

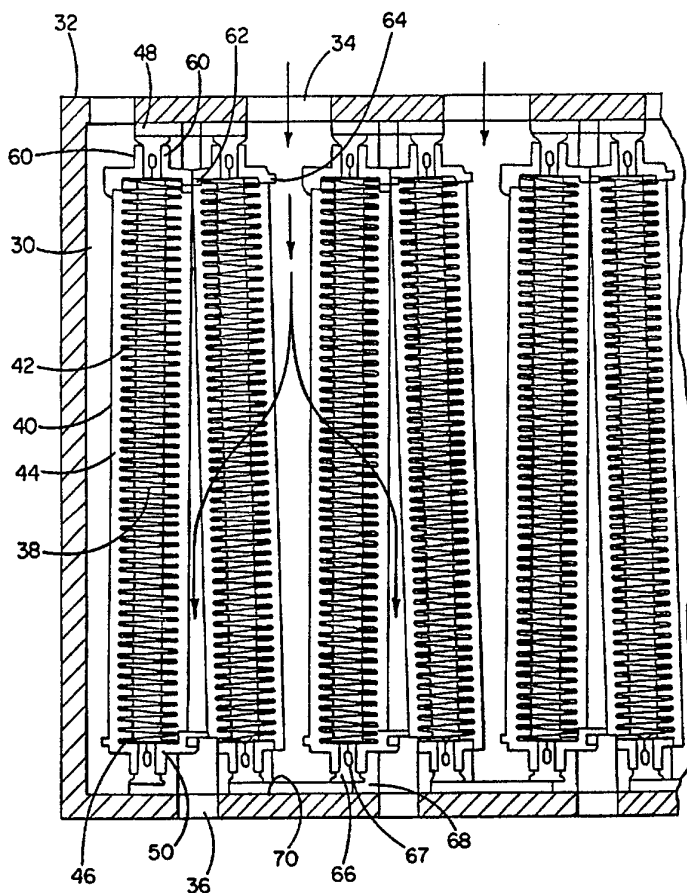


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<b>(21) International Application Number:</b> PCT/US94/02312 <b>(22) International Filing Date:</b> 2 March 1994 (02.03.94) <b>(30) Priority Data:</b> 08/027,497      5 March 1993 (05.03.93)      US <b>(71) Applicant:</b> PALL CORPORATION [US/US]; 2200 Northern Boulevard, East Hills, NY 11548 (US). <b>(72) Inventors:</b> WHITE, Donald, H.; 923 Alfred Lane, Homer, NY 13077 (US). MATKOVICH, Vlado, I.; 11 Old Estate Road, Glen Cove, NY 11542 (US). <b>(74) Agents:</b> SAMUELS, Frederick, N. et al.; Suite 300, 700 Thirteenth Street, N.W., Washington, DC 20005 (US).		<b>(81) Designated States:</b> AT, AU, BB, BG, BR, BY, CA, CH, CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SK, UA, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

**(54) Title:** GAS PURIFICATION SYSTEM**(57) Abstract**

A purification assembly (18) is described including a particulate assembly (20) for removing particulate contaminants and a sorbent assembly (22) for removing gaseous contaminants. The particulate assembly (18) includes a pleated filter medium (38) and the sorbent assembly (22) includes a pleated sorbing medium, such as a mat of fibers on which a sorbent material is bonded by an adhesive.



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## GAS PURIFICATION SYSTEM

### 5                                    TECHNICAL FIELD

          The present invention is related to a gas  
purification system. More particularly, the  
invention is related to a particulate assembly for  
removing particulate contaminants and a sorbent  
10 assembly for removing odorous and/or toxic  
contaminants from the air in the cabin of an  
aircraft. The invention is also related to various  
sorbing media for removing odorous and/or toxic  
gases.

### 15                                   BACKGROUND ART

          Numerous materials and devices of varying  
design are available for the removal of contaminants  
from gaseous fluids such as air. The contaminants  
20 range from those which are mildly offensive or  
odorous to others which are highly toxic. Removal  
applications range from removal of particulates  
and/or gases resulting from industrial processes  
being exhausted to the environment at large to the  
25 purification of air being introduced from the  
environment at large to both large and small  
confined areas, such as homes and office buildings.  
Another application, is the purification of air to  
remove odorous, toxic and particulate contaminants  
30 from air being recycled within an enclosed and  
isolated area, such as that of the passenger  
compartment or cabin of an aircraft. The cabin of  
an aircraft is unique in at least one respect from  
other passenger carrying compartments or even  
35 confined areas generally. Most aircraft cabins,

particularly those of large commercial aircraft are isolated from the environment at large, and the passengers occupying the cabin are not permitted ingress or egress and only limited fluid

5 communication with the environment exterior to the aircraft during the duration of the flight. In most commercial aircraft, compressed air is extracted from an engine compressor stage as makeup air and supplied to the cabin while some of the cabin air is

10 vented to the external atmosphere. However, energy costs are increased in the process of supplying cabin air in this manner.

Considering the "captive" or confining nature of an airline flight from the perspective of the

15 passenger who is unable to significantly alter his or her environment during the duration of the flight, aircraft manufacturers are becoming increasingly concerned with the air quality standards of the air in the cabin. Accordingly, it

20 is highly desirable to provide an effective system for removing airborne contaminants both of a particulate and gaseous nature. An adequate system used for the removal of airborne contaminants from an aircraft cabin should be capable of removing both

25 particulate contaminants, such as microorganisms, particulates from tobacco smoke, and fibers from clothing, carpets and upholstery, as well as odorous and toxic gases, such as those present in tobacco smoke, byproducts and degradation products of the

30 materials used in the construction of the aircraft, cooking odors and aircraft fuel. A purification system which achieves these objects would also have the concomitant effect of requiring less air to be supplied from the engine compressor stage and

35 thereby resulting in fuel savings and lower

operating costs.

In large commercial aircraft such as the Boeing 747-400 and the Boeing 777, cabin air frequently contains a high degree of contaminants due to the large number of passengers. Conventional filtration assemblies have combined particulate filtration materials with sorption materials but have proven to be impractical in commercial aircraft because they may have a high resistance to air flow or become clogged quickly and, thus, require frequent replacement. Due to the unitary nature of conventional filtration assemblies, when a portion of the filtration assembly becomes clogged or exhibits high resistance to air flow, the entire filtration assembly must be replaced or at least cleaned. This procedure is expensive, time consuming and cumbersome and it requires a great deal of man hours from aircraft maintenance personnel.

Qualities sought in air purification systems of the type used to purify the air in a confined area, and particularly of the type used in aircraft cabins, relate most frequently to the types of material or media used in such systems. Among these are high sorption capacity, high sorption rate, long filter life, low pressure loss, low pressure differentials across the sorption material or medium or the filter medium; light weight or low density of the material or medium; minimal loss of material from the sorption material or medium; and low manufacturing costs. Thus, materials and media are preferred which can be used in systems which filter large volumes of air and are capable of effective and efficient removal of contaminants. To reduce cost and the expenditure of labor, such material and

media should have an extended service life, be durable and permit easy replacement of the sorption material or medium and the filter medium. To provide an efficient system without stressing either the sorption material or medium or the filter medium or necessitating higher power requirements or larger components to operate the system, a low pressure drop or differential across the sorption material or medium and the filter medium is highly desirable.

While liquids containing one or more reagents may be highly effective in removing gaseous contaminants, by their very nature they are practical only in laboratory or other settings where trained personnel are available to handle or change the active component. Beds of solid sorbents, such as activated carbon and molecular sieves, have proven quite effective and much easier to handle in many applications. They may be used in perforated canisters of the disposable type or those in which the contents may be replaced and/or regenerated. Associated with the former are certain disadvantages such as cost, where both the contents and the container must be discarded. The latter type of device, in which the contents are replaced or regenerated, however, requires the handling of fine granules or powder which may occasion spillage or, under some circumstances, cause the active component itself to become airborne and act as a pollutant.

Some media and devices have been employed for sorption of contaminants which immobilize a solid adsorbent on or within the pores of a polymeric foam material or fibrous mesh. While such devices have advantages over those devices which employ liquids or beds of solid sorbents, there are certain disadvantages associated with their use. Thus, such

media tend to shed the solid adsorbent from the surface of the medium or even when entrapped within the mesh due to vibration, hard impact against the medium, flexing of the medium or rough handling  
5 generally. Another shortcoming of such media and devices, as well as some of the packed bed devices, is the pressure drop across such media tends to be high.

Contaminants are removed from air most  
10 efficiently by media or material having large surface areas. Given the strict space requirements in enclosed compartments such as aircraft cabins, it is difficult to realize sorption media or material and/or filter media which have large surface areas  
15 while having compact construction.

#### DISCLOSURE OF THE INVENTION

The present invention is directed to an air purification system for removing contaminants from a  
20 fluid stream such as air. The air purification system includes an air purification assembly which removes contaminants from the air. A feature of the present invention is that the air purification assembly includes pleated modules. An advantage of  
25 the present invention is that the pleated modules also increase the surface area of the medium.

The present invention is further directed to gas sorbing media capable of removing gases, particularly odorous and toxic gases, from a fluid  
30 stream, such as air. The media of the invention include a non-woven fibrous mat which is adhesively coated with fine, inorganic, microporous sorbent particles. A predominant number of the particles have particle sizes less than about  $35\mu$  and are  
35 impregnated with a gas removal agent.

Preferred as the microporous sorbent particle of the present invention are alumina particles and preferred as the gas removal agent is a permanganate.

5       The present invention is also directed to a method of making such gas sorbing media and to purification assemblies which include such gas sorbing media. A preferred embodiment of such an assembly includes a first or upstream stage which is  
10 provided for removal of particulate matter. The purification assembly includes a second or downstream stage which is provided with a gas-sorbing medium of the type described immediately above.

15       Further, the present invention is directed to a purification system which comprises a particulate assembly for removing particulate contaminants and a sorbent assembly for removing gaseous contaminants. The particulate assembly includes a pleated filter  
20 medium. The sorbent assembly is in fluid communication with the particulate assembly and includes a pleated sorbing medium.

      The present invention is also directed to a purification system for the cabin of an aircraft.  
25 The purification system includes a purification assembly having a housing and two or more pleated modules mounted to the housing. The purification system further includes a ventilation apparatus coupled to the purification assembly and having a  
30 blower arranged to circulate air between the cabin of the aircraft and the purification assembly. In a preferred embodiment, the purification system may further include a particulate assembly for removing particulate contaminants and a sorbent assembly for  
35 removing gaseous contaminants. The particulate

assembly may be positioned upstream from the sorbent assembly to prevent particulates from clogging of the sorbent assembly.

5                    BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the air purification system of the present invention.

Figure 2 is a cross-sectional view of a particulate assembly of the present invention.

10                  Figure 3 is a block diagram of a first embodiment of the air purification assembly of the present invention.

Figure 4 is a block diagram of a second embodiment of the air purification assembly of the present invention.

15                  Figure 5 is a block diagram of a third embodiment of the air purification assembly of the present invention.

Figure 6 is a block diagram of a fourth embodiment of the air purification assembly of the present invention.

20                  Figure 7 is a block diagram of a fifth embodiment of the air purification assembly of the present invention.

25

MODES OF CARRYING OUT THE INVENTION

Depicted in FIG. 1 is an air purification system for the cabin of an aircraft in accordance with the present invention. The system generally comprises a blower 10 for circulating air through the cabin 12 and a duct arrangement, such as an inlet duct 14 and an outlet duct 16, for directing air between the blower 10 and the cabin 12. The cabin, the blower, and the duct arrangement are of the type typically found in an aircraft.

The air purification system further comprises an air purification assembly 18 which is coupled in the duct arrangement between the blower 10 and the cabin 12 to purify air circulated through the cabin 12. The air purification assembly 18 includes a particulate assembly 20 and a sorbent assembly 22. The particulate assembly is especially effective in removing particulate matter, preferably including microorganisms, from a gas, such as air. The sorbent assembly 22 is especially effective in removing odor-causing substances and other undesirable substances from air and/or rendering them innocuous. In FIG. 1, the air purification assembly 18 is illustrated in black box form with the particulate assembly 20 preferably disposed upstream from the sorbent assembly 22.

#### Particulate Assembly

In accordance with one aspect of the invention, the particulate assembly 20 comprises a plurality of removable filter modules 30 disposed in a housing 32. The configuration and dimensions of the housing as well as the configuration, dimensions, and number of the filter modules may vary depending, for example, on the space and air flow requirements of the aircraft. In general the housing 32 may include an inlet side 34 with one or more openings and an outlet side 36 with one or more openings, one or both of which are removably attached to one or more impervious side walls. The housing thus defines a gas flow path from the inlet side to the outlet side. In the illustrated embodiment, the housing is generally configured as a parallelepiped with the inlet side opposite the outlet side.

The filter modules 30 may be variously arranged

within the housing. For example, they may be mounted within the housing so that adjacent modules are parallel to one another and form a generally U-shaped design. Preferably, adjacent filter modules 5 30 are mounted within the housing in a V-shaped design, as shown in Figure 2. In both the U-shaped and the V-shaped designs, each pair of adjacent modules form a bight and an opening which communicates with the inlet openings or the outlet 10 openings of the housing. Adjacent filter modules 30 may be contiguous at one end and spaced from each other at the other end. Further, the filter modules 30 may preferably be arranged in a U- or V-shaped design in which the opening between adjacent filter 15 modules 30 at the inlet side 34 is larger than the opening between adjacent filter modules 30 at the outlet side 36. For example, the distance between adjacent filter modules 30 at the inlet opening may be as much as twice the distance between adjacent 20 filter modules 30 at the outlet opening. Up to 40 or more filter modules may be mounted within the housing.

Each filter module 30 preferably includes a pleated filter panel 38 which defines an envelope 25 configured as a parallelepiped and has an upstream surface which communicates with an inlet opening and a downstream surface which communicates with an outlet opening. Each filter panel 38 includes a porous filter medium for removing particulates, 30 preferably including microorganisms, and may further include a support and/or drainage material along one or both sides of the filter medium. A great variety of porous filter media may be used, including porous foams, porous membranes, and woven or non-woven 35 fibrous materials formed, for example, from a

polymeric material. However, porous filter media for use in aircraft preferably have a prescribed degree of flame resistance and are preferably relatively light weight. Consequently, a preferred  
5 filter medium comprises glass fibers. An example of a suitable filter medium having sufficient flame resistance is a fibrous depth filter medium made of a porous, non-woven, resin-impregnated glass fiber material. However, any other type of porous medium  
10 that is capable of meeting the flame resistance standards set forth for materials for the inside of aircraft can be used.

The effective pore rating of the filter medium may vary and can be chosen based on factors such as  
15 pressure drop across the filter panel, dirt capacity of the filter panel, and the nature of the particulate matter to be removed. The filter medium is preferably at least HEPA rated (i.e., has a minimum efficiency of 99.97% for 0.3  $\mu\text{m}$  particles of  
20 monodispersed dioctylphthalate) and is preferably hydrophobic.

Space within the cabin of an aircraft is severely limited so it is generally desirable to increase the available surface area of the filter  
25 panel 38 within a given envelope. This can be accomplished in a variety of ways, including by using the U- or V- shaped design, increasing the depth of the pleats, or increasing the pitch of the pleats. Preferably, the pleats have a depth of less  
30 than about 1 inch. Most preferably, the depth is about .35 inches. The pitch of the filter panels 38 may be as high as 18 pleats per inch or more. For flimsy filter panels, it can be difficult to maintain separation of the pleats and the structure  
35 of the filter panel. For this reason, one or more

combs 40 may be engaged with the upstream surface and/or the downstream surface of the filter panels 38, as depicted in FIG. 2. Each tooth 42 of a comb 40 is disposed between adjacent pleats to maintain separation of the pleats and immobilize the pleats, and the spine 44 of the comb 40 supports and provides structural integrity to the filter panel. Alternatively, separation can be maintained between the pleats by joining one or more strips of a material, such as a hot melt adhesive, along the peaks of the pleats as disclosed in U.S. Patent No. 5,098,767, which is incorporated herein by reference.

In keeping with the invention, to facilitate easy removal of the filter modules 30 from the housing 32, each filter module 30 further comprises a frame 46 which preferably borders the pleated filter panel. The frame 46 may enhance the structural integrity of the filter module, e.g., by making the module more rigid. Each comb 40 may be attached to the frame 46 to even further enhance the structural integrity of the filter module. The frame may be variously configured, but in the illustrated embodiment it includes four edge members: an inlet edge member 48, an outlet edge member 50, and two end edge members 52, 54. The edge members are preferably sealed to one another and to the pleated filter panel in any convenient manner which prevents bypass of unfiltered air around the pleated filter panel.

The inlet edge member and the outlet edge member may be very similar. For example, each may comprise a pair of opposing L-shaped members 60. One L-shaped member 60 may include a socket 62 at each end while the other includes a post 64 at each

end which may fit within, e.g., snap-fit within, the corresponding socket 62. This post-and-socket relationship may be used to connect and properly position adjacent filter modules 30. Sandwiched  
5 between and bonded to the L-shaped members is a clip member 66 which grips and seals in any convenient manner the flap 67 of the pleated filter panel 38. The clip member 66 may also include a ridge 68 which  
10 attached to the housing, to prevent bypass of the unfiltered air between the filter module and the housing.

The end edge members 52, 54 are preferably joined to the inlet and outlet edge members 48, 50  
15 in any suitable manner which provides a strong, rigid frame to support the filter panel. The end edge members 52, 54, are also joined to the pleated end faces of the filter panel 38 in any suitable manner. For example, the end edge members may be  
20 bonded to the pleated end of the filter panel 38 using a potting compound or an adhesive or a solvent or by melt-bonding or welding the end edge members to the pleated end face. A seal (not shown) may be  
25 coupled between each end edge member 52, 54 and the side wall of the housing to prevent bypass of the unfiltered air between the filter module and the housing.

In the illustrated embodiment, the filter modules 30 are connected to one another by the post-and-socket relationship of the frame members and are  
30 positively sealed to the housing by means of the seals between the frame members and the housing. However, the removable filter modules 30 may be mounted and sealed to the housing in a variety of  
35 ways. For example, opposing frame members may

include ridges which slide within a corresponding pair of grooves in the housing, or vice versa. Further, the seal between each filter module and the housing may be effected by an interference fit  
5 between the filter module and the housing.

#### Sorbent Assembly

In accordance with another aspect of the invention, the sorbent assembly comprises a sorbing  
10 medium which is capable of removing gases, particularly odorous and/or toxic gases, from a flow of fluid such as air. As used herein, the terms "sorbed", "sorbing", etc., refer to various sorption phenomena including absorption and adsorption. The  
15 terms "gas" and "gaseous" particularly as they refer to pollutants include not only those substances normally existing in the gas phase at and somewhat below room temperature but also to the vapors of substances which normally exist as liquids but are  
20 somewhat volatile under similar conditions. The terms "fibers" and "filaments", as used herein, have the same meaning: elongated strands or threads of flexible material.

The sorbing medium preferably comprises a mat  
25 of fibers or filaments and particles of a sorbent material which are impregnated with a gas removal agent and which are bonded to each fiber by an adhesive. The fibers or filaments of the sorbing medium of the present invention may be formed from  
30 polymeric materials, both natural and synthetic. These include polyolefins, such as polyethylene and polypropylene polyesters, polyamides, such as nylon, and cotton. Preferred are polyesters, such as polybutylene terephthalate and polyethylene  
35 terephthalate. Most preferred is polyethylene

terephthalate in a form commercially available as Reemay®. The fibers of the sorbing medium of the present invention may be treated with a fire retardant.

5        Straight, non-porous, continuous fibers are preferred, particularly for the synthetic materials, in contrast to crimped fibers which tend to increase the pressure drop ( $\Delta P$ ) across the sorbing medium. Suitable for use in the sorbing medium of the  
10        present invention are fibers having diameters ranging from about 15  $\mu\text{m}$  to about 40  $\mu\text{m}$ . Preferred are fibers having diameters of about 20  $\mu\text{m}$  to about 35  $\mu\text{m}$  and more preferred are fibers having diameters of about 24  $\mu\text{m}$  to about 28  $\mu\text{m}$ . Most preferred, when  
15        the fibers are formed from the preferred polymeric material, polyethylene terephthalate, are fibers having diameters nominally of about 27  $\mu\text{m}$ . As the diameter of the fibers decreases for a given density medium, the amount of sorbent particles which can be  
20        adhered thereto increases. Such an increase in the number of particles has both positive and negative effects, in that increased amounts of sorbent particles can increase the capacity to sorb  
25        pollutants while also increasing the  $\Delta P$  across the sorbing medium. Assuming mats are formed of about the same density, using fibers having diameters below about 15  $\mu\text{m}$  increases the  $\Delta P$  to a level which is not preferred for the sorbing medium of the  
30        present invention, although the absorption of gaseous components improves. When the diameter of the fibers is greater than about 40  $\mu\text{m}$ , the  $\Delta P$  across a sorbing medium is satisfactory but the sorption of gaseous contaminants is not very high.

35        The mats of a sorbing medium of the present invention are preferably formed as non-woven fibrous

mats. They serve as a matrix or substrate for the sorbent material. When the fibers forming the mat are made of a synthetic material, they are preferably spun-bonded from the synthetic fibers which are randomly arranged. The fibers are also preferably bonded to one another at some of the fiber to fiber contact points or junctions. This is the form particularly preferred for the spun-bonded Reemay® mats. Alternatively, the mats may be formed from mechanically entangled fibers, particularly when naturally occurring materials are used.

Sorbent materials suitable for use in a sorbing medium of the present invention are inorganic, microporous, fine powder sorbents. These include alumina, silica gel, adsorbent clays, such as Fuller's earth and kaolin, zeolites and molecular sieves. Because of its susceptibility to oxidation, and potential combustion in some situations, in the presence of an oxidizing agent such as potassium permanganate, carbon is generally undesirable in the sorbing medium of the present invention. Preferred as the sorbent material is alumina and most preferred are activated, amorphous transition aluminas. Typically, these aluminas have surface areas as measured by the B.E.T. method (described in U.S. Patent No. 4,925,572) of about 250 to about 350 m<sup>2</sup>/g. Preferred are aluminas having a B.E.T. surface area of about 325 m<sup>2</sup>/g.

Suitable for use in a sorbing medium of the present invention are sorbents having particle sizes up to about 35μm. Preferably, the particle sizes of the sorbent materials are, on average, no larger than the diameter of the fibers employed in the web. The preferred ratio of the diameter of the fiber employed to the average particle size is about 3:1.

Microporous sorbent materials having average particle sizes of no more than about 20  $\mu\text{m}$  are preferred and most preferred are those materials wherein about 95% of the particles have particle  
5 sizes of 10  $\mu\text{m}$  or less. The activated alumina preferred in a sorbing medium of the present invention typically has an average particle size of about 3 to about 7  $\mu\text{m}$ .

Suitable pore sizes of the pores in the sorbent  
10 materials of the sorbing medium of the present invention are preferably those which permit sorption of both gases and liquids. Accordingly, the pore sizes preferably range from about 8 to about 100 ångströms and most preferred are those materials,  
15 particularly activated alumina, having pore sizes of about 20 to about 50 ångströms. When a molecular sieve is used, those designated as 13 X, having pore sizes of about 8 ångströms, are suitably employed.

Materials most preferred as the gas removal  
20 agent are those substances which may be introduced to the pores of the sorbent materials without adversely affecting any component of the medium, including the sorbent, the fibrous mat, and the adhesive. Typically, the gas removal agents are  
25 inorganic materials which react with a gaseous component removed from the fluid passing through the sorbing medium by a chemical reaction such as an oxidation/reduction reaction or an acid/base reaction. Such reactions are effective for removing  
30 most odorous and toxic gases. Preferred are alkali metal and alkaline earth metal hydroxides and permanganates. Particularly preferred is potassium permanganate.

When the gas removal agent is potassium  
35 permanganate, the sorbing medium or the sorbent

assembly may be recycled when the potassium permanganate is spent. Generally, the  $\text{MnO}_4^-$  ion is reduced in service to a water insoluble product. However, the insoluble product may be reduced

5 further to a water soluble material which may be easily removed from the sorbing medium. For example, the spent sorbing medium or sorbent assembly may be soaked for a period of about 20 minutes to about one hour in an aqueous solution

10 containing by weight at least 5.0% sodium bisulfate and at least 2.5% oxalic acid in proportions of approximately 2:1, respectively. The sorbing medium or sorbent assembly may then be rinsed and retreated with potassium permanganate.

15 Any adhesive which does not react adversely either with the other components of the system (i.e., the gas removal agent, such as potassium permanganate, the sorbent or gaseous components to which the medium is expected to be exposed) is

20 suitable for use in sorbing medium the present invention. Examples of suitable adhesives include but are not limited to vinyl acetate polymer, latex polymer, and acrylic polymer based adhesives. The latter include derivatives of acrylic acid, such as

25 polymers employing acrylates, methacrylates, acrylamides and acrylic acid polymers as well as copolymers and terpolymers formed from such "acrylic" monomers and other monomers, typically unsaturated monomers, such as styrene. Preferred

30 are those acrylic based polymers available from Rohm & Haas known as Rhoplex® acrylic binders. Particularly preferred is Rhoplex® P-376 which is a styrenated acrylate, more specifically a terpolymer formed from butyl acrylate, styrene and methacrylic

35 acid.

Thus, the gas sorbing media of the present invention include non-woven fibrous mats in which, when synthetic materials are used, preferably the fibers are bonded to one another at fiber to fiber contact points or fiber junctions forming a spun bonded mat. Each of the fibers is adhesively coated with microporous sorbent particles, preferably activated alumina particles. These gas sorbing particles, which are of a very fine average particle size, are impregnated with a gas sorbing or removal agent, preferably potassium permanganate.

The sorbing media of the present invention may be prepared by a relatively simple multi-step procedure. Initially, the sorbent particles and adhesive are added either simultaneously or sequentially to a large vat of water at ambient temperature. The sorbent particles are added at a rate of about 50 to about 100 lbs (about 22.7 kg to about 45.4 kg), preferably about 75 lbs (about 34 kg), per 100 gallons (378.5 liters) of water. The adhesive is added at a rate of about 0.5 to about 1 liter of monomer, preferably about 0.7 liter, per 100 gallons (378.5 liters) of water. The vat, provided with a mixer, is mixed during and after the sorbent material and adhesive are added. When the slurry of adhesive and sorbent particles is adequately dispersed, the mixture is pumped to a second vat where the fibrous mat of the invention is either dipped in a batch treatment process or is fed continuously through the vat in a continuous process. In an alternate procedure, the adhesive and sorbent particle slurry could be sprayed on the mat. The mat is treated at a rate of about 2 to about 4 ounces of sorbent per square yard of mat (about 68 to about 136 g/m<sup>2</sup>), preferably about 3

ounces/yd<sup>2</sup> (102 g/m<sup>2</sup>) when a mat is formed from the preferred 24  $\mu$ m - 28  $\mu$ m fibers. When mats of similar density are prepared, the amount of sorbent used may be adjusted as discussed above. The

5 sorbent-impregnated mat is then dried by placing the mat in or passing it through an oven or heater at a temperature and duration suitable to dry the mat and cure the adhesive. The temperature or range of temperature and time should be sufficient to cure

10 the synthetic polymeric adhesive but not high enough to melt the fibers forming the mat. Typically this is at a temperature of about 200 to about 350°F (about 93 to about 177°C) for about 10 to about 20 hours. Preferably, when the materials used are the

15 preferred polyethylene terephthalate and the acrylic polymeric adhesive Rhoplex® P-376, a temperature of about 240 to about 325°F (about 115 to about 163°C) is used, most preferably a temperature of about 250°F (about 120°C) and a time of about 14 hours is

20 used. Alternatively, when a programmed time and temperature relationship are used, a heating program of 2 hours at 325°F (163°C), 3 hours at 280°F (138°C) and 9 hours at 240°F (116°C) is preferred for the preferred composition discussed immediately.

25 After curing and without rinsing, the sorbent impregnated mat is contacted with an aqueous solution of a gas removal agent, preferably potassium permanganate, either by immersing the mat in a tank of the gas removal agent in a batch

30 process or passing the coated mat through a vat containing the gas removal agent. The concentration of gas removal agent is about 5 to about 10 grams per 100 ml of solution. When using the preferred potassium permanganate, the concentration of the

35 permanganate is about 5 to about 10 g/100 ml.

Preferably a saturated solution (e.g., 6.3 g/100 ml solution at 20°C) of potassium permanganate is employed. After removing the mat from the permanganate solution, the medium is dried without rinsing. The final concentration of potassium permanganate in the medium is, by weight, about 3% to about 7%, preferably about 4% to about 5%, based on the weight of the inorganic sorbent particles.

The treatment of the sorbent-immobilized mat with a gas removal agent may be conducted, like the sorbent immobilization step, either batchwise or in a continuous process by either spraying the solution of gas removal agent onto the sorbent-immobilized mat or by immersing or drawing the sorbent-immobilized mat through the solution of gas removal agent. Preferred periods of immersion or contact between the mat and the solution in a continuous process are about 5 to about 30 minutes, preferably 15 minutes.

When used as a material for sorbing odorous and toxic gases, the sorbing medium of the present invention may be incorporated into filtration units, devices and systems in a variety of configurations and arrangements. Further, the sorbing medium may be provided with a coarse support and/or drainage medium on either or both of the upstream and downstream sides of the sorbing medium to provide flow passages and reduce pressure loss. In its simplest form, the sorbing medium may be used in single uncalendared flat sheets. Alternatively, prior to assembly, the sorbing medium may preferably be calendared and assembled as single or multiple layers or sheets, calendaring taking place either before or after assembly of the plurality of layers or sheets.

Individually, a sorbing medium of the present invention may have thicknesses ranging from about 5 to about 15 mils (about 127 to about 380  $\mu\text{m}$ ). A multilayer sorbing medium of the present invention  
5 may have thicknesses of about 10 to about 30 mils (about 254 to about 762  $\mu\text{m}$ ). A preferred embodiment employs a multilayer sorbing medium consisting of three layers, each layer originally having a thickness of about 10 mils (254  $\mu\text{m}$ ). The 30 mil  
10 (762  $\mu\text{m}$ ) triple-layer sorbing medium is calendared to achieve a final thickness of about 18 mils (457  $\mu\text{m}$ ). This is the preferred rate of calendaring, to achieve a final product of about 50% to about 75% of the thickness of the original uncalendared material.

15 Another preferred embodiment of a sorbing medium of the invention comprises the triple-layer calendared sorbing medium discussed immediately above in which the intermediate layer is perforated. The intermediate, perforated layer may include  
20 apertures of varying shapes. The apertures may be formed as circular or oval holes or as slits or slots. Alternatively, the intermediate layer may be formed of continuous strips juxtaposed in spaced relationship to one another to provide spaces  
25 therebetween. A most preferred embodiment is one which includes a perforated intermediate layer in which up to about 30%, preferably about 10% of the material is removed by hole punching. Preferably the holes range from about 0.25 to about 1 inch  
30 (about 0.65 to about 2.5 cm) in diameter, preferably about 0.5 inch (about 1.25 cm) in diameter.

This arrangement in which the intermediate layer is provided with openings, shows an increase  
35 in the velocity of the gas entering the sorbing

medium in the regions where apertures are provided in the intermediate layer and lower velocities in those regions of the sorbing medium where the intermediate layer is imperforate. The result of providing apertures in the intermediate layer is a lower overall  $\Delta P$  and a longer service life for the medium.

As an alternative to using the flat sheets of a sorbing medium, other configurations may be used in which the sorbing medium is folded or preferably pleated or corrugated. Pleating of the sorbing medium may be performed by an in-line corrugator or a blade type corrugator. Although most of the active surface area which provide the effective gas sorption and treatment is determined by the surface area of the microporous, solid sorbent particles (which includes both the outer surface and the pores of each particle), the surface area of the sorbing medium as a whole is improved by a pleated arrangement. This pleated arrangement may take the form of a pleated panel in which the peaks (and troughs) of each pleat are arranged in a plane. The pleated panel may then be formed into a sorbent module by attaching frame members to the edges of the pleated panel in a manner similar to that described for the filter modules of the particulate assembly.

In an alternative arrangement, the pleats of the pleated sheet may be characterized as "micropleats". The micropleated sheet may then be formed into a macropleated structure in which each leg of the macropleated structure is formed from the micropleated sheet and in which the axes of the micropleats and macropleats are parallel. Such an arrangement, in which the micropleated sheet is

optionally formed with a bending radius no greater than a critical radius and/or is stabilized by a bead of adhesive across the peaks of the micropleats is described in U.S. Patent No. 5,098,767 to

5 Linnersten, which is incorporated herein by reference. In this type of arrangement, the sorbing medium may be sealed within a housing.

The sorbing medium may also be formed into a cylindrical configuration in which the sorbing  
10 medium is arranged coaxially with respect to the axis of the cylinder. In such an arrangement, the sorbent assembly includes endcaps at either end of the cylindrical, sorbing medium one or both of which may be provided with an opening to serve either as a  
15 fluid inlet or a fluid outlet, depending upon whether the device is used for inside-out fluid flow or outside-in fluid flow. In such a sorbent assembly, the sorbing medium may be arranged in a flat cylindrical configuration or a pleated  
20 cylindrical configuration.

#### Air Purification Assembly

An air purification assembly according to the present invention may be embodied in a wide variety  
25 of ways. For example, in one embodiment, the air purification assembly may include a particulate assembly as previously described but not include a sorbent assembly. In another embodiment, the air purification assembly may include a sorbent assembly  
30 as previously described but not include a particulate assembly. In still other embodiments, the air purification assembly may include both a particulate assembly and a sorbent assembly, the sorbent assembly preferably being placed downstream  
35 from the particulate assembly. Generally, the

particulate assembly has a larger surface area and different flow characteristics than the sorbent assembly. Accordingly, by placing the sorbent assembly downstream from the particulate assembly, the particulate assembly can remove particulates from the air which would otherwise quickly foul the sorbent assembly. When the particulates being removed would not easily foul the sorbent assembly, then it is possible for the sorbent assembly to be positioned upstream from the particulate assembly.

In the embodiment of the air purification assembly 18 shown in Figure 1, the particulate assembly 20 and the sorbent assembly 22 may each comprise separate units connected to one another in the duct arrangement. For example, the particulate assembly may be arranged as shown in Figure 2 and the sorbent assembly may be arranged in the micropleat/macropoleat configuration previously described. The housings of the particulate and sorbent assemblies could then be fastened together with the outlet of the particulate assembly communicating with the inlet of the sorbent assembly. Alternatively, the particulate assembly unit and the sorbent assembly unit could be spaced from each other in the duct arrangement.

In other embodiments of the air purification system, the particulate assembly and the sorbent assembly may be integrally combined in a single housing. For example, the filter modules previously described may be combined with the sorbent modules previously described in a variety of configurations. In the embodiment depicted in FIG 3, a plurality of filter modules F are disposed in a multiple V-shaped design and placed within a housing (not shown). At least one sorbent module S is positioned downstream

from each particulate filter module F disposed in the housing. The filter modules F and the sorbent modules S may be connected to each other and/or to the housing in any convenient manner. For example, the modules may be removably mounted to each other and/or to the housing as previously described.

When the air purification assembly is to be employed in an environment where there are a great deal of contaminants to be sorbed, it may be desirable to place more than one sorbent module S downstream from each filter module F as shown in Figure 4. On the other hand, when the air purification assembly is to be employed in an environment where there are few contaminants to be sorbed, it may be desirable to place a smaller sorbent module S downstream from each filter module F, as shown in Figure 5. For example, the surface area of the sorbent module S may be as little as 30% or less of the surface area of the filter module F. To ensure that all of the air which passes through a filter module F also passes through a sorbent module S, the housing may include baffles 100 which direct the air from the filter module F to the sorbent module S.

For the effective purification of cabin air, it is sometimes not necessary that each particulate filter module have a sorbent module associated with it. For example, every other filter module may be associated with a sorbent module. Alternatively, a sorbent module S may be associated with both legs of every other pair of V-shaped filter modules F in the housing, as shown in Fig. 6. In yet another alternative, a sorbent module S is associated with every filter module F but the sorbent module S is smaller than the filter module F, as shown in Fig.

7. All of the air passing through the air purification system shown in Figs. 6 and 7 passes through the filter module F but only part of the air passes through the sorbent module S.

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WHAT IS CLAIMED IS:

1. A purification assembly comprising:  
5 a housing having an inlet side and an outlet side; and a plurality of pleated filter panels mounted in said housing, each panel defining a parallelepiped having opposite upstream and downstream faces communicating with the inlet side  
10 and the outlet side of the housing, respectively, and first and second edge members, each edge member having at least one of a socket and a post, wherein a post of an edge member of one filter panel fits in a socket of an edge member of an adjacent panel.
- 15
2. A purification assembly as claimed in claim 1 wherein said plurality of filter panels include at least first, second, and third pleated filter panels, wherein the first and second filter  
20 panels form a bight and an opening which communicates with the inlet side of the housing and the second and third filter panels form a bight and an opening which communicates with the outlet side of the housing.
- 25
3. A purification assembly as claimed in claim 1 wherein the first and second edge members include first and second L-shaped members and, further comprising a clip disposed between the L-  
30 shaped members to grip a pleated filter panel.
4. A purification assembly comprising:  
a housing having an inlet side and an outlet side; and a plurality of pleated filter  
35 panels mounted in said housing, each panel defining

a parallelepiped having opposite upstream and downstream faces communicating with the inlet side and the outlet side of the housing, respectively, and each panel having a comb engaged with at least one of the upstream and downstream faces, and each panel having a glass fiber filter medium.

5. A purification assembly as claimed in claim 4 wherein each comb has a plurality of teeth and each comb is engaged with a panel such that a tooth is positioned between adjacent pleats to maintain separation of adjacent pleats.

6. A purification assembly as claimed in claims 1 or 4 wherein each pleated filter panel is removably mounted in said housing.

7. A purification assembly as claimed in claim 4 wherein the filter medium includes a non-woven, resin impregnated glass fiber material.

8. A purification system for purifying the air in the cabin of an aircraft comprising:  
a purification assembly including a housing having an inlet side and an outlet side and a plurality of pleated modules removably mounted to said housing; and  
ventilation apparatus coupled to the purification assembly and including a blower arranged to circulate air between the cabin of the aircraft and the purification assembly.

9. A purification assembly as claimed in claim 8, wherein the plurality of pleated filter panels include particulate filter panels and sorbent

filter panels, the particulate filter panels being disposed upstream from the sorbent filter panels.

10. A purification assembly as claimed in  
5 claim 8, wherein a pair of adjacent filter panels are arranged to form a bight and an opening.

11. A purification assembly comprising:  
a particulate assembly for removing  
10 particulate contaminants, said particulate assembly including a plurality of particulate filter panels, each particulate filter panel including a pleated filter medium, and  
a sorbent assembly in fluid communication  
15 with said particulate assembly, said sorbent assembly including a plurality of sorbent filter panels, each sorbent filter panel including a pleated sorbing medium.

12. A purification assembly as claimed in  
20 claim 11 wherein said particulate assembly and said sorbent assembly are integrally combined.

13. A purification assembly as claimed in  
25 claim 12 wherein at least one sorbent filter panel is positioned downstream from each particulate filter panel.

14. A purification assembly as claimed in  
30 claim 12 wherein the surface area of the sorbent filter panels is less than the surface area of the particulate filter panels.

15. A purification assembly as claimed in  
35 claim 11 wherein said particulate assembly includes

a plurality of interconnected V-shaped sections wherein each particulate filter panel forms a leg of a V-shaped section and each particulate filter panel includes a pleated filter medium.

5

16. A purification assembly as claimed in claim 11 wherein each particulate filter panel is removably mounted in said particulate assembly and each sorbent filter panel is removably mounted in  
10 said sorbent filter assembly.

17. A purification assembly as claimed in claim 15 wherein a sorbent filter panel is disposed downstream from each leg of every other V-shaped  
15 section of said particulate filter assembly.

18. A sorbing medium comprising a non-woven fibrous mat, each fiber of which is adhesively coated with inorganic, microporous sorbent particles  
20 predominantly having a particle size no greater than about 35  $\mu\text{m}$ , the sorbent being impregnated with a gas removal agent.

19. A sorbing medium as claimed in claim 18  
25 wherein the fibers includes a polyester material.

20. A sorbing medium as claimed in claim 19 wherein the fibers include polyethylene terephthalate.  
30

21. A sorbing medium as claimed in claim 19 wherein the fibers include polybutylene terephthalate.

35 22. A sorbing medium as claimed in claim 18

wherein the sorbent particles include alumina.

23. A sorbing medium as claimed in claim 18  
wherein the sorbent particles include an adsorbent  
5 clay.

24. A sorbing medium as claimed in claim 18  
wherein the gas removal agent includes permanganate.

10 25. A sorbing medium as claimed in claim 18  
wherein the gas removal agent includes potassium  
permanganate.

26. A method of making a sorbing medium  
15 comprising the steps of:

- (a) contacting a non-woven fibrous mat  
with an adhesive and particles of an inorganic,  
microporous sorbent having particle sizes of  
predominantly not more than about 35  $\mu\text{m}$  to form a  
20 sorbent particle impregnated mat;
- (b) drying and curing said sorbent  
particle impregnated mat; and
- (c) contacting said dried and cured  
sorbent particle impregnated mat with a solution of  
25 a gas removal agent.

27. A method of making a sorbing medium as  
claimed in claim 26 wherein step (a) includes  
contacting the fibrous mat with a slurry of adhesive  
30 and inorganic, microporous sorbent particles.

28. A method of making a sorbing medium as  
claimed in claim 26 wherein step (a) includes  
dipping the fibrous mat in a slurry of adhesive and  
35 inorganic, microporous sorbent particles.

29. A method of making a sorbing medium as claimed in claim 26 wherein step (a) includes spraying the fibrous mat with a slurry of adhesive and inorganic, microporous sorbent particles.

5

30. A method of making a sorbing medium as claimed in claim 26 wherein step (c) includes dipping the sorbent impregnated fibrous mat in the solution of a gas removal agent without rinsing the  
10 sorbent impregnated fibrous mat.

31. A method of making a sorbing medium as claimed in claim 26 wherein step (c) includes spraying the sorbent impregnated fibrous mat with  
15 the solution of a gas removal agent without rinsing the sorbent impregnated fibrous mat.

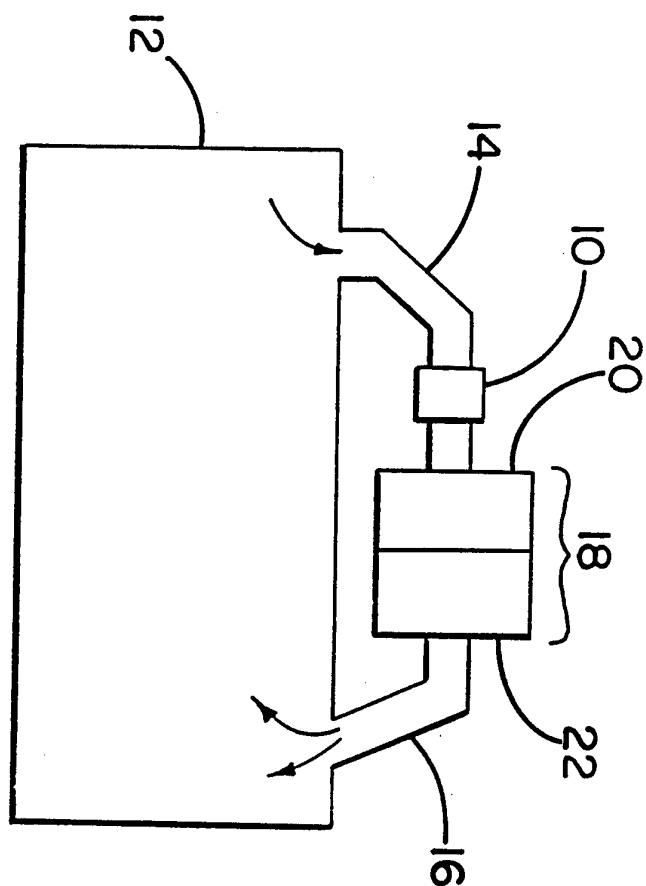
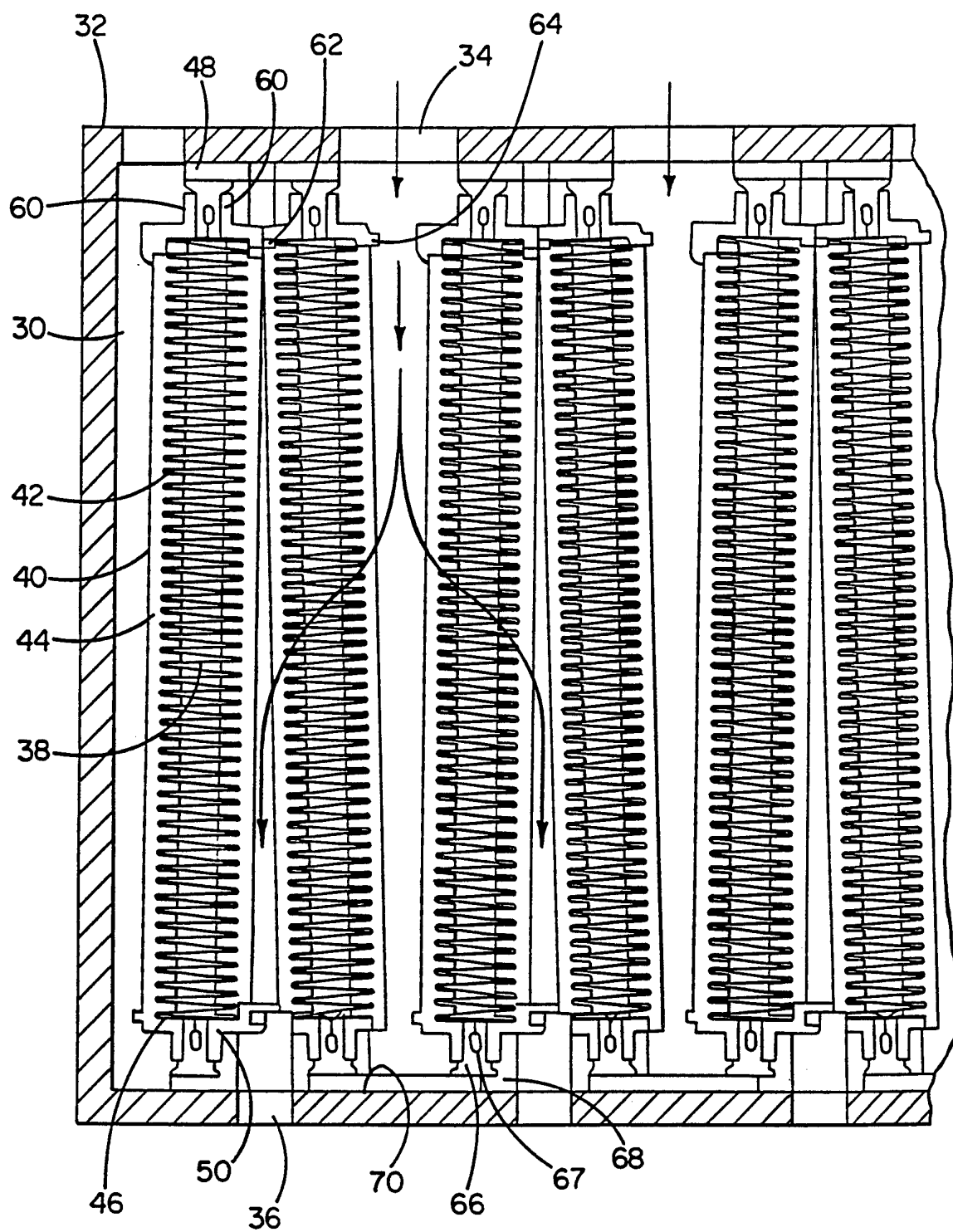


FIG. 1



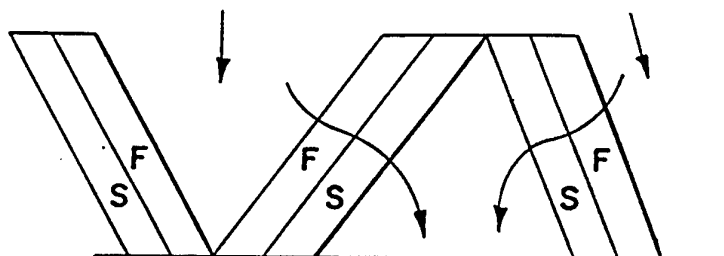


FIG. 3

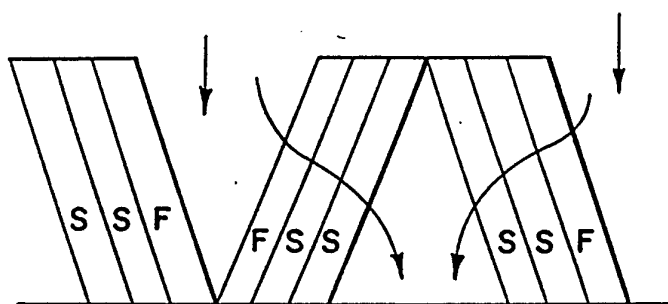


FIG. 4

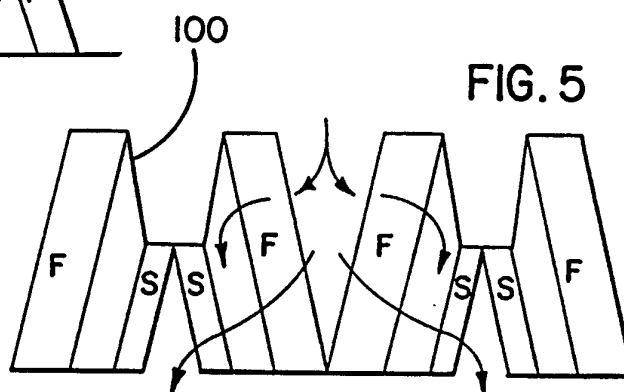


FIG. 5

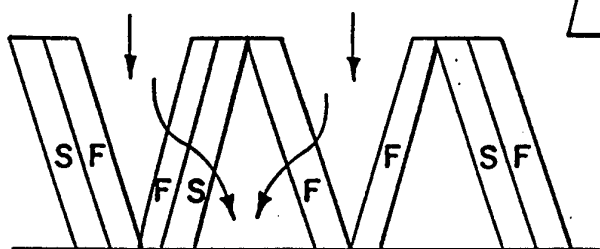


FIG. 6

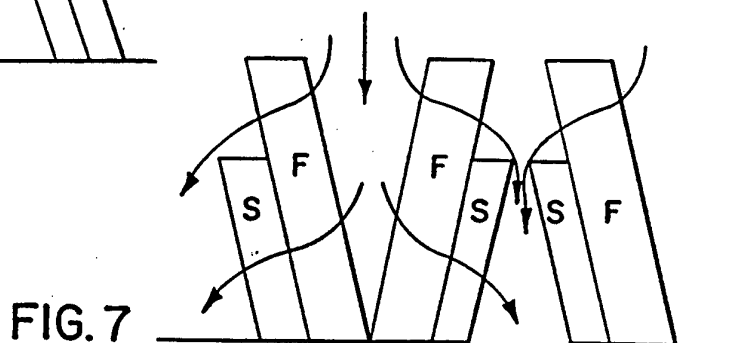


FIG. 7

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US94/02312

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : B01D 35/00, 46/00, 50/00

US CL : 55/486, 497, 501, 521, 524, 528, DIG 5; 96/134, 135, 154

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)

U.S. : 55/486, 489, 497, 501, 504, 521, 524, 528, DIG 5; 96/129, 132, 134, 135, 154

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

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

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GB, A, 880,427 (DRAGER) 18 October 1961, Figs. 1-3.	4,6,7
Y	US, A, 3,631,582 (LUCAS et al) 04 January 1972, col. 3, lines 1-8.	4-6
Y	DE, A, 2,739,815 (SALIE et al) 28 September 1978, Fig. 1.	4-7
A	US, A, 4,225,328 (STIEHL) 30 September 1980, the entire document.	1-17
Y	US, A, 4,289,513 (BROWNHILL et al) 15 September 1981, col. 7, lines 29-53.	18-31
Y	US, A, 4,547,950 (THOMPSON) 22 October 1985, Figs. 1-2.	4-7

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

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

Date of the actual completion of the international search 15 JUNE 1994	Date of mailing of the international search report JUL 05 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer <i>Debbie Will</i> SCOTT BUSHEY Telephone No. (703) 308-0651

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US94/02312

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,553,992 (BOISSINOT et al) 19 November 1985, abstract.	18, 24-25
A	US, A, 4,610,706 (NESHER) 09 September 1986, the entire document.	1-10
Y	US, A, 4,626,265 (ADILETTA) 02 December 1986, col. 4, lines 41-50.	8-17
Y	US, A, 4,909,815 (MEYER) 20 March 1990, abstract.	8-17
A	US, A, 5,098,767 (LINNENSTEN) 24 March 1992, entire document.	4
A,P	US, A, 5,223,011 (HANNT) 29 June 1993, entire document.	1-8, 10