

FILTER ELEMENT WITH MIXED PLEAT HEIGHTS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 63/395,079, filed August 4, 2022, which is incorporated by reference in its entirety herein.

BACKGROUND OF THE INVENTION

[0002] There is a need in the art for improved pleated filter elements.

[0003] The present invention provides for ameliorating at least some of the disadvantages of the prior art. These and other advantages of the present invention will be apparent from the description as set forth below.

BRIEF SUMMARY OF THE INVENTION

[0004] An aspect of the invention provides a cylindrical porous filter comprising an inner core and an outer cage, with an annular gap between the inner core and the outer cage, with a cylindrical hollow porous filter element arranged in the annular gap between the inner core and the outer cage, the annular gap having a width; wherein the cylindrical hollow porous pleated filter element has first and second end surfaces, the cylindrical hollow porous pleated filter element comprising a plurality of filter element groups, each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the first bridge and the second bridge each have a height greater than the width of the annular gap; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height in the range of 25% to 35%

lower than the height of the second bridge; the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleat, being in a laid-over state.

[0005] In an aspect, each first bridge has a front first bridge surface and a rear first bridge surface; each of the longitudinal pleats has a pair of longitudinal pleat legs, each of the longitudinal pleat legs having a first longitudinal pleat leg surface and a second longitudinal pleat leg surface; each second bridge has a front second bridge surface and a rear second bridge surface; the at least one longitudinal counter-pleat having a pair of longitudinal counter-pleat legs, each of the longitudinal counter-pleat legs having a first longitudinal counter-pleat leg surface and a second longitudinal counter-pleat leg surface; the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleat, being in a laid-over state in which a longitudinal pleat leg surface of one longitudinal pleat is in intimate contact with at least one of any of a longitudinal pleat leg surface of an adjoining leg of the one longitudinal pleat, a longitudinal pleat leg surface of an adjacent longitudinal pleat, a rear first bridge surface, and a front second bridge surface; and, a longitudinal counter-pleat leg surface of the at least one longitudinal counter-pleat is in intimate contact with at least one of any of a longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat, a front first bridge surface, and a rear second bridge surface.

[0006] In another aspect, a method of filtering fluid is provided, the method comprising passing the fluid through an aspect of a cylindrical porous filter comprising an inner core and an outer cage, with an annular gap between the inner core and the outer cage, with a cylindrical hollow porous filter element arranged in the annular gap between the inner core and the outer cage, the annular gap having a width; wherein the cylindrical hollow porous pleated filter element has first and second end surfaces, the cylindrical hollow porous pleated filter element comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the first bridge and the second bridge each have a height greater than the width of the annular gap; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the

height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height in the range of 25% to 35% lower than the height of the second bridge; the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleat, being in a laid-over state.

[0007] In another aspect, a cylindrical hollow porous pleated filter element is provided, the cylindrical hollow porous pleated filter element comprising a plurality of filter element groups, each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height is in the range of 25% to 35% lower than the height of the second bridge.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0008] Figure 1 is a drawing showing, diagrammatically, pleats with mixed pleat heights for use in preparing a filter element according to an aspect of the invention, (wherein, for ease of reference, the pleats are shown expanded before compression to form a pleated porous filter element, and an inner core and outer cage are also shown), showing an aspect of a pleated cylindrical hollow porous filter element arranged in an annular gap between the inner core and the outer cage, the annular gap having a width; the pleated cylindrical hollow porous filter element comprising a plurality of filter element groups, each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, each first filter element sub-group alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height, wherein first and second groups of longitudinal pleats facing inwardly (tips facing toward an inner core; heights (I)H1-(I)H2) and the at least one longitudinal counter-pleat facing

outwardly (tip facing toward an outer cage; counter-pleat; height (O)H1) have different design and height patterns (continuously repeated units and non-symmetric orientation), before the pleats are compressed together in the prepared filter.

[0009] Figure 2A is a photograph showing the filter element as shown in Figure 1; and Figure 2B is a photograph showing, in a partial cut-away view, a computed tomography (CT) scan of an assembled filter element with mixed pleat heights as generally shown in Figures 1 and 2A; Figure 2C is a drawing showing the filter element as shown in Figure 2A partially compressed.

[0010] Figure 3 is a drawing showing a cut-away perspective diagrammatic view of a filter including a filter element with mixed pleat heights shown in Figure 2B (filter element not fully compressed) according to another aspect of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] In accordance with an aspect of the invention, a cylindrical porous filter is provided comprising an inner core and an outer cage, with an annular gap between the inner core and the outer cage, with a cylindrical hollow porous filter element arranged in the annular gap between the inner core and the outer cage, the annular gap having a width; wherein the cylindrical hollow porous pleated filter element has first and second end surfaces, the cylindrical hollow porous pleated filter element comprising a plurality of filter element groups, each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the first bridge and the second bridge each have a height greater than the width of the annular gap; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height in the range of 25% to 35% lower than the height of the second bridge;

the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleat, being in a laid-over state.

[0012] In another aspect, a cylindrical hollow porous pleated filter element is provided, the cylindrical hollow porous pleated filter element comprising a plurality of filter element groups, each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height is in the range of 25% to 35% lower than the height of the second bridge.

[0013] In another aspect, a method of filtering fluid is provided, the method comprising passing the fluid through an aspect of a cylindrical porous filter comprising an inner core and an outer cage, with an annular gap between the inner core and the outer cage, with a cylindrical hollow porous filter element arranged in the annular gap between the inner core and the outer cage, the annular gap having a width; wherein the cylindrical hollow porous pleated filter element has first and second end surfaces, the cylindrical hollow porous pleated filter element comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the first bridge and the second bridge each have a height greater than the width of the annular gap; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height in the range of 25% to 35%

lower than the height of the second bridge; the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleat, being in a laid-over state; preferably, the method including obtaining the filtered fluid.

[0014] Aspects of the method can include outside-in flow in which a fluid to be filtered flows from the outer cage through the filter element into the inner core, or include inside-out flow in which fluid flows from the inner core through the filter element to the outer cage.

[0015] In a preferred aspect, a first impervious end cap is connected to the first end surface of the filter element.

[0016] In an aspect, each first bridge has a front first bridge surface and a rear first bridge surface; each of the longitudinal pleats has a pair of longitudinal pleat legs, each of the longitudinal pleat legs having a first longitudinal pleat leg surface and a second longitudinal pleat leg surface; each second bridge has a front second bridge surface and a rear second bridge surface; the at least one longitudinal counter-pleat having a pair of longitudinal counter-pleat legs, each of the longitudinal counter-pleat legs having a first longitudinal counter-pleat leg surface and a second longitudinal counter-pleat leg surface; the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleat, being in a laid-over state in which a longitudinal pleat leg surface of one longitudinal pleat is in intimate contact with at least one of any of a longitudinal pleat leg surface of an adjoining leg of the one longitudinal pleat, a longitudinal pleat leg surface of an adjacent longitudinal pleat, a rear first bridge surface, and a front second bridge surface; and, a longitudinal counter-pleat leg surface of the at least one longitudinal counter-pleat is in intimate contact with at least one of any of a longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat, a front first bridge surface, and a rear second bridge surface.

[0017] In some aspects, a second (inner) longitudinal pleat leg surface of a longitudinal pleat leg of one longitudinal pleat is in intimate contact with a second (inner) longitudinal pleat leg surface of an adjoining leg of the one longitudinal pleat, and a first (outer) longitudinal pleat leg surface of a longitudinal pleat leg of one longitudinal pleat is in intimate contact with a rear first bridge surface, or a front second bridge surface, or a first (outer) longitudinal pleat leg surface of an adjacent longitudinal pleat and/or a second (inner) longitudinal counter-pleat leg surface of a longitudinal counter-pleat leg of the at least one longitudinal counter-pleat is in intimate contact with a second (inner) longitudinal

counter-pleat leg surface of an adjoining leg of the at least one longitudinal counter-pleat, and a first (outer) longitudinal counter-pleat leg surface of the longitudinal counter-pleat leg of the at least one longitudinal counter-pleat may be in intimate contact with a rear second bridge surface, or a front first bridge surface.

[0018] In some aspects, the first bridges have heights that are in a range of 10% to 25% greater than the annular gap between the inner core and the outer cage and/or the second bridges have heights that are in a range of 10% to 25% greater than the annular gap between the inner core and the outer cage.

[0019] Advantageously, filter elements, filters including the filter elements, and filter devices including the filters, can have lower packing densities and higher permeabilities, while maintaining desirable pressure differentials and reduced membrane area, while edge-flow resistance is reduced.

[0020] Embodiments of filter elements according to aspects of the invention are generally hollow cylindrical in form and comprise pleated porous media including mixtures of pleat heights wherein a plurality of longitudinal pleats face inwardly (tips facing toward an inner core; heights (I)H1-(I)H2) and at least one longitudinal counter-pleat faces outwardly (tip facing toward an outer cage; counter-pleat; height (O)H1).

[0021] Each of the components of the invention will now be described in more detail below, wherein like components have like reference numbers.

[0022] Figure 1 illustrates, diagrammatically (wherein, for ease of reference, the pleats are shown expanded before compression to form the pleated porous filter element), an aspect of a pleated cylindrical hollow porous filter element 3000 is arranged in the annular gap G between a perforated inner core 800 and an outer cage 900, the annular gap having a width W; the pleated cylindrical hollow porous filter element having a longitudinal axis (*see*, Fig. 3) and first and second end surfaces, the cylindrical hollow porous pleated filter element comprising a plurality of filter element groups GRP,

[0023] each of the plurality of filter element groups GRP comprising a first filter element sub-group SG1 comprising a first bridge B1 (having a front first bridge surface and a rear first bridge surface) followed by a plurality of longitudinal pleats 100A, 200A having

longitudinal pleat heights, each first filter element sub-group SG1 alternating with a second filter element sub-group SG2 comprising a second bridge B2 (having a front second bridge surface and a rear second bridge surface) followed by at least one longitudinal counter-pleat 100B having a longitudinal pleat height;

[0024] wherein the first bridge B1 and the second bridge B2 have respective heights B1H, B2H greater than the width of the annular gap;

[0025] wherein the plurality of longitudinal pleats in the first filter element sub-group SG1 has a first pleat with a tallest height (I)H1, and a second longitudinal pleat with a shortest height (I)H2, wherein the height (I)H1 of the first longitudinal pleat is in the range of 25% to 35% lower than the height BH1 of the first bridge B1, and the height (I)H2 of the second longitudinal pleat is in the range of 65% to 75% lower than the height BH1 of the first bridge B1; and

[0026] wherein the at least one longitudinal counter-pleat in the second filter element sub-group SG2 has a longitudinal counter-pleat height (O)H1 in the range of 25% to 35% lower than the height BH2 of the second bridge B2;

[0027] the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal pleat, being in a laid-over state (shown in Figures 2B and 3).

[0028] In accordance with this illustrated aspect, the groups and sub-groups in the filter element have different design and height patterns (continuously repeated units and non-symmetric orientation), i.e., group = sub-group 1: B1, (I)H1, (I)H2; sub-group 2: B2, (O)H1; group = sub-group 1: B1, (I)H1, (I)H2; sub-group 2: B2, (O)H1; wherein the filter element has any suitable number of repeating groups.

[0029] Each pleat comprises a pair of legs, each leg having an inner surface, and outer surface (thus, the legs have opposing interior surfaces and opposing exterior surfaces), a leg length, and a crown or tip where the legs meet (adjoined) and the pleat is folded over. Each leg has a root abutting the core (for longitudinal counter-pleats) or cage (longitudinal pleats), and the pleats extend axially from the core or cage, respectively.

[0030] In the aspect shown in Figure 1, the lengths of each leg of pleats (I)H1 are equal to each other, lengths of each leg of pleats (I)H2 are equal to each other, and the lengths of each

leg of pleats (O)H1 are equal to each other, and the lengths of each leg in the pair of pleats (I)H2 and (O)H1 are equal to each other.

[0031] As will be discussed in more detail below, and shown in, for example, Figures 2B and 3, the formed filter element will have laid-over pleats. Accordingly, the first bridge, the longitudinal pleats, the second bridge, and the at least one longitudinal counter-pleats, are in a laid-over state in which a longitudinal pleat leg surface of one longitudinal pleat is in intimate contact with at least one of any of a longitudinal pleat leg surface of an adjoining leg of the one longitudinal pleat, a longitudinal pleat leg surface of an adjacent longitudinal pleat, a rear first bridge surface, and a front second bridge surface; and, a longitudinal counter-pleat leg surface of the at least one longitudinal counter-pleat is in intimate contact with at least one any of a longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat, a front first bridge surface, and a rear second bridge surface.

[0032] Typically, each second (inner) longitudinal counter-pleat leg surface of one longitudinal counter-pleat is in intimate contact with a second (inner) longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat, and a first (outer) counter-pleat leg surface of one longitudinal counter-pleat may also be in intimate contact with a rear first bridge surface, or a front second bridge surface, and/or each second (inner) longitudinal pleat leg surface of one longitudinal pleat is in intimate contact with a second (inner) longitudinal pleat leg surface of an adjoining leg of the one longitudinal pleat, and a first (outer) pleat leg surface of one longitudinal pleat may also be in intimate contact with a first (outer) longitudinal pleat leg surface of an adjacent longitudinal pleat, a front first bridge surface, or a rear second bridge surface.

[0033] Illustratively, using the aspect illustrated in Figure 1 for reference, in the laid-over state, the rear first bridge surface will be in intimate contact with the first (outer) longitudinal pleat leg surface of the first longitudinal pleat leg of the following longitudinal pleat (100A), the second (inner) longitudinal pleat leg surface of the first longitudinal pleat leg will be in intimate contact with the second (inner) longitudinal pleat leg surface of the adjoining second longitudinal pleat leg of that longitudinal pleat (100A). The first (outer) longitudinal pleat leg surface of the second longitudinal pleat leg of that longitudinal pleat (100A) will be in intimate contact with the first (outer) longitudinal pleat leg surface of the first longitudinal pleat leg of the following (adjacent) longitudinal pleat (200A), and so on with reference to

Figure 1, e.g., the front second bridge surface will be in intimate contact with the first (outer) longitudinal pleat leg surface of the second longitudinal pleat leg of the longitudinal pleat (200A) following (adjacent) longitudinal pleat (100A), and the rear second bridge surface will be in intimate contact with the first (outer) longitudinal counter-pleat leg surface of the first longitudinal counter-pleat leg of the following (adjacent) longitudinal counter-pleat (100B).

[0034] Using Figures 1, 2B, 2C, and 3 for reference (Figure 2B showing a fully compressed filter element with laid over pleats), a cylindrical perforated inner core 800 is coaxially disposed along the inner periphery of the pleated porous filter element 3000, and a cylindrical cage 900 is disposed along the outer periphery of the filter element, and an annular gap G is present between the inner core and the outer cage, with the pleated porous filter element arranged in the gap between the inner core and the outer cage, the gap having a width W.

[0035] The first bridge B1 and the second bridge B2 have respective heights B1H, B2H greater than the width of the annular gap and thus the bridges B1 and B2 each have ends that are bent facing the outer cage and the inner core as part of the laid-over state. In some aspects, the first bridges have heights that are in a range of 10% to 25% greater than the annular gap between the inner core and the outer cage and/or the second bridges have heights that are in a range of 10% to 25% greater than the width of annular gap between the inner core and the outer cage.

[0036] The heights of the longitudinal pleats and the longitudinal counter-pleats are each less than the width of annular gap between the inner core and the outer cage.

[0037] As shown in Figure 2B, in the assembled filter element, the longitudinal pleats are bent near their tips (facing the inner core) and the longitudinal counter-pleat is bent near its tip (facing the outer cage) as part of the laid-over pleat.

[0038] The opposing surfaces of adjoining legs of the pleats need not be in intimate contact over the entire axial length of the filter element, but the greater is the length in the axial direction of the region of intimate contact, the more effectively used is the space between the inner and outer periphery of the filter element 3000. Therefore, adjoining legs are in intimate contact over a continuous region which can extend for at least approximately

50%, in some aspects, at least approximately 75%, or approximately 95-100% of the axial length of the filter element 3000.

[0039] There are no particular restrictions on the type of porous filter medium 500 (*see*, Fig. 3) which can be employed in the porous filter element of the present invention, and it can be selected in accordance with the fluid which is to be filtered and the desired filtering characteristics. Preferably, the porous filter medium/filter element comprises a polymeric medium. The filter element/filter can be used to filter fluids such as liquids, gases, or mixtures thereof used in various industries. For example, the filter element/filter can be used to filter process fluids in the microelectronic industry for wet-etch cleans (e.g., a material removal process that uses liquid chemicals or etchants to remove materials from a wafer). CMP (chemical-mechanical planarization), for producing ultra pure water (UPW), and for lithography modules, and the fluids can include, for example, standard clean 1 (SC1) fluids, standard clean 2 (SC2) fluids, Isopropyl Alcohol (IPA; including hot IPA), Sulfuric Acid (H_2SO_4 including hot H_2SO_4), Tetramethyl quaternary ammonium hydroxide (TMAH; including hot TAMH), hydrogen peroxide (H_2O_2 , including hot H_2O_2), Ammonium Hydroxide (NH_4OH ; including hot NH_4OH), and Hydrogen Fluoride (HF; including hot HF), among others, used independently or mixed with each other.

[0040] Typically, the pleated porous filter element comprises, or is, a membrane. The membranes can have any suitable pore structure, e.g., a pore size (for example, as evidenced by bubble point, or by K_L as described in, for example, U.S. Patent 4,340,479, or evidenced by capillary condensation flow porometry), an average pore size; a mean flow pore (MFP) size (e.g., when characterized using a porometer, for example, a Porvair Porometer (Porvair plc, Norfolk, UK), or a porometer available under the trademark POROLUX (Porometer.com; Belgium)), a pore rating, a pore diameter (e.g., when characterized using the modified OSU F2 test as described in, for example, U.S. Patent 4,925,572), or removal rating media. The pore structure used depends on the size of the particles to be utilized, the composition of the fluid to be treated, and the desired effluent level of the treated fluid. In some aspects, the membrane has (depending on the application), an average pore size in the range of 10 nm to 150 nm.

[0041] The porous membrane can have any desired critical wetting surface tension (CWST, as defined in, for example, U.S. Patent 4,925,572). The CWST can be selected as is

known in the art, e.g., as additionally disclosed in, for example, U.S. Patents 5,152,905, 5,443,743, 5,472,621, and 6,074,869. Typically, the membrane has a CWST of in the range of 28 dynes/cm (28×10^{-5} N/cm) to 34 dynes/cm (34×10^{-5} N/cm).

[0042] Exemplary membranes are disclosed in U.S. Patents 4,702,840 and 4,900,449. Other membranes, including those disclosed in U.S. Patents 4,906,374; 4,886,836; 4,964,989; 5,019,260; 4,340,479; 4,855,163; 4,744,132; 4,707,266; 4,203,848; 4,618,533, 6,039,872; 6,780,327; 6,783,937; and 7,189,322, may also be suitable. Exemplary membranes include, but are not limited to, nylon membranes, polytetrafluoroethylene (PTFE) membranes, high-density polyethylene (HDPE) membranes, and highly asymmetric polyarylsulfone (HAPAS) membranes. Exemplary membranes may be used individually or in combination with any other exemplary membranes with the same or different characteristics.

[0043] The filter can include additional elements, layers, or components, that can have different structures and/or functions, e.g., at least one of any one or more of the following: prefiltration, support, drainage, spacing and cushioning.

[0044] For example, in the aspect of the filter 3100 as shown in Figure 3, in addition to a cylindrical perforated inner core 800 coaxially disposed along the inner periphery of the filter element and a cylindrical outer cage 900 disposed along the outer periphery of the filter element 3000, the illustrated filter includes a first pleated mesh 501 contacting a first (e.g., upstream) surface of the porous medium 500 of the filter element, and a second pleated mesh 502 contacting a second (e.g., downstream) surface of the porous medium 500 of the filter element, providing a three-layer composite. In those aspects wherein the filter includes first and/or second pleated meshes, references to contact between surfaces of the pleats refers to contact between the meshes on the referenced surfaces of the filter element, e.g., a second (inner) longitudinal counter-pleat leg surface of one longitudinal counter-pleat being in intimate contact with a second (inner) longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat, refers to the mesh on the second (inner) longitudinal counter-pleat leg surface of one longitudinal counter-pleat being in intimate contact with the mesh on a second (inner) longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat.

[0045] The components (meshes, filter medium) forming the filter element can be formed into a composite by conventional filter manufacturing techniques, either prior to or simultaneous with corrugation.

[0046] The meshes (the term “mesh” also includes “screen”) prevent opposing surfaces of the filter medium from coming into contact with one another and enables fluid to evenly flow to or from substantially all portions of the surface of the filter medium when the pleats are in the laid-over state. Thus, virtually the entire surface area of the filter medium may be effectively used for filtration.

[0047] A variety of meshes are suitable for use in aspects of the invention. The meshes can be made of any materials having suitable edgewise flow characteristics, i.e., suitable resistance to fluid flow through the layer in a direction parallel to its surface. The edgewise flow resistance of the drainage meshes is preferably low enough that the pressure drop in the drainage layer is less than the pressure drop across the filter medium, thereby providing an even distribution of fluid along the surface of the filter medium.

[0048] Typically, a filter 3100 according to an aspect of the present invention will be equipped with end caps 850 (only one of which is shown in Fig. 3) at one or both ends of the filter element 3000. The end caps 850 can be either blind (closed) or open end caps, and the material of which they are formed and their shape can be selected in accordance with the filtering conditions and the materials of the members to which the end caps are to be joined. Preferably, the end caps 850 are attached to the filter element 3000, but they may also be attached to the inner core 800 or the outer cage 900. Conventional techniques can be used to attach the end caps to the filter element.

[0049] If desired, in some aspects, an insert in the form of a strip of material having a good affinity for the end cap material can be corrugated into the ends of the filter element 3000 to improve the seal between both ends of the filter element 3000 and the end caps 850. For example, when the end caps are made of a fluoropolymer, a strip of another fluoropolymer, such as a fluorinated ethylene-propylene (FEP) resin, can be corrugated into the ends of the filter element as the insert. The insert need only be wide enough to bond the filter medium to the end cap, and therefore, it might extend for only a portion of the axial length of the filter element 3000. A typical width for the insert is approximately 0.5 inches.

[0050] Aspects of the filter device and filter are suitable for outside-in flow in which a fluid to be filtered flows from an outer periphery (e.g., the outer cage) through the filter element into the hollow center (e.g., the inner core), or it can be used for inside-out flow in which fluid flows from the hollow center (e.g., the inner core) through the filter element to the outer periphery (e.g., the outer cage).

[0051] The filter element 3000 illustrated in Figure 3 can be manufactured by a variety of techniques, for example, as described in U.S. Patent 5,543,047.

[0052] In one technique, the filter composite is first corrugated to form a corrugated sheet, cut to a suitable length or suitable number of pleats, and then formed into a cylindrical shape. The lengthwise edges of the corrugated sheet are then sealed to each other by conventional means to form a cylindrical filter element. The pleats of the filter element are then laid over as the filter element 3000 is inserted into a cage 900. After the filter element has been fit into the cage 900, a core 800 is inserted into the hollow center of the filter element 10, and then end caps are attached to the ends of the filter element to form a completed filter.

[0053] The filter comprising the filter element is disposed in a housing comprising at least one inlet and at least one outlet and defining at least one fluid flow path between the inlet and the outlet, wherein the filter is across the fluid flow path, to provide a filter device. Preferably, the filter device is sterilizable. Any housing of suitable shape and providing at least one inlet and at least one outlet may be employed.

[0054] The housing can be fabricated from any suitable rigid impervious material, including any impervious thermoplastic material, which is compatible with the fluid being processed. For example, the housing can be fabricated from a metal, such as stainless steel, or from a polymer. In a preferred aspect, the housing is a polymer, in some aspects, a transparent or translucent polymer, such as an acrylic, polypropylene, polystyrene, or a polycarbonated resin.

[0055] The following example further illustrates the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLE

[0056] This example demonstrates an improvement in permeability of a test filter device containing a filter element according to an aspect of the invention compared to test filter devices including a commercial available filter element that has laid-over longitudinal pleats (as generally described in U.S. Patent 5,543,047).

[0057] The filter element, a high-density polyethylene (HDPE) membrane, is pleated (with upstream and downstream meshes) using a Rabofsky PM600 corrugator such that the first and second bridge heights are 1 inch (wherein the width of the gap is .85 inches) the (I)H1 heights are 0.6 inches, the (I)H2 heights are 0.4 inches, and the (O)H1 heights are 0.3 inches (*see*, Figs. 1, 2A and 2B). The pore size is 15 nm.

[0058] The commercially available filter element (HDPE membrane) has longitudinal pleat heights of 1 inch.

[0059] The filter element according to an aspect of the invention and the commercially available filter element have the same perforated inner cores and outer cages, and the same gap width of .85 inches. Each filter element has an open end cap at one end and a closed end cap at the other end, and are placed in a test housing arranged for outside-in flow.

[0060] The test device with the filter element according to an aspect of the invention has the same pressure drop but at a lower membrane area than the test device with the commercially available filter element. Thus, the permeability (flow per unit area per unit pressure drop) of the filter elements according to an aspect of the invention show an enhancement of up to 20%.

[0061] 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.

[0062] The use of the terms “a” and “an” and “the” and “at least one” and similar referents in the context of describing the invention (especially in the context of the following

claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The use of the term “at least one” followed by a list of one or more items (for example, “at least one of A and B”) is to be construed to mean one item selected from the listed items (A or B) or any combination of two or more of the listed items (A and B), 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.

[0063] Preferred aspects of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred aspects 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.

CLAIM(S):

1. A cylindrical porous filter comprising:

an inner core and an outer cage, with an annular gap between the inner core and the outer cage, with a cylindrical hollow porous pleated filter element arranged in the annular gap between the inner core and the outer cage, the annular gap having a width;

wherein the cylindrical hollow porous pleated filter element has first and second end surfaces, the cylindrical hollow porous pleated filter element comprising a plurality of filter element groups,

each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height;

wherein the first bridge and the second bridge each have a height greater than the width of the annular gap;

wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and

wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height is in the range of 25% to 35% lower than the height of the second bridge; the first bridge, the longitudinal pleats, the second bridge, and the longitudinal counter-pleat, being in a laid-over state.

2. The cylindrical porous filter of claim 1, wherein a first impervious end cap is connected to the first end surface of the filter element.

3. The cylindrical porous filter of any one of claims 1-3, wherein each first bridge has a front first bridge surface and a rear first bridge surface;

each of the longitudinal pleats has a pair of longitudinal pleat legs, each of the longitudinal pleats legs having a first longitudinal pleat leg surface and a second longitudinal pleat leg surface;

each second bridge has a front second bridge surface and a rear second bridge surface;

the at least one longitudinal counter-pleat having a pair of longitudinal counter-pleat legs, each of the longitudinal counter-pleat legs having a first longitudinal counter-pleat leg surface and a second longitudinal counter-pleat leg surface;

the first bridge, the longitudinal pleats, the second bridge, and the longitudinal pleat, being in a laid-over state in which

a longitudinal pleat leg surface of one longitudinal pleat in intimate contact with at least one of any of a longitudinal pleat leg surface of an adjoining leg of the one longitudinal pleat, a longitudinal pleat leg surface of an adjacent longitudinal pleat, a rear first bridge surface, and a front second bridge surface; and,

a longitudinal counter-pleat leg surface of longitudinal counter-pleat is in intimate contact with at least one of any of a longitudinal counter-pleat leg surface of an adjoining leg of the one longitudinal counter-pleat, a front first bridge surface, and a rear second bridge surface.

4. The cylindrical porous filter of any one of claims 1-3, wherein the first bridges have heights that are in a range of 10% to 25% greater than the annular gap between the inner core and the outer cage.

5. The cylindrical porous filter of any one of claims 1-4, wherein the second bridges have heights that are in a range of 10% to 25% greater than the annular gap between the inner core and the outer cage.

6. A method of processing fluid, the method comprising passing the fluid through the cylindrical porous filter of any one of claims 1-5.

7. The method of claim 6, including passing the fluid to be filtered through the outer cage, the cylindrical hollow porous pleated filter element, and the inner core.

8. A cylindrical hollow porous pleated filter element comprising:
a plurality of filter element groups, each of the plurality of filter element groups comprising a first filter element sub-group comprising a first bridge followed by a plurality of

longitudinal pleats having longitudinal pleat heights, alternating with a second filter element sub-group comprising a second bridge followed by at least one longitudinal counter-pleat having a longitudinal counter-pleat height; wherein the plurality of longitudinal pleats in the first filter element sub-group has a first pleat with a tallest height, and a second longitudinal pleat with a shortest height, wherein the height of the first longitudinal pleat is in the range of 25% to 35% lower than the height of the first bridge, and the height of the second longitudinal pleat is in the range of 65% to 75% lower than the height of the first bridge; and wherein the at least one longitudinal counter-pleat in the second filter element sub-group has a longitudinal counter-pleat height is in the range of 25% to 35% lower than the height of the second bridge.