(54) Title: PLEATED FILTER ELEMENT AND METHOD OF FORMING A PLEATED FILTER ELEMENT

(57) Abstract

A filter element (10) according to the present disclosure includes a plurality of longitudinally extending pleats including outwardly radiating primary pleats (P) and inwardly radiating secondary pleats (s), with at least one secondary pleat positioned between two adjacent primary pleats. Each primary pleat (P) has a predetermined radial height (H), and each secondary pleat (s) has a radial height (h) that is less than the radial height of each primary pleat and different from the radial height of at least one other secondary pleat. A filter element (10) according to the present disclosure provides greater filter area, an increased overall filter density, and access to more radial flow paths at the outer diameter of the filter element.

PLEATED FILTER ELEMENT
AND METHOD OF FORMING A PLEATED FILTER ELEMENT

Cross-Reference to Related Application

5   The present application claims priority to U.S. Provisional Patent Application

Serial No. 60/034,964, filed January 7, 1999, the disclosure of which is incorporated

herein by reference in its entirety.

Background of the Disclosure

10   1.   Field of the Disclosure

The present disclosure relates to a fluid filtering device and, more particularly, to a

pleated filter element and a method of forming a pleated filter element. Even more

particularly, the present disclosure relates to a pleated filter element having a modified W-

pleat construction, and a method of forming such a filter element.

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2.   Background of the Related Art

Filtration is the process of separating particles, or contaminants from a fluid (liquid

or gas), and can be accomplished by passing the fluid through a porous filter medium that

stops or captures the particles while permitting the fluid to pass there through. Such fluid

20   filtering is used extensively in the manufacture of polymer products, medicinal products,

mineral and metallurgical processing, petroleum refining, water purification, emissions

control, and in beverage and food preparation.

Most conventional filter media may be categorized into two broad categories: a

surface-type filter medium and a depth-type filter medium. As its name implies, the

25   surface-type filter medium stops fluid contaminants on its surface. Examples of surface-

type filter media are calendered melt-blown material, cellulose and/or paper, membranes,

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woven screen, porous metal, and porous non-woven material. In contrast, a depth-type

filter medium captures contaminants within the medium, i.e. between an upstream surface

and a downstream surface of the medium. An example of a depth-type filter medium is a

resin bonded filter.

5   In general, as a fluid is forced through the filter medium and filtered, over time the

pressure drop across the filter medium will gradually increase. Such increase is due to the

collection of particles, or contaminants on the filter medium, i.e., the filter medium

gradually becomes loaded with the contaminants trapped or stopped thereby. An

increasing pressure drop across the filter medium, however, translates into an increasing

10   load on the means (such as a blower or pump) employed to force the fluid through the

filter medium. In addition, since the life of a filter is generally defined by a maximum

allowable pressure drop, a slower increase in pressure drop translates into a longer filter

life.

When a surface-type filter medium is used, one method of minimizing the pressure

15   drop across the filter medium is to maximize the available surface area of the filter

medium. In order to increase the surface area in a surface-type filter, pleated filter media

have been developed. Pleated surface-type filters typically include relatively thin

cellulosic or synthetic filter media that is folded in an accordion-like fashion to produce a

plurality of pleats. Each pleat is typically made up of a pair of rectangular panels, with

20   fold lines separating the panels.

In a cylindrical pleated filter element, the short sides of the rectangular panels of

the pleats usually extend radially outwardly with respect to the axis of the filter element,

and thus provide the radial height of the pleats, while the long sides of the rectangular

panels of the pleats extend axially between ends of the filter element. The maximum

25   number of full pleats (i.e., pleats that extend between the inner and outer diameters of the

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filter element) is determined by an inner circumference of the filter element divided by the

thickness of the pleats.

Because of the radial geometry of the pleats in a cylindrical pleated filter element,

however, there is a significant degree of spacing between outer tips of the pleats. In order

5   to minimize the spacing between outer tips of the pleats, filter elements having larger inner

diameters and, thus, shorter pleat heights have been used. Furthermore, spiral pleat filters

and "W-pleat" filters have been developed in order to minimize pleat spacing and provide

even more filtering surface area.

A W-pleat filter element is comparable to a standard pleated filter element in that it

10   includes a plurality of longitudinal pleats disposed in a cylindrical configuration. The W-

pleat filter element, however, also includes relatively short pleats extending radially

inward from the outer periphery of the filter between the pleats of standard height. The

short pleats are the same height and arise at a uniform frequency about the circumference

of the filter, i.e., there is one short pleat between every two full-length pleats. Examples of

15   W-pleat filters can be found in U.S. Patent No. 2,627,350 (1953) to Wicks; U.S. Patent

No. 3,002,861 (1962) to Harms; U.S. Patent No. 3,799,354 (1974) to Buckman et al.; and

German Patent No. 3,935,503 (1991) to Nick et al. Most W-pleat filters are made using

cam-actuated pleating machines that only provide repetitive and uniform pleat patterns,

resulting in short pleats of the same height and arising at a uniform frequency.

20   One problem associated with the W-pleat construction, however, is a less than

optimum pleat density and the migration of the shortened pleats towards the axis of the

filter. Such migration is undesired because it can cause binding, blockages, increased

pressure drops across the filter, reduced filter lives, and damage the filter media.

A spiral pleat filter element is comparable to a standard pleated filter in that it

25   includes a plurality of longitudinal pleats disposed in a cylindrical configuration. In a

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spiral pleat filter, however, the ends of the pleats are rolled over to minimize the spacing

between adjacent pleat surfaces near an outer diameter of the filter element, such that more

filter surface area can be provided in a filter of equal diameter. Examples of spiral pleated

filters can be found in U.S. Patent Nos. 2,395,449, 2,401,222 and 2,420,414 (1946) to

5   Briggs; U.S. Patent No. 2,801,001 (1957) to Bowers; and U.S. Patent Nos. 5,543,047

(1996) and 5,690,765 (1997) to Stoyell et al.

While both the spiral pleat and the W-pleat designs provide surface-type filters

with increased filter surface area, the spiral pleat designs do not have the pleat migration

problems associated with the W-pleat designs. As compared with a W-pleat filter,

10   however, the rolled-over pleats of a spiral pleated filter provide fewer and more difficult to

access radial flow paths near the outer diameter of the filter, leading to a greater pressure

drop across the filter. In addition, the rolled-over pleats of a spiral pleated filter provide

longer flow paths and, therefore, a greater chance of the flow paths becoming blocked in

high load or large particle contaminant applications.

15   Furthermore, spiral pleated filters are more difficult to axially insert into a

cylindrical cage of a cartridge assembly incorporating the filter element, since the rolled-

over pleats have a tendency to straighten out prior to being inserted into the cage.

Inserting a spiral pleated filter element into a cage creates drag, which can cause damage

to the filter media and can, as a practical matter, limit the axial length of a filter cartridge

20   incorporating a spiral pleated filter element.

What is still needed, accordingly, is a filter element that provides filter surface area

gains comparable to a spiral pleated filter, yet has increased radial flow paths at the outer

diameter of the filter, and is conducive to being inserted into an elongated cylindrical cage.

There is also a need for a pleated filter design that prevents pleat migration.

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Summary of the Disclosure

A filter element constructed according to the present disclosure has a plurality of longitudinally extending pleats including outwardly radiating primary pleats and inwardly radiating secondary pleats, with at least one secondary pleat positioned between two

5   adjacent primary pleats. Each primary pleat has a predetermined radial height, and each secondary pleat has a radial height that is less than the radial height of each primary pleat and different from the radial height of at least one other secondary pleat.

A filter element according to the present disclosure has been found to provide improved filter area gains, a greater overall filter density between inner and outer

10   peripheries of the filter element, and an increased number of radial flow paths available at the outer periphery of the filter. A filter element according to the present disclosure also provides improved inter-pleat support to reduce the likelihood of pleat migration and binding.

According to another aspect of the present disclosure, the filter element is

15   preferably a pleated composite including a filter medium and at least one of an upstream diffusion medium and a downstream diffusion medium. The diffusion media provide support to the filter medium, help to efficiently distribute fluid, and ensure that flow channels formed between and within the pleats are not filled and blocked with contaminants. According to an additional aspect of the present disclosure, the pleated

20   composite of the filter element is heat-set to further reduce the likelihood of pleat migration and binding.

The present disclosure also provides a cartridge assembly having a cylindrical cage, a cylindrical core coaxially positioned within the cylindrical cage, and a cylindrical filter element, as described above, coaxially positioned between the core and the cage.

25   The primary pleats of the filter element each have a predetermined radial height about

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equal to a difference between an outer radius of the core and an inner radius of the cage.

A method of forming a filter element according to the present disclosure includes pleating filter medium to form a plurality of longitudinally extending pleats including primary pleats and secondary pleats, wherein at least one secondary pleat is positioned

5   between two adjacent primary pleats, each primary pleat has a predetermined height, and each secondary pleat has a height that is less than the height of each primary pleat and different from the height of at least one other secondary pleat. According to one aspect, the method further includes cutting the pleated filter medium to a desired length, and forming the cut length of the pleated filter medium into a cylinder such that the primary

10   pleats extend radially outwardly and the secondary pleats extend radially inwardly.

These and other aspects of the subject disclosure will become more readily apparent to those having ordinary skill in the art, from the following detailed disclosure of the preferred embodiments in combination with the drawings.

15   **Brief Description of the Drawings**

So that those having ordinary skill in the art to which the present disclosure relates will more readily understand how to construct a filter element in accordance with the present disclosure, a preferred embodiment of the presently disclosed filter element will be described in detail hereinbelow with reference to the drawings wherein:

20   Fig. 1 is a perspective view of a pleated filter element according to the present disclosure;

Fig. 2 is a perspective view, partially cut-away, of a cartridge assembly including the pleated filter element of Fig. 1 contained between an inner core and an outer cage of the cartridge assembly, wherein a portion of the filter element is shown unwrapped from

25   within the cage;

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Fig. 3 is an enlarged sectional view of the cartridge assembly of Fig. 2; and

Figs. 3a-3c are sectional views of cartridge assemblies including other examples of

pleated filter elements according to the present disclosure.

5   **Detailed Description of the Preferred Embodiments**

Referring now to Figs. 2 and 3, wherein like reference numerals identify similar

structural elements of the present disclosure, there is illustrated a cylindrical cartridge

assembly 8 including a pleated filter element 10 constructed according to the present

disclosure. In addition to the cylindrical pleated filter element 10, the cartridge assembly

10   8 includes a cylindrical inner perforated core 12 coaxially disposed within the filter

element, and a cylindrical outer perforated cage 14 coaxially disposed on the filter

element.

Referring also to Fig. 1, the filter element 10 disclosed herein has a "modified" W-

pleat construction, which will be described in greater detail hereinbelow. Such a filter

15   element 10 has been found to provide filter area gains typical of a spiral pleated filter, with

an increase in the number of available radial flow paths of the filter at the outer cage 14.

In addition, such a filter element 10 has been found to provide a greater overall filter

density between the inner core 12 and the outer cage 14, with the greater overall filter

density improving inter-pleat support to reduce the likelihood of pleat migration and

20   binding.

Modified W-Pleat Construction

Referring to Figs. 1 and 3, a filter element 10 according to the present disclosure

includes a plurality of longitudinally extending pleats "P" and "s" each of which has a pair

25   of pleat legs joined to one another. The pleats include outwardly radiating primary pleats

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"P" and inwardly radiating secondary pleats "$s_1, s_2, s_3 \ldots s_\alpha$", where "$\alpha$" is an actual

number of secondary pleats, with at least one secondary pleat positioned between two

adjacent primary pleats. It should be noted that in Figs. 1 and 3 the pleats "P" and "s" are

shown spaced apart more than they actually are for purposes of illustration. In an actual

5   filter element constructed in accordance with the present invention, the pleats are

positioned closer together so that adjacent pleats touch near the core 12, whereby a greater

amount of filter is fit between the core 12 and the cage 14.

Referring in particular to Fig. 3, each primary pleat "P" extends to a predetermined

height "H", and the secondary pleats "$s_1, s_2, s_3 \ldots s_\alpha$" are each provided with a height "$h_1,$

10     $h_2, h_3, \ldots h_\alpha$", respectively, that is less than the predetermined height "H". In other words,

the legs of each inwardly radiating secondary pleat "s" are joined at roots located between

the crest and the root of the adjacent primary pleats "P". Each secondary pleat "$s_1, s_2, s_3 \ldots$

$\ldots s_\alpha$" also has a radial height "$h_1, h_2, h_3, \ldots h_\alpha$" that is different from the radial height of at

least one other secondary pleat.

15   In the particular embodiment shown of a filter element 10 constructed in

accordance with the present disclosure, each secondary pleat "$s_1, s_2, s_3 \ldots s_\alpha$" additionally

has a radial height "$h_1, h_2, h_3, \ldots h_\alpha$" that is different from each of the radial heights of each

other secondary pleat. It should be understood, however, that a filter element constructed

in accordance with the present disclosure can alternatively be provided with secondary

20   pleats wherein some of the secondary pleats "$s_1, s_2, s_3 \ldots s_\alpha$" have equal heights. In any

event, a filter element 10 constructed in accordance with the present disclosure includes

secondary pleats "$s_1, s_2, s_3 \ldots s_\alpha$" provided with heights "$h_1, h_2, h_3, \ldots h_\alpha$" that are each less

than the predetermined height "H" of the primary pleats "P" and different from the radial

height of at least one other secondary pleat.

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The theoretical predetermined height of the primary pleats "P" is equal to half a difference between an inner and an outer diameter of the filter element 10. Preferably, the filter element 10, the inner core 12 and the outer cage 14 are sized such that the inner diameter of the filter element is about equal to an outer diameter "d_{core}" of the core 12, and

5   the outer diameter of the filter element is about equal to an inner diameter "d_{cage}" of the cage 14. Accordingly, the theoretical predetermined height of the primary pleats "P" is preferably equal to about half a difference between the core outer diameter "d_{core}" and the cage inner diameter "d_{cage}".

10   <u>Calculation of Secondary Pleat Heights</u>

The modified W-pleat design disclosed herein provides a consistent and optimum filter density between the core outer diameter "d_{core}" and the cage inner diameter "d_{cage}". In general, a theoretical number "β" of the secondary pleats "$s_1, s_2, s_3 \ldots s_\beta$" and their individual heights "$h_1, h_2, h_3, \ldots h_\beta$" are calculated based upon the pleat thickness "t", the

15   core outer diameter "d_{core}" and the cage inner diameter "d_{cage}".

To begin with, since only the primary pleats "P" extend from the outer cage 14 to the inner core 12, the theoretical number "n" of primary pleats "P" is generally determined by the following equation:

$$\frac{\pi \, d_{core}}{t}$$

20   Then, a secondary pleat "s" is added for every change in diameter "Δd" between the core outer diameter "d_{core}" and the cage inner diameter "d_{cage}". The change in diameter "Δd" is defined as the diameter change required to increase the circumference by one pleat thickness, and is generally determined by the following equation:

$$\frac{t}{\pi}$$

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The height "$h_1, h_2, h_3, \ldots h_\beta$" of each of the secondary pleats "$s_1, s_2, s_3 \ldots s_\beta$",

respectively, can then be determined by the following equations:

$$h_1 = [d_{cage} - (d_{core} + 1\ t/\pi)]/2$$
$$h_2 = [d_{cage} - (d_{core} + 2\ t/\pi)]/2$$
$$h_3 = [d_{cage} - (d_{core} + 3\ t/\pi)]/2$$

.

.

$$h_\beta = [d_{cage} - (d_{core} + \beta\ t/\pi)]/2$$

Accordingly, a theoretical tallest secondary pleat "s_1" has a height "h_1", while a

theoretical shortest secondary pleat "s_β" has a height "h_β". The theoretical total number

"β" of secondary pleats "s" can be calculated by the equation:

$$(d_{cage} - d_{core})\ \pi/t$$

As an example, secondary pleat heights "h" of a filter element 10 pleated in

accordance with the present disclosure are set forth in Table I, below. The pleated filter

element 10 described in Table I is positioned between an inner core 12 having an outer

diameter "d_{core}" of about 1.312 inches and an outer cage 14 having an inner diameter

"d_{cage}" of about 2.455 inches. The pleated filter element 10 includes pleats "P" and "s"

each having an average pleat thickness "t" of approximately 0.060 inches.

Thus, the primary pleats "P" each have a theoretical predetermined height equal to

about approximately 0.572 inches, the theoretical number of primary pleats "P" is equal to

about sixty-nine (69), and the change in diameter "Δd" is equal to approximately 0.0191

inches. The resulting heights "h" of the secondary pleats "s", and the theoretical number

"β" of secondary pleats "s" are provided as follows:

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<u>Table I</u>

Theoretical Height for each Secondary Pleat

Secondary Pleat "s"	Secondary Pleat Height "h" (Inches)
s_1	$h_1 = .562$
s_2	$h_2 = .552$
s_3	$h_3 = .543$
s_4	$h_4 = .533$
s_5	$h_5 = .524$
s_6	$h_6 = .514$
s_7	$h_7 = .505$
s_8	$h_8 = .495$
s_9	$h_9 = .486$
s_{10}	$h_{10} = .476$
s_{11}	$h_{11} = .466$
s_{12}	$h_{12} = .457$
s_{13}	$h_{13} = .447$
s_{14}	$h_{14} = .438$
s_{15}	$h_{15} = .428$
s_{16}	$h_{16} = .419$
s_{17}	$h_{17} = .409$
s_{18}	$h_{18} = .400$
s_{19}	$h_{19} = .390$
s_{20}	$h_{20} = .381$
s_{21}	$h_{21} = .371$
s_{22}	$h_{22} = .361$
s_{23}	$h_{23} = .352$
s_{24}	$h_{24} = .342$
s_{25}	$h_{25} = .333$
s_{26}	$h_{26} = .323$
s_{27}	$h_{27} = .314$
s_{28}	$h_{28} = .304$
s_{29}	$h_{29} = .295$
s_{30}	$h_{30} = .285$
s_{31}	$h_{31} = .275$
s_{32}	$h_{32} = .266$
s_{33}	$h_{33} = .256$
s_{34}	$h_{34} = .247$
s_{35}	$h_{35} = .237$
s_{36}	$h_{36} = .228$
s_{37}	$h_{37} = .218$

5   The pleated filter element 10 as calculated and set forth in Table I, therefore, has a

theoretical total of one hundred and six (106) pleats: sixty-nine (69) primary pleats "P"

and thirty-seven (37) secondary pleats "s". It should be noted that the aspects of the

pleated filter element 10 set forth in Table I are only to be considered as an example, and

10   not a limitation of the present disclosure.

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Although not shown, over twenty more secondary pleats of decreasing heights "h" of between 0.199 and 0.008 inches can be included in Table I. However, secondary pleats "s" having an actual height "h" below a practical minimum height are not included in the filter element. The practical minimum height of the pleats is dependent, for example, on

5   the capabilities of the pleating machine used to pleat the filter element, the thickness of the pleats, and the filter material. In the particular example of the pleated filter element of Table I, the practical minimum height is considered to be about 0.200 inches. Accordingly, secondary pleats "s" having an actual height "h" less than 0.200 inches are not considered for inclusion in the filter element.

10

Method of Pleating

The pleated filter element 10 of the present disclosure can be manufactured by a variety of techniques. In general, however, the filter and diffusion media to be pleated may be stored on separate rolls and simultaneously fed to a pleating machine and formed

15   into a composite as the layers are pleated. After the filter composite has been pleated in accordance with the present disclosure, the filter composite is heated so that the filter composite, and in particular, the diffusion media 22, 24 thereof become heat-set.

Although not shown, the pleated, heat-set filter composite which emerges from the pleating machine is then cut to a prescribed length or prescribed number of pleats as

20   determined by the intended dimensions of the filter element 10. The length of pleated filter composite is then formed into a cylindrical shape, and the lengthwise edges of the pleated filter composite are sealed to each other along a seam by conventional means, such as by ultrasonic welding, to retain the pleated filter composite in a cylindrical form. The cylindrical inner core 12 may then be axially inserted into the cylindrical filter element 10,

25   the filter element and core axially inserted into the cylindrical outer cage 14, and the end

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caps 30 attached to the ends of the filter element to form a completed cartridge assembly

8, as shown in Fig. 1.

To provide a filter element 10 according to the present disclosure having secondary

pleats "s" of varying radial heights "h", a pleating machine having independently actuated

5   pleating blades may be used. For example, Karl Rabofsky GmbH, of Berlin, Germany,

provides servo-actuated pleating machines that are suitable for producing a filter element

according to the present disclosure. U.S. Patent Nos. 4,465,213 and 4,465,214, both of

which are incorporated herein by reference in their entireties, disclose exemplary servo-

actuated pleating machines. In particular, however, the Robofsky R178PC pleating

10   machine has been used to provide a pleated filter element according to the present

disclosure.

A program used to instruct the Robofsky R178PC pleating machine to make the

filter element exemplified in Table I is shown here in Table II.

15   Table II

Program for instructing a Robofsky R178PC pleating machine
to produce a pleated filter element in accordance with the present disclosure

Program Line	Bottom Blade (movement in inches)	Top Blade (movement in inches)	Repeat	To Produce
1	0.520	0.562	1	extra pleat
2	0.562	0.562	2	P, P
3	0.265	0.562	1	s_{31}
4	0.562	0.562	2	P, P
5	0.323	0.562	1	s_{25}
6	0.562	0.562	2	P, P
7	0.380	0.562	1	s_{19}
8	0.562	0.562	2	P, P
9	0.437	0.562	1	s_{13}
10	0.562	0.562	2	P, P
11	0.428	0.562	1	s_{14}
12	0.562	0.562	2	P, P

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Table II (continued)

Program Line	Bottom Blade (movement in inches)	Top Blade (movement in inches)	Repeat	To Produce
13	0.485	0.562	1	s_8
14	0.562	0.562	2	P, P
15	0.250	0.562	1	s_{37}
16	0.562	0.562	2	P, P
17	0.304	0.562	1	s_{27}
18	0.562	0.562	2	P, P
19	0.361	0.562	1	s_{21}
20	0.562	0.562	2	P, P
21	0.351	0.562	1	s_{22}
22	0.562	0.562	2	P, P
23	0.409	0.562	1	s_{16}
24	0.562	0.562	2	P, P
25	0.466	0.562	1	s_{10}
26	0.562	0.562	2	P, P
27	0.250	0.562	1	s_{35}
28	0.562	0.562	2	P, P
29	0.285	0.562	1	s_{29}
30	0.562	0.562	2	P, P
31	0.275	0.562	1	s_{30}
32	0.562	0.562	2	P, P
33	0.332	0.562	1	s_{24}
34	0.562	0.562	2	P, P
35	0.390	0.562	1	s_{18}
36	0.562	0.562	2	P, P
37	0.447	0.562	1	s_{12}
38	0.562	0.562	2	P, P
39	0.250	0.562	1	s_{36}
40	0.562	0.562	2	P, P
41	0.495	0.562	1	s_7
42	0.562	0.562	2	P, P
43	0.256	0.562	1	s_{32}
44	0.562	0.562	2	P, P
45	0.313	0.562	1	s_{26}
46	0.562	0.562	2	P, P
47	0.371	0.562	1	s_{20}
48	0.562	0.562	2	P, P
49	0.418	0.562	1	s_{15}
50	0.562	0.562	2	P, P
51	0.476	0.562	1	s_9
52	0.562	0.562	2	P, P

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Table II (continued)

Program Line	Bottom Blade (movement in inches)	Top Blade (movement in inches)	Repeat	To Produce
53	0.250	0.562	1	s_{34}
54	0.562	0.562	2	P, P
55	0.294	0.562	1	s_{28}
56	0.562	0.562	2	P, P
57	0.342	0.562	1	s_{23}
58	0.562	0.562	2	P, P
59	0.399	0.562	1	s_{17}
60	0.562	0.562	2	P, P
61	0.456	0.562	1	s_{11}
62	0.562	0.562	2	P, P
63	0.250	0.562	1	s_{33}
64	0.562	0.562	2	P, P
65	0.520	0.562	1	extra pleat

5   As shown by Table II, the program instructs the movement of an upper blade and a

lower blade to produce the primary pleats "P" and the secondary pleats "$s_1, s_2, s_3 \ldots s_\alpha$" of

the filter element 10 as disclosed herein. As also shown, the order of the secondary pleats

"s" as calculated in Table I has been mixed to produce the machine instructions of Table

II. The mixing of the secondary pleats "s" is done to ensure that the largest number of

10   primary and secondary pleats "P, s" as theoretically calculated in Table I can actually fit

into the predetermined dimensions of the cylindrically-shaped filter element 10.

It should be noted that each of the primary pleats "P" of the pleated filter element

10 set forth in Table I have been provided with an actual height "H" that is less than the

theoretical height of the primary pleats "P" to facilitate the axial insertion of the resulting

15   filter element 10 between the core 12 and the cage 14 to form the cartridge assembly 8. In

the machine instructions of Table II, therefore, the actual height "H" of the primary pleats

"P" is 0.01 inches less than the theoretical height of 0.572 inches. In addition, as a

practical matter, some of the primary pleats "P" may be left out of the filter element 10 to

ensure that the filter element 10 will fit between the core 12 and the cage 14. Accordingly,

five (5) of the primary pleats "P" have been left out of the machine instructions of Table II, such that an actual number of primary pleats "P" is equal to the theoretical number "N" minus five.

It should also be noted that each of the secondary pleats "s" of the pleated filter

5   element 10 set forth in Table I has been provided with an actual height that is less than the theoretical height "h". In the machine instructions of Table II, therefore, the actual height "h" of each the secondary pleats "s" is 0.01 inches less than the theoretical height "h" shown in Table I. In addition, some of the tallest secondary pleats "s" may be left out of the filter element 10 to ensure that the filter element 10 will fit between the core 12 and

10   the cage 14. Accordingly, the six tallest secondary pleats "$s_1, s_2, \ldots s_6$" have been left out of the machine instructions of Table II. Since secondary pleat "s_6" has an actual height "h_6" equal to about 0.504 inches, a predetermined maximum secondary pleat height "h_{max}" has been found empirically in this case to be about 0.504 inches.

The filter element 10, therefore, is pleated to include an actual number "α" of

15   secondary pleats "s" equal to the theoretical number "β" minus the number "y" of secondary pleats having a height greater than the predetermined maximum secondary pleat height "h_{max}" of about 0.504 inches and less than the practical minimum pleat height of about 0.200 inches. As an alternative to leaving primary and secondary pleats out of the filter element 10 to ensure that the filter element fits in the outer cage 14, the pleat

20   thickness "t" can be increased slightly when calculating the pleats in order to provided fewer pleats.

It has further been found that the heights "h" of the secondary pleats "s" preferably do not fall below a preferred minimum secondary pleat height "h_{min}", to ensure that the shorter secondary pleats hold their pleated shape and do not blow radially outward of the

25   filter element 10. Accordingly, "h" should be greater than or equal to "h_{min}", in addition to

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being less than "h_{max}". The minimum secondary pleat height "h_{min}" is generally dependent

on the pleat thickness and the capabilities of the pleating machine, and may also be

dependent on the particular filter and diffusion media incorporated in the filter element.

For the pleated filter element 10 set forth in Table I, a preferred minimum

5   secondary pleat height "h_{min}" has been found to be 0.250 inches. All secondary pleats "s"

having a calculated height "h" less than "h_{min}" (but greater than the practical minimum

pleat height of 0.200 inches) are provided with an actual height equal to "h_{min}". Since the

secondary pleats "$s_{33}, s_{34}, s_{35}, s_{36}$ and s_{37}", for example, each have an actual height "h_{33},

h_{34}, h_{35}, h_{36} and h_{37}", respectively, less than the "h_{min}" of 0.250 inches, they are each given

10   a height equal to "h_{min}" during production of the pleated filter 10, as shown on lines 15,

27, 39, 53 and 63 in Table II.

Referring to Table II, the remaining secondary pleats "$s_7, s_8, \ldots s_{32}$", as calculated

in Table I, are mixed in order and each are positioned between adjacent pairs of primary

pleats "P". The secondary pleats "s" may be distributed among the primary pleats "P" in a

15   random manner or in a uniform manner to obtain the largest total number of primary and

secondary pleats. In the example shown in Table II, the secondary pleats "s" have been

randomly mixed. Alternatively, the secondary pleats "s" may be distributed among the

primary pleats "P" in a uniform manner so that the similar distributions of secondary pleat

heights "h" may be repeated every ninety degrees of the filter element 10, for example, or

20   every forty-five degrees.

It is envisioned that many variations of the distribution and arrangement of the

secondary pleats "s" with respect to the primary pleats "P" are possible without departing

from the spirit and scope of the presently disclosed filter element 10. For example, a filter

element 110 according to the present disclosure can include two secondary pleats "s"

25   between every adjacent pairs of primary pleats "P", as shown in Fig. 3a; a filter element

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210 according to the present disclosure can include two secondary pleats "s" between

every two adjacent primary pleats "P", as shown in Fig. 3b; and a filter element 310

according to the present disclosure can include one secondary pleat "s" between every two

adjacent primary pleats "P", as shown in Fig. 3c. In addition, although not shown, a filter

5   element according to the present disclosure can have varying numbers of secondary pleats

"s" between adjacent primary pleats "P". Again, many variations of the distribution and

arrangement of the secondary pleats "s" with respect to the primary pleats "P" are possible

without departing from the spirit and scope of the presently disclosed filter element 10.

Referring again to Table II, extra pleats are made at the beginning of the machine

10   instructions, i.e., line 1, and the end of the machine instructions, i.e., line 65, so that a

length of the pleated filter composite can be cut at the extra pleats, then formed into a

cylindrical shape. Then the cut extra pleats are sealed to each other along a seam by

conventional means to retain the pleated filter composite in a cylindrical form.

15   Benefits of Filter Elements Pleated in Accordance with the Present Disclosure

Filter elements pleated in accordance with the present disclosure have been found

to have a far greater surface area usable for filtration than conventional radial pleated filter

elements having the same inner and outer diameters, such as the BetaFine D® filter

manufactured by Cuno, Incorporated of Meriden, CT. In general, it has been found that a

20   filter element 10 pleated according to the present invention has about thirty percent (30%)

more surface area than a conventional straight radial pleated filter element. In

comparison, a conventional W-pleated filter element has only about twenty percent (20%)

more surface area than a conventional straight radial pleated filter element.

In addition, a filter element 10 constructed in accordance with the present

25   disclosure has also been found to provide a greater and more consistent filter density

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between the inner core 12 and the outer cage 14 of a cartridge assembly 8 than either a

conventional W-pleated filter (having a uniform repeating pattern of one half pleat

between two pairs of full pleats) or a conventional straight radial pleated filter, as

demonstrated here by Table III.

5

Table III

Theoretical Comparison of Pleat Densities

Diameter intervals "D" between Inner Core and Outer Cage of Cartridge Assembly	Pleat Density (%)		
	Straight Radial Pleated Filter	W-Pleated Filter (uniform pattern of one short pleat between two tall pleats)	Filter element constructed in Accordance with the Present Disclosure
$D_1 = \text{"}d_{core}\text{"}$	100	100	100
D_2	89	89	100
D_3	80	81	100
D_4	73	73	100
D_5	67	67	100
D_6	62	93	100
D_7	58	87	100
D_8	54	81	100
D_9	51	76	96
$D_{10} = \text{"}d_{cage}\text{"}$	48	72	91

In Table III, the theoretical pleat densities for a given pleat thickness "t", core

10   outer diameter "d_{core}" and cage inner diameter "d_{cage}" are calculated and compared for a

conventional straight pleated filter, a conventional W-pleated filter, and a filter element 10

pleated according to the present disclosure. The theoretical pleat densities are equal to the

number of actual pleats provided by each filter divided by the maximum number of

theoretical pleats that can be provided at each diameter interval "D", where "D" is the

15   difference between "d_{cage}" and "d_{core}" divided by ten. The maximum number of theoretical

pleats is equal to the diameter at each interval multiplied by π and divided by the thickness

"t" of the pleats. As shown, a filter element 10 constructed in accordance with the present

disclosure provides the greater and more consistent pleat density between the inner core 12

and the outer cage 14, as compared with a conventional straight radial pleated filter and a

20   conventional W-pleated filter.

- 20 -

The greater and more consistent filter density of the presently disclosed filter

element 10 results in improved inter-pleat support and a more even distribution of loads

applied to the filter element. The greater and more consistent filter density, therefore,

minimizes pleat migration and binding, and increases the ability of the pleats to retain

5   particles in a pulsating flow system.

Filter elements pleated in accordance with the present disclosure have been found

to provide a greater filter life than conventional straight pleated filter elements, such as the

BetaFine-D® filter. Furthermore, filter elements pleated in accordance with the present

disclosure have been found to have advantages over spiral pleated filter elements, such as

10   the PolyPro XL® filter manufactured by Cuno, Incorporated of Meriden, CT. In particular,

a filter element 10 according to the present disclosure provides filter area and filter density

gains similar to a spiral pleated filter element, with an increase in the number of radial

flow paths of the filter available at the outer cage 14 of a cartridge assembly 8 containing

the filter element 10. In addition, a filter element 10 according to the present invention is

15   more easily inserted into a cage 14 than a spiral pleated filter element, whose pleats must

be rolled over, or "spiraled" before being inserted into the cage.

Composite Construction

Preferably, the filter element 10 of the present disclosure comprises a pleated

composite including a filter medium 20 and at least one of an upstream diffusion medium

20   22 and a downstream diffusion medium 24, as shown best in Fig. 1. Here, upstream and

downstream refer to the exterior and interior surfaces of the filter element 10 when the

filter is being subjected to radially inward fluid flow, or to interior and exterior surfaces of

the filter when the filter element is being subjected to radially outward fluid flow.

The diffusion media 22, 24 provide support to the filter medium 20 and enable

25   fluid to evenly flow to or from substantially all portions of the surface of the filter medium

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20 so that virtually the entire surface area of the filter medium may be effectively used for

filtration. Preferably, the filter element 10 comprises a three-layer composite of a filter

medium 20, and both an upstream diffusion medium 22 and a downstream diffusion

medium 24.

5   There are no particular restrictions on the type of filter medium 20 that can be

employed in the present filter element 10, and the filter medium can be selected in

accordance with the fluid to be filtered and the desired filtering characteristics. The filter

medium 20 can be used to filter fluids such as liquids, gases, or mixtures thereof, and may

comprise a porous film or a fibrous sheet or mass, or any combination thereof; may have a

10   uniform or graded pore structure and any appropriate effective pore size; may include

single or multiple layers; and may be formed from any suitable material, such as a natural

material, synthetic polymer, glass, or metal.

          According to preferred embodiments of the present disclosure, the filter medium is

comprised of one or more sheets of non woven thermoplastic micro fibers. The non

15   woven thermoplastic micro fibers may be melt blown, spunbond, carded, or

hydroentangled, for example. In addition, the filter medium may be calendered, or

compressed, to further modify its porosity. For lower temperature filtering applications

(i.e., below 180° F), the thermoplastic can comprise polypropylene, for example, while for

higher temperature applications (i.e., above 180° F) or chemical compatibility with other

20   fluids, the thermoplastic can comprise nylon, polyester or melt-processible fluoropolymer,

for example.

          The filter medium 20 may comprise a single layer, or a plurality of layers.

Furthermore, it is possible for the filter medium 20 to include two or more layers having

different filtering characteristics (e.g., one layer acting as a pre-filter for the second layer).

25   The filter medium is preferably provided in sheet form, as opposed to being melt blown

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directly onto the diffusion medium, for example, such that the sheet can be inspected prior to being incorporated into the filter. The use of discrete sheets of depth filter medium has been found to simplify quality control inspection of the filter medium and make the physical properties of each filter cartridge more consistent. Controlling the consistency of

5   the physical properties of the filter medium provides a unique ability to achieve sharp, well-defined, and optimized control over the removal efficiency and dirt capacity of the resulting filter cartridge.

The diffusion media 22, 24 are preferably distinct from the filter medium 20. The upstream and downstream diffusion media 22, 24 can be made of any materials such as a

10   mesh, screen or a porous woven or non-woven sheet.

Meshes and screens (also called netting) come in various forms. For high temperature applications, a metallic mesh or screen may be employed, while for lower temperature applications, a polymeric mesh may be particularly suitable. Polymeric meshes come in the form of woven meshes and extruded meshes, either of which may be

15   employed. Specific examples of suitable extruded polymeric meshes are those available from Nalle Plastics of Austin, TX under the trade names Naltex®, Zicot®, and Ultraflo®. Other examples of suitable extruded polymeric meshes are those available from Applied Extrusion Technologies, Inc. of Middletown, DE under the trade name Delnet® extruded polypropylene mesh, which can be extruded at various strand orientations.

20   Meshes are particularly suitable as the diffusion media 22, 24 when the filter medium 20 is a fibrous laid-down medium. Diamond netting, e.g., Naltex LWS®, is particularly suitable for pleated filter applications because it can be readily pleated with short pleat heights, holds a set well after being heated, and has good fluid distribution properties.

25

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When the filter medium 20 is a membrane, a sheet of woven or non-woven fabric

may be more suitable for use as the diffusion media 22, 24 since a fabric is usually

smoother than a mesh and produces less abrasion of adjoining layers of the filter

composite. An example of a suitable non-woven fabric for use as a diffusion medium is a

5   polyester non-woven fabric sold under the trade designation Reemay 2011 by Reemay,

Inc. of Old Hickory, TN.

The upstream and downstream diffusion media 22, 24 can be of the same or

different construction. Alternatively, the upstream and downstream diffusion media 22,

24 may have different characteristics and these characteristics may be varied to provide a

10   desired effect. For example, where the overall thickness of the filter composite is fixed,

the thickness of the upstream diffusion medium 22 may be made greater than the thickness

of the downstream diffusion medium 24.

An example of a pleated filter element 10 constructed according to the present

disclosure includes an upstream diffusion medium 22 of Delnet® extruded polypropylene

15   mesh, and a downstream diffusion medium 24 of Typar T-135® spunbond, non-woven

polypropylene, available from Reemay Inc. Another example of a pleated filter element

10 constructed according to the present disclosure includes an upstream diffusion medium

22 of Naltex Symmetrical Filtration Netting LWS® 37-3821 extruded polypropylene mesh,

and a downstream diffusion medium 24 of the Typar T-135® spunbond, non-woven

20   polypropylene.

Optimum Combination of Total Filter Area and Upstream Diffusion Medium

It has been found, that a filter element 10 pleated in accordance with the present

disclosure should not always be made to have the most filter area that will fit between a

25   core and a cage of a cartridge assembly. Referring to Table IV, for example, an optimum

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combination of total filter area and upstream diffusion medium 22 for a filter element 10

pleated in accordance with the present disclosure has been found to depend on the

particular type and sizes of contaminants to be filtered.

5

<div align="center">Table IV
Filter Area v. Upstream Diffusion Layers</div>

Filter Rating (microns)	Contaminant size (microns)	Length of Filter Composite (feet)	Upstream Diffusion Layer	Life (grams)
0.2	0-10	9.2	5 mil Delnet®	198
0.2	0-10	7.3	13 mil Nalle LWS®	150
0.5	0-10	9.2	5 mil Delnet®	201
0.5	0-10	8.5	13 mil Nalle LWS®	258
0.5	0-10	7.3	20 mil Nalle LWS®	284
1	0-10	9.2	5 mil Delnet®	192
1	0-10	8.0	13 mil Nalle LWS®	254
1	0-10	7.3	20 mil Nalle LWS®	306
2.5	0-150	9.2	5 mil Delnet®	177
2.5	0-150	7.3	20 mil Nalle LWS®	392
5	0-150	10.0	5 mil Delnet®	94
5	0-150	7.8	20 mil Nalle LWS®	282
10	0-150	8.4	10 mil Delnet®	239
10	0-150	7.8	20 mil Nalle LWS®	331
20	0-150	8.4	10 mil Delnet®	262
20	0-150	7.8	20 mil Nalle LWS®	386
0-70	0-150	8.4	5 mil Delnet®	198
40-70	0-150	7.8	20 mil Nalle LWS®	376

Table IV shows the results of single pass tests on various filter elements pleated in

10   accordance with the present disclosure. Each single pass test was performed at a flow rate

of three gallons per minute, with water containing between about 0.39 to about 1.0 grams

of contaminant per gallon of water. Two standard contaminants were used: 0-150 micron

contaminant (ISO COARSE, A.T.D. 12103-1, A4, available from Powder Technologies,

Inc. of Burnsville, MN); and 0-10 micron contaminant (A.T.D. nominal 0-10 microns, also

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available from Powder Technologies, Inc).

All of the filter elements tested were pleated in accordance with the present

disclosure, included a filter medium 20 of non woven thermoplastic micro fibers, a

downstream diffusion medium 24 of Typar T-135® spunbond, non-woven polypropylene,

5   an outer diameter of about 2.5 inches and a length of about 10 inches. The life of a filter

for purposes of the tests illustrated in Table IV is defined as the amount of contaminant

challenged for the pressure drop across the filter to increase by 20 psid due to contaminant

loading in the tested filter.

Based upon the results shown in Table IV, for example, it has been found that a

10   filter element 10 pleated in accordance with the present disclosure, having a rating of 0.2

microns and for filtering contaminants of 0-10 microns, preferably will have a filter

composite length of at least 9.0 feet and an upstream diffusion layer 22 of 5 mil Delnet®.

However, filter elements 10 pleated in accordance with the present disclosure, having

ratings of 0.5, 1.0 and 2.5 microns, and for filtering contaminants of 0-150 microns,

15   preferably will each have a filter composite length of not more than about 7.3 feet and an

upstream diffusion layer 22 of 20 mil Nalle LWS®. In addition, filter elements 10 pleated

in accordance with the present disclosure, having ratings of 5.0, 10.0, 20.0 and 40.0 to

70.0 microns, and for filtering contaminants of 0-150 microns, preferably will each have a

filter composite length of not more than about 7.8 feet and an upstream diffusion layer 22

20   of 20 mil Nalle LWS®.

The Cartridge Assembly

The cylindrical core 12 of the cartridge assembly 8 supports the inner periphery of

the filter element 10 against forces in the radial direction and also helps to give the filter

25   element axial strength and rigidity against bending. The core 12 may be of conventional

design and may be made of any material having sufficient strength and which is

compatible with the fluid being filtered. Openings 26 are formed through the core to

permit the passage of fluid between the outside and the center of the core. An alternative

core would include a splined shaft, or a core that can be removed during manufacturing.

5   The outer cage 14 of the cartridge assembly 8 may be of conventional design with

openings 28 formed therein for the passage of fluid. Alternative cages include expandable

mesh sleeve, a porous extruded tube, or a wrap consisting of cord, woven or non-woven

material. The material of which the cage 14 is made can be selected based on the fluid

being filtered and the filtering conditions.

10   Usually, a cartridge assembly 8 according to the present invention will be equipped

with end caps 30 at one or both ends. The end caps 30 can be either blind 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 30 are attached to the filter element 10, but

15   they may also be attached to the core 12 or the cage 14. Conventional techniques can be

used to attach the end caps 30 to the cartridge assembly 8, such as by use of an epoxy, by

thermobonding, or by spin welding.

Although the presently disclosed filter element 10 has been described and

illustrated with respect to a preferred embodiment, it is apparent that modifications and

20   changes can be made thereto without departing from the spirit and scope of the presently

disclosed filter element as defined by the following claims.

WHAT IS CLAIMED IS:

1.   A cylindrical filter element comprising:

a plurality of longitudinally extending pleats including outwardly radiating primary

pleats and inwardly radiating secondary pleats, at least one secondary pleat positioned

between two adjacent primary pleats, each primary pleat having a predetermined radial

height, each secondary pleat having a radial height that is less than the radial height of

each primary pleat and different from the radial height of at least one other secondary

pleat.

2.   A filter element as recited in Claim 1, wherein each secondary pleat has a

different radial height.

3.   A filter element according to claim 1, wherein one secondary pleat is

between every adjacent pairs of primary pleats.

4.   A filter element according to claim 1, wherein two secondary pleats are

between every adjacent pairs of primary pleats.

5.   A filter element according to claim 1, wherein one secondary pleat is

between every adjacent primary pleats.

6.   A filter element according to claim 1, wherein two secondary pleats are

between every adjacent primary pleats.

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7.   A filter element according to claim 1, wherein a theoretical number of primary pleats is about equal to:

$$\frac{\pi d_{inner}}{t}$$

where "d_{inner}" is equal to an inner diameter of the filter element, and "t" is equal to a thickness of the pleats.

8.   A filter element according to claim 7, wherein an actual number of primary pleats is less than the theoretical number of primary pleats.

9.   A filter element according to claim 1, wherein a theoretical number "β" of secondary pleats is about equal to:

$$\frac{(d_{outer} - d_{inner})\,\pi}{t}$$

where "d_{inner}" is equal to an inner diameter of the filter element, "d_{outer}" is equal to an outer diameter of the filter element, and "t" is equal to a thickness of the pleats.

10.   A filter element according to claim 9, wherein the secondary pleats each have a height "$h_1, h_2, h_3, .. h_\beta$" about equal to:

$$h_1 = [d_{outer} - (d_{inner} + 1t/\pi)]/2$$
$$h_2 = [d_{outer} - (d_{inner} + 2t/\pi)]/2$$
$$h_3 = [d_{outer} - (d_{inner} + 3t/\pi)]/2$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$h_\beta = [d_{outer} - (d_{inner} + \beta\, t/\pi)]/2$$

11.   A filter element according to claim 9, wherein an actual number of secondary pleats is less than the theoretical number of secondary pleats.

12. A filter element according to claim 11, wherein the actual number of secondary pleats is about equal to:

$$\beta - y$$

where "y" is equal to the number of secondary pleats having a theoretical height "h" greater than a predetermined maximum secondary pleat height and the number of secondary pleats having a theoretical height "h" less than a predetermined practical minimum pleat height.

13. A filter element according to claim 1, wherein each secondary pleat has a radial height that is less than or equal to a predetermined maximum secondary pleat height.

14. A filter element according to claim 1, wherein each secondary pleat has a radial height that is greater than or equal to a preferred minimum secondary pleat height.

15. A filter element according to claim 1, wherein the filter element comprises a pleated composite including a filter medium and at least one of an upstream diffusion medium and a downstream diffusion medium.

16. A filter element according to claim 15, wherein the at least one diffusion medium comprises one of an extruded netting and a spunbond, non-woven polymer.

17. A filter element according to claim 15, wherein the at least one diffusion medium comprises a thermoplastic selected from a group including polypropylene, nylon,

polyester and fluoropolymer.

18. A filter element according to claim 15 including an upstream diffusion medium and a downstream diffusion medium, wherein the upstream diffusion medium comprises extruded polypropylene netting, and the downstream diffusion medium comprises spunbond, non-woven polypropylene.

19. A filter element according to Claim 15 wherein the filter medium comprises a thermoplastic selected from a group including polypropylene, nylon, polyester and fluoropolymer.

20. A filter element according to Claim 15 wherein the filter medium comprises non woven micro fibers.

21. A filter element according to claim 15, wherein the pleated composite is heat-set.

22. A filter element according to claim 1 for filtering contaminants not greater than about 10 microns, wherein the filter element comprises a pleated composite including:

a filter medium of non woven thermoplastic polypropylene micro fibers;

a downstream diffusion medium of Typar T-135® spunbond, non-woven polypropylene; and

an upstream diffusion layer of 5 mil Delnet®.

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23.   A filter element according to claim 1 for filtering contaminants not greater

than about 150 microns, wherein the filter element comprises a pleated composite

including:

a filter medium of non woven thermoplastic polypropylene micro fibers;

a downstream diffusion medium of Typar T-135® spunbond, non-woven

polypropylene; and

an upstream diffusion layer of 20 mil Nalle LWS®.

24.   A cartridge assembly including the filter of claim 1 and further comprising

a cylindrical core coaxially positioned within the cylindrical filter element, and a

cylindrical cage coaxially positioned about the cylindrical filter element.

25.   A cartridge assembly comprising:

a)   a cylindrical cage;

b)   a cylindrical core coaxially positioned within the cylindrical cage; and

c)   a cylindrical filter element coaxially positioned between the core and the

cage and including a plurality of longitudinally extending pleats including outwardly

radiating primary pleats and inwardly radiating secondary pleats, at least one secondary

pleat positioned between two adjacent primary pleats, each primary pleat having a

predetermined radial height about equal to a difference between an outer diameter of the

core and an inner diameter of the cage, each secondary pleat having a radial height that is

less than the radial height of each primary pleat and different from the radial height of

each other secondary pleat.

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26.   A cartridge assembly according to claim 25, wherein each secondary pleat of the filter element has a different radial height.

27.   A cartridge assembly according to claim 25, wherein one secondary pleat is between every adjacent pairs of primary pleats of the filter element.

28.   A cartridge assembly according to claim 25, wherein a theoretical number of primary pleats is about equal to:

$$\frac{\pi d_{core}}{t}$$

where "d_{core}" is equal to an outer diameter of the core, and "t" is equal to a thickness of the pleats.

29.   A cartridge assembly according to claim 28, wherein an actual number of primary pleats is less than the theoretical number of primary pleats.

30.   A cartridge assembly according to claim 25, wherein a theoretical number "β" of secondary pleats is about equal to:

$$\frac{(d_{cage} - d_{core})\pi}{t}$$

where "d_{cage}" is equal to an inner diameter of the cage, "d_{core}" is equal to an outer diameter of the core, and "t" is equal to a thickness of the pleats.

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31.   A cartridge assembly according to claim 30, wherein the secondary pleats each have a height "$h_1, h_2, h_3, \ldots h_\beta$" about equal to:

$$h_1 = [d_{cage} - (d_{core} + 1 \ t/\pi)]/2$$
$$h_2 = [d_{cage} - (d_{core} + 2 \ t/\pi)]/2$$
$$h_3 = [d_{cage} - (d_{core} + 3 \ t/\pi)]/2$$

$$\cdot$$
$$\cdot$$

$$h_\beta = [d_{cage} - (d_{core} + \beta \ t/\pi)]/2$$

32.   A cartridge assembly according to claim 30, wherein an actual number of secondary pleats is less than the theoretical number of secondary pleats.

33.   A cartridge assembly according to claim 32, wherein the actual number of secondary pleats is about equal to:

$$\beta - y$$

where "y" is equal to the number of secondary pleats having a height "h" greater than a predetermined maximum secondary pleat height "h_{max}" and the number of secondary pleats having a theoretical height "h" less than a predetermined practical minimum pleat height.

34.   A cartridge assembly according to claim 25, wherein the secondary pleats each have a height less than or equal to a predetermined maximum secondary pleat height.

35.   A cartridge assembly according to claim 25, wherein the secondary pleats each have a height greater than or equal to a preferred minimum secondary pleat height.

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36.   A method of forming a filter element comprising:

pleating filter medium to include a plurality of longitudinally extending pleats

including primary pleats and secondary pleats, wherein at least one secondary pleat is

positioned between two adjacent primary pleats, each primary pleat has a predetermined

height, and each secondary pleat has a height that is less than the height of each primary

pleat and different from the height of at least one other secondary pleat.

37.   A method according to claim 36, further comprising:

cutting the pleated filter medium to a desired length; and

forming the cut length of the pleated filter medium into a cylinder such that the

primary pleats extend radially outwardly and the secondary pleats extend radially

inwardly.

38.   A method according to claim 36, wherein the filter medium is pleated to

include one secondary pleat between adjacent pairs of primary pleats.

39.   A method according to claim 36, wherein the filter medium is pleated to

include two secondary pleats between adjacent pairs of primary pleats.

40.   A method according to claim 36, wherein the filter medium is pleated to

include one secondary pleat between adjacent primary pleats.

41.   A method according to claim 36, wherein the filter medium is pleated to

include two secondary pleats between adjacent primary pleats.

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42.   A method according to claim 36, wherein the filter medium is pleated to

include a theoretical number of primary pleats equal to about:

$$\frac{\pi d_{inner}}{t}$$

where "d_{inner}" is equal to an inner diameter of the filter element, and "t" is equal to a

thickness of the pleats.

43.   A method according to claim 36, wherein the filter medium is pleated to

include an actual number of primary pleats less than about:

$$\frac{\pi d_{inner}}{t}$$

where "d_{inner}" is equal to an inner diameter of the filter element, and "t" is equal to a

thickness of the pleats.

44.   A method according to claim 36, wherein the filter medium is pleated to

include an actual number of secondary pleats equal to about:

$$[(d_{outer} - d_{inner})\pi/t] - y$$

where "d_{inner}" is equal to an inner diameter of the filter element, "d_{outer}" is equal to an outer

diameter of the filter element, "t" is equal to a thickness of the pleats, and "y" is equal to

the number of secondary pleats having a theoretical height greater than a predetermined

maximum secondary pleat height "h_{max}" and the number of secondary pleats having a

theoretical height "h" less than a predetermined practical minimum pleat height.

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45.   A method according to claim 36, wherein the filter medium is pleated to

include a theoretical number "β" of secondary pleats equal to about:

$$\frac{(d_{outer} - d_{inner})\pi}{t}$$

where "d_{inner}" is equal to an inner diameter of the filter element, "d_{outer}" is equal to an outer

diameter of the filter element, and "t" is equal to a thickness of the pleats.

46.   A method according to claim 45, wherein the filter medium is pleated to

include secondary pleats each having a height "$h_1, h_2, h_3, .. h_\beta$" about equal to:

$$h_1 = [d_{outer} - (d_{inner} + 1\ t/\pi)]/2$$
$$h_2 = [d_{outer} - (d_{inner} + 2\ t/\pi)]/2$$
$$h_3 = [d_{outer} - (d_{inner} + 3\ t/\pi)]/2$$
$$.$$
$$.$$
$$h_\beta = [d_{outer} - (d_{inner} + \beta\ t/\pi)]/2$$

47.   A method according to claim 46, wherein the filter medium is pleated so

that secondary pleats having a height greater than a predetermined maximum secondary

pleat height are left out of the filter element.

48.   A method according to claim 46, wherein the filter medium is pleated so

that secondary pleats having a height less than a preferred minimum secondary pleat

height are pleated to have the preferred minimum secondary pleat height.

49.   A method according to claim 36, wherein the filter medium is provided as

part of a composite that includes at least one of an upstream diffusion medium and a

downstream diffusion medium.

50.   A method according to claim 49, further comprising heat-setting the pleated composite.

51.   A method according to claim 36, further comprising coaxially positioning a cylindrical core within the cylindrical filter element.

52.   A method according to claim 51, further comprising coaxially positioning a cylindrical cage element about the cylindrical filter element.

53.   A method according to claim 52, wherein the filter medium is pleated so that the predetermined radial height of the primary pleats is about equal to a difference between an outer radius of the core and an inner radius of the cage.
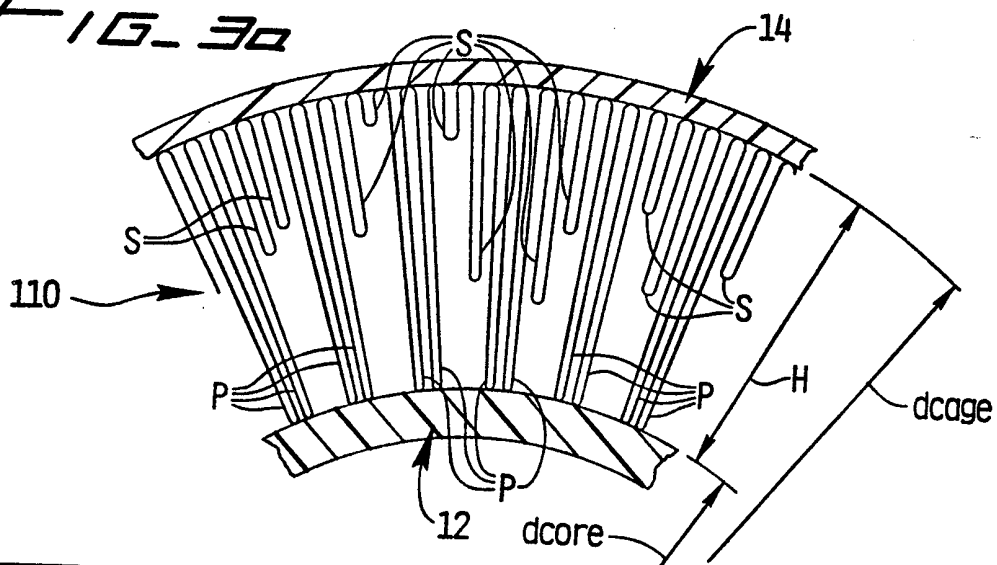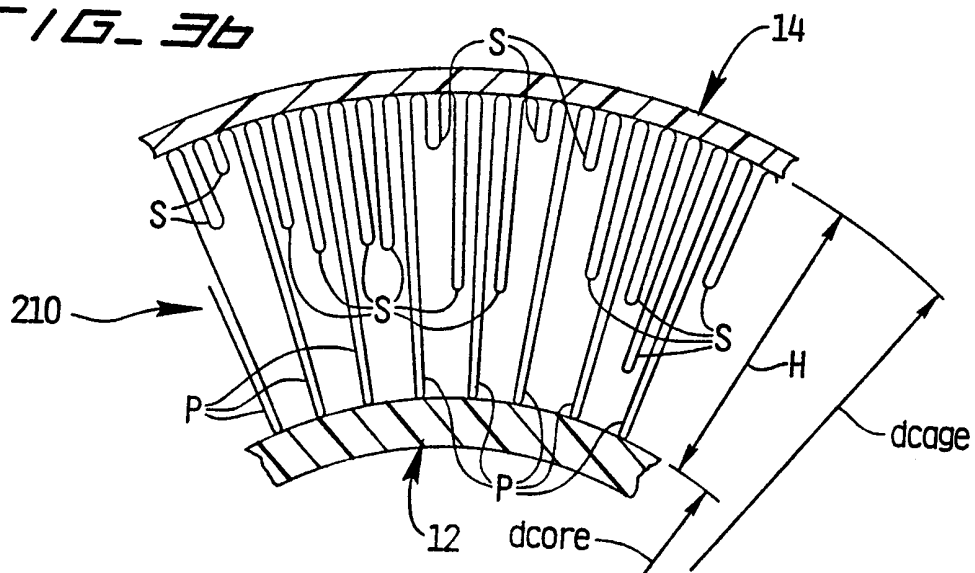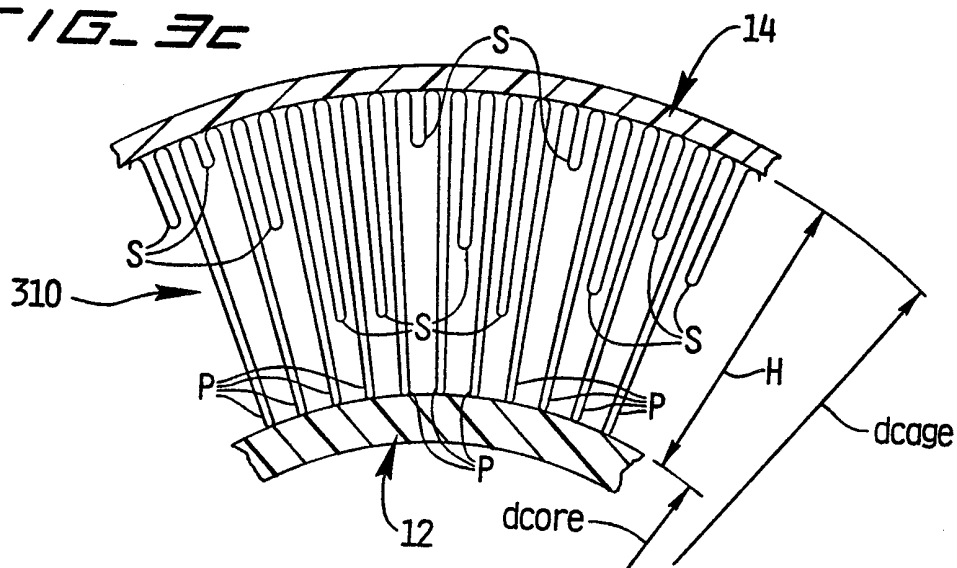
FIG_1
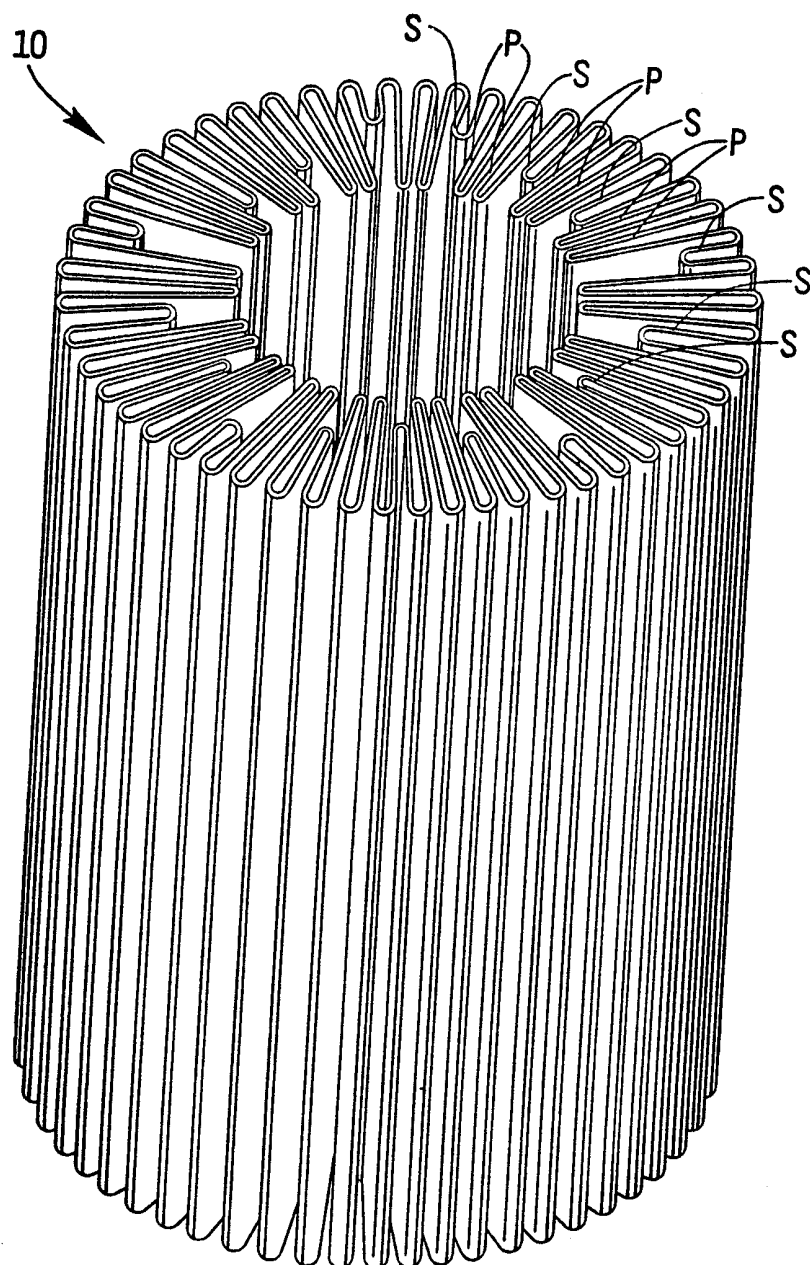
FIG_2
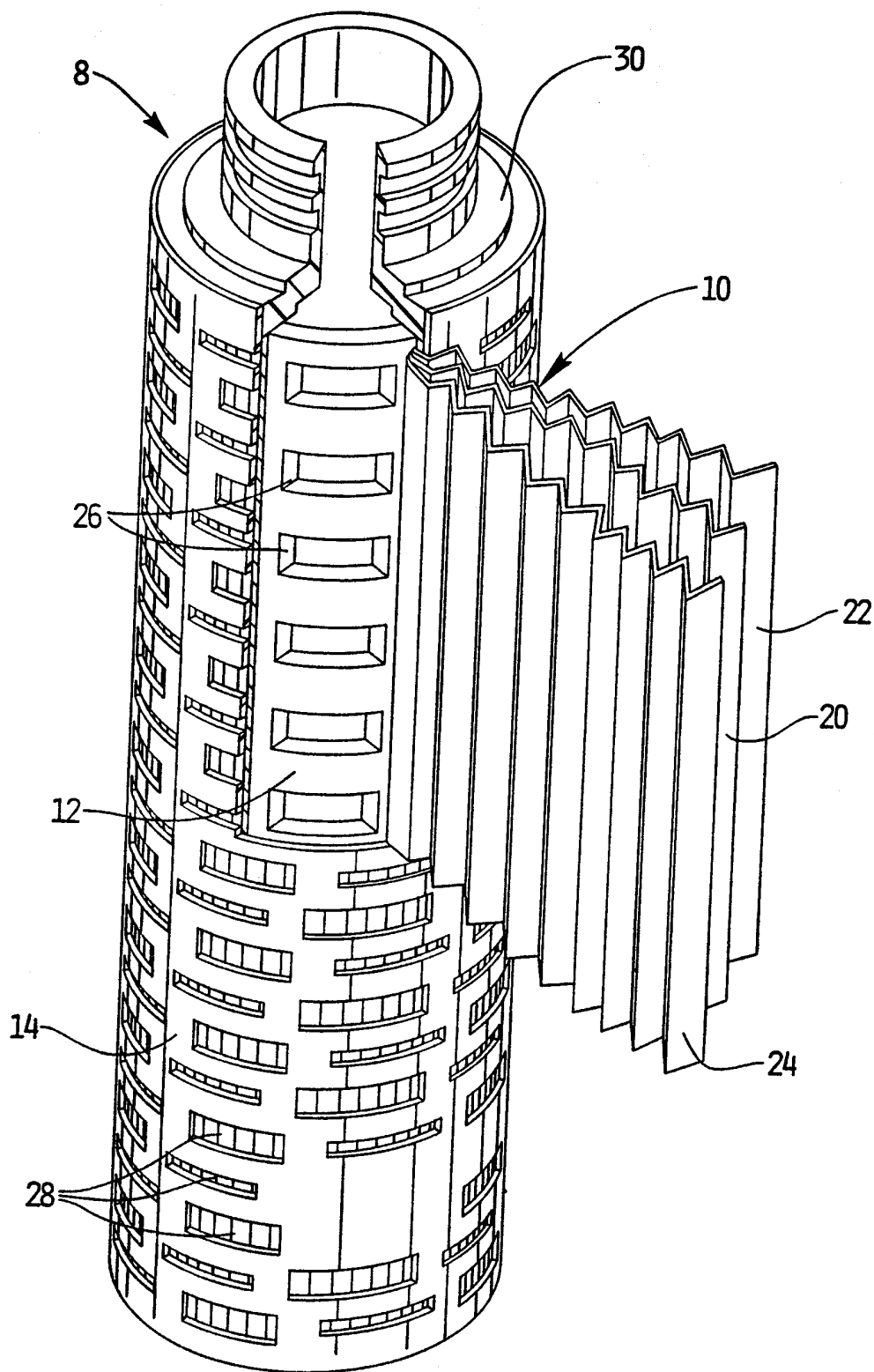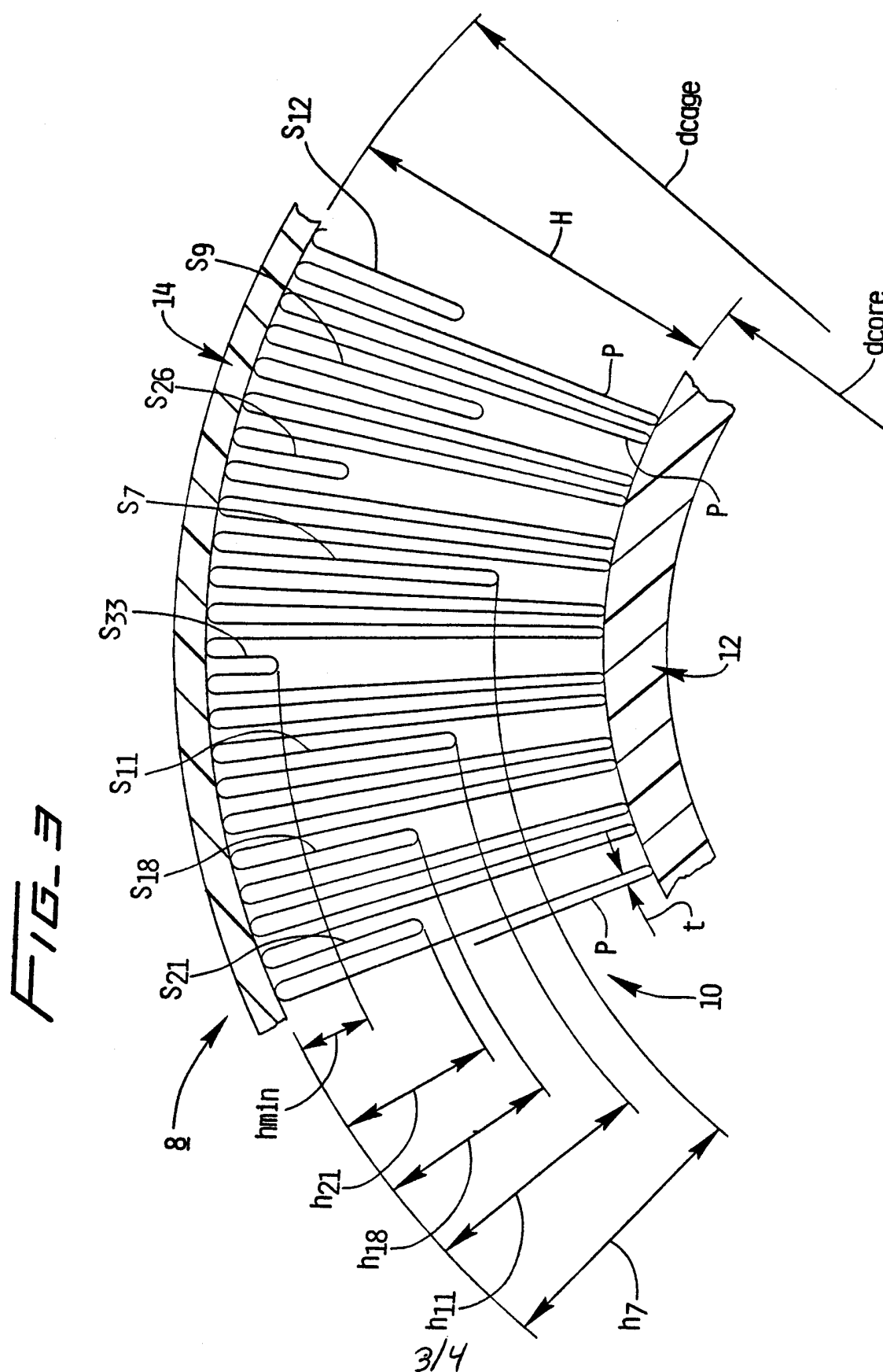
FIG-3

FIG_3a

FIG_3b

FIG_3c

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   B01D29/21   B01D27/06   B01D46/52

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   B01D

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95 17945 A (DETROIT HOLDING LTD ;KAEHLER KAI (DE)) 6 July 1995 (1995-07-06) page 10, line 7 -page 11, line 5; figures 1-3,11,12 ---	1,2, 5-11, 24-29, 36,37, 51,52
X	GB 1 196 534 A (FAUDI FEINBAU GMBH) 24 June 1970 (1970-06-24) the whole document ---	1,2,5,6, 24-26, 36,37
X	US 2 627 350 A (J.D.WICKS) 3 February 1953 (1953-02-03) cited in the application column 3, line 37 - line 74; figures 3-5 ---	1,2,5,6, 24-26, 36,37

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|X| Further documents are listed in the continuation of box C. |X| Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 May 2000	16/05/2000

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 673 503 A (FUJIMOTO ETSUO) 16 June 1987 (1987-06-16) figure 2	1,2,5,6
A	GB 735 842 A (GENERAL MOTORS LTD) 31 August 1955 (1955-08-31) the whole document	1

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 9517945	A	06-07-1995	AU	1381295 A	17-07-1995
GB 1196534	A	24-06-1970	DE	1611083 A	19-05-1971
			FR	1575392 A	18-07-1969
US 2627350	A	03-02-1953	NONE		
US 4673503	A	16-06-1987	NONE		
GB 735842	A		NONE		