	88.8	38.7	19.7	13.1	6.1
	Down	308.7	185.3	117.3	77.0	51.6	28.5	15.6	8.1	6.3	3.8	1.4	0.5	0.2	0.0	0.0	0.0
	ß	93.8	93.9	93.8	93.4	94.7	87.3	81.5	101.8	105.8	113.3	171.8	188.4	243.8	100000.0	100000.0	100000.0
90%	Up	28685.7	17368.1	10856.8	7187.1	4808.4	2507.3	1428.1	860.8	693.8	451.8	250.4	94.7	42.7	20.8	12.7	7.8
	Down	374.3	225.9	141.8	91.8	61.5	30.5	15.3	8.4	6.7	2.9	1.2	0.3	0.1	0.0	0.0	0.0
	ß	76.8	76.5	77.7	78.4	79.8	82.1	93.8	102.8	102.8	155.4	204.1	368.8	485.8	100000.0	100000.0	100000.0
100%	Up	28867.4	17634.4	11073.7	7276.8	4856.3	2607.8	1422.0	854.5	686.8	445.4	244.8	88.8	43.8	24.4	14.3	8.3
	Down	415.4	244.7	153.8	100.8	66.2	34.1	18.4	10.3	8.0	4.8	1.7	0.0	0.0	0.0	0.0	0.0
	ß	68.8	71.7	72.1	72.1	74.9	73.8	77.3	83.3	80.8	87.8	144.0	100000.0	100000.0	100000.0	100000.0	100000.0
Average	Up	25413.8	16426.1	9711.8	6367.4	4314.3	2193.8	1235.8	742.3	582.6	385.0	208.9	79.3	36.1	17.3	11.0	5.3
	Down	103.9	61.2	36.7	24.2	15.4	7.8	4.2	2.3	1.7	1.1	0.8	0.1	0.0	0.0	0.0	0.0
	ß	244.8	252.1	261.1	263.2	281.6	277.7	283.3	317.8	340.8	347.3	428.0	887.7	100000.0	100000.0	100000.0	100000.0

FIG. 20

ISO 16889 - FILTER ELEMENT MULTIPASS REPORT SHEET

Test File Name: 100524-00-1

TEST RESULTS II

Particle counts (per mL) and filtration ratio																	
Time interval		d > 4 µm(c)	d > 5 µm(c)	d > 6 µm(c)	d > 7 µm(c)	d > 8 µm(c)	d > 10 µm(c)	d > 12 µm(c)	d > 14 µm(c)	d > 16 µm(c)	d > 17 µm(c)	d > 20 µm(c)	d > 25 µm(c)	d > 32 µm(c)	d > 36 µm(c)	d > 40 µm(c)	d > 60 µm(c)
	Initial	8568.7	5264.8	2202.8	1307.2	927.0	458.4	243.0	117.8	64.7	53.8	26.4	4.8	2.8	0.8	0.8	0.9
10%	Up	11268.3	6869.7	4385.6	2867.0	1969.8	1028.3	563.3	301.4	220.3	154.1	111.3	48.2	24.4	13.8	9.6	4.1
	Down	18.0	8.7	6.2	3.7	2.2	0.8	0.4	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0
	ß	764.8	784.4	737.4	778.3	885.8	1288.9	1471.9	1032.8	1408.8	1309.0	1278.2	1869.3	829.5	468.5	828.4	100000.0
20%	Up	10660.5	8511.7	4144.6	2764.3	1884.3	885.2	576.2	361.3	283.9	182.3	103.7	48.6	22.6	12.8	8.5	4.3
	Down	2.0	1.6	0.8	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	5398.0	5328.0	5504.5	7349.1	7378.9	10729.6	33230.4	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
30%	Up	10637.3	8483.4	4118.3	2736.1	1878.2	878.3	551.7	281.7	232.8	186.9	157.1	48.9	22.7	13.5	7.8	3.8
	Down	1.5	0.8	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	7038.2	7768.2	9610.8	11277.2	17820.8	24878.3	42269.8	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
40%	Up	10882.8	8504.7	4138.9	2769.3	1892.0	994.5	671.2	359.8	284.7	186.4	102.2	47.2	28.8	14.8	8.5	4.7
	Down	1.2	0.6	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	8840.9	13537.0	14978.6	16949.3	20415.0	28857.3	23318.3	27784.1	22394.8	100000.0	100000.0	100000.0	100000.0	100000.0	100002.0	100000.0
50%	Up	10808.6	8497.6	4131.7	2748.3	1880.8	983.6	664.9	345.8	279.2	188.4	104.8	45.9	22.0	12.8	7.8	4.2
	Down	1.3	0.7	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	8123.0	9427.1	8828.7	8612.4	8801.6	14375.8	20580.8	12704.2	9824.8	8201.9	7495.0	3198.3	1642.7	685.8	583.7	100000.0
60%	Up	10858.3	8526.8	4154.1	2746.8	1879.0	960.3	658.8	349.8	283.4	186.8	107.4	45.8	23.8	12.8	8.1	4.8
	Down	1.3	0.8	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	8582.6	11292.7	12378.8	14022.3	11793.5	19652.6	19756.3	12626.8	11841.8	14244.1	9245.4	3619.9	100000.0	100000.0	100000.0	100000.0
70%	Up	10864.3	8628.0	4143.6	2753.3	1882.8	960.7	668.8	342.8	282.3	185.1	106.6	48.3	23.0	12.6	8.2	4.3
	Down	3.8	1.8	1.0	0.6	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	2880.8	3534.2	4254.7	4664.7	4878.8	6187.8	14195.9	12652.0	13451.0	13449.8	100000.0	100000.0	100000.2	100000.0	100000.0	100000.0
80%	Up	10840.0	8498.8	4135.8	2752.4	1886.8	883.3	573.6	362.2	284.9	190.2	106.6	47.3	24.8	13.8	9.0	4.9
	Down	18.2	10.3	6.8	4.0	2.8	1.8	1.3	1.1	1.0	0.8	0.6	0.4	0.2	0.1	0.1	0.0
	ß	591.8	893.8	605.3	679.8	684.8	596.0	437.2	352.8	286.7	248.8	176.7	134.1	148.8	125.0	184.6	137.8
90%	Up	10781.8	8577.8	4180.1	2781.2	1883.0	1011.8	580.6	359.6	236.7	184.8	110.2	45.0	24.8	13.8	8.8	4.8
	Down	23.4	13.4	8.8	3.7	2.4	1.1	0.7	0.8	0.5	0.4	0.2	0.1	0.0	0.0	0.0	0.0
	ß	461.8	631.8	618.3	748.8	811.1	884.6	780.3	844.8	566.2	521.7	458.8	447.0	926.8	100000.0	100000.0	100000.0
100%	Up	10918.4	6841.0	4236.1	2835.2	1844.6	1006.6	685.8	380.2	291.8	186.2	111.1	48.0	28.7	16.3	10.2	5.7
	Down	14.2	6.8	3.2	1.5	0.6	0.3	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	771.4	1003.2	1311.0	1827.8	3131.2	3842.8	2392.8	3496.4	4537.3	7672.4	2412.8	100000.0	100000.0	100000.0	100000.0	100000.0
Average	Up	10787.4	8554.1	4189.2	2775.0	1902.9	966.3	671.4	351.7	284.2	182.8	108.2	48.8	23.0	13.1	8.3	4.3
	Down	3.8	2.2	1.3	0.8	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	2820.3	3018.3	3105.2	3468.2	3878.3	6814.7	6868.3	7816.8	6818.2	9468.3	9812.1	6773.1	3683.8	2963.1	2040.1	100000.0

FIG. 22

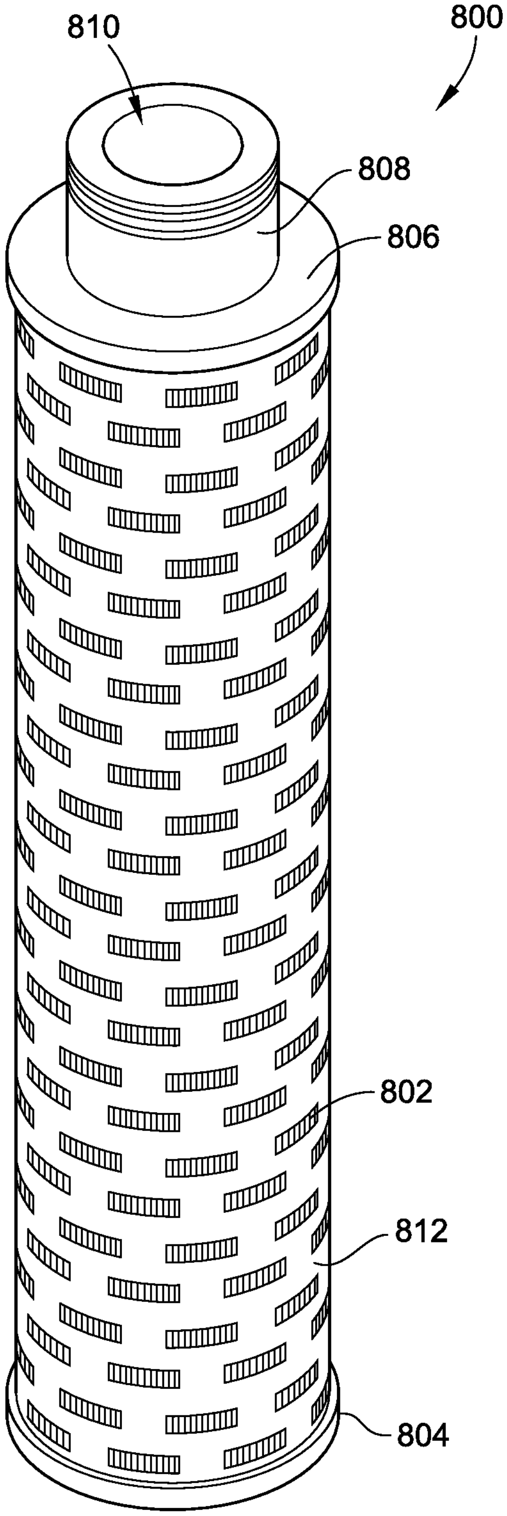

FIG. 23

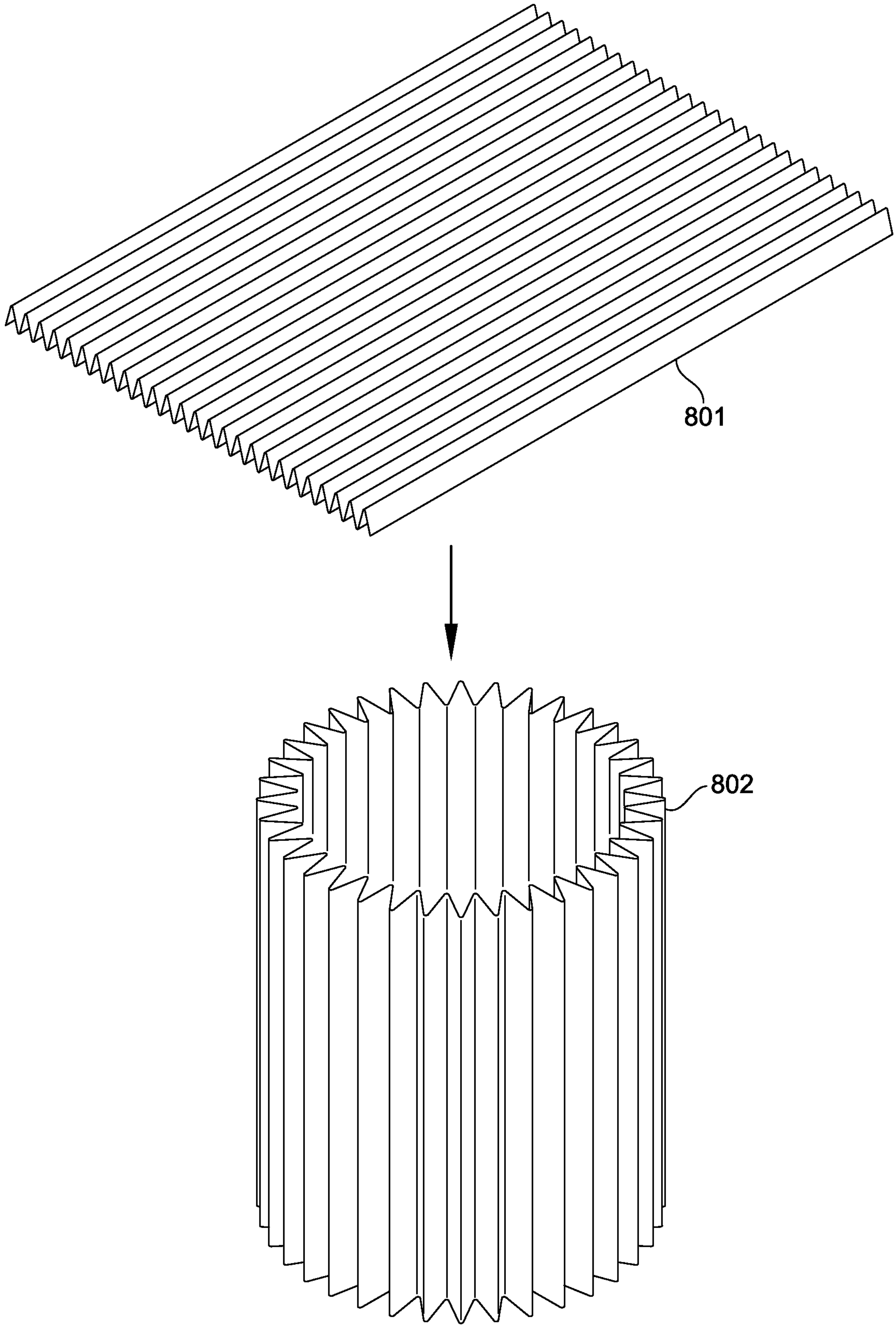

FIG. 24