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## (54) Humidifier assembly

(57) The invention provides an assembly of humidification elements (10) for use in a humidifier unit. The elements consist of porous polymeric membranes (1,2) and support materials formed into planar envelope-type or hollow tubular configurations which are treated with a water- and oil repellent organic polymer in such a way that at least a portion of the structure forming the pores is coated with the organic polymer, yet the pore volume and air permeability of the porous materials are only minimally affected. Assemblies having spiral-wound, folded, and parallel arrangements of elements are disclosed.

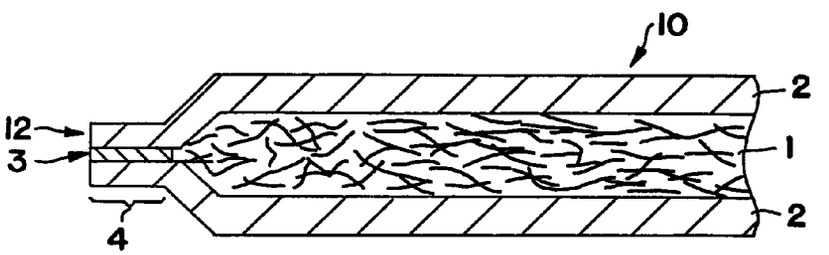



FIG. 1

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## Description

The invention relates to an assembly for humidifying air, more particularly, to an assembly in which elements comprising porous membranes are used to provide humidified air.

For reasons of improved comfort and health, reduction of static electricity, reduction of dimensional changes in buildings and furniture, etc., humidity contol of conditioned air in both living and work spaces has become more common. Many types of equipment which introduce moisture, usually in the form of water vapor or an aerosol, into relatively dry air are known in the art. These types include heated-water humidifiers, natural evapororation humidifiers, spray humidifiers, ultrasonic humidifiers membrane-type, and others. The equipment may be included as a core unit of a central HVAC (Heating, Ventilation, Air Conditioning) system, be remotely located as part of an HVAC system, or independently situated as a separate unit

Humidifiers which use assemblies of polymeric films and membranes to produce humidified air have come under increased investigation because of certain advantages conferred by use of the films and membranes. For example, high working surface area per volume of space oocupied can be obtained; cleanliness, they do not contribute water-borne bacteria, spores, water droplets or aerosol, or other `water-borne particles to the ambient environment; good humidification efficiency at low operating cost can be obtained.

Membrane humidifiers are typically constructed using hydrophobic membranes or films which resist passage of liquid water through them, but are permeable to water vapor. Thus, when such membranes are placed so that liquid water contacts one surface of the membrane, and air to be humidified is passed over the other surface, water vapor transpires through the membrane into the air stream and is carried out of the humidifier. However, despite their promise, membrane humidifiers have not come into widespread use due to certain problems stemming from the structure of their assemblies; and in their ability to operate efficiently for long periods of time. Many of the operational problems arise from the fact that the feed water supplied to a humidifier can vary broadly, from locale to locale, both in composition and quality.

A known construction used to form humidifying elements in membrane humidifiers is an envelope construction, alternatively described in the art as tubular, flattened tube, bag-like, sleeve-shaped, etc., which may be arranged in a spiral-wound or folded assembly within a humidifier unit. Such an element can comprise a hydrophobic porous polymeric membrane formed into an envelope provided with an opening into the hollow interior to receive and discharge water. Usually, a number of parallel ribs, rich bonded to only one of the interior surfaces, are used to separate the interior surfaces of the envelope and to provide a space for liquid water. The envelope-type element can then be arranged, with spacers to permit passage of air interposed between layers, into spiral-wound or folded assemblies. Membrane humidifiers of this type are disclosed in U.S. Patent No. 5,273,689 (to Yokoya, et al.). A drawback to such a construction is that, when the element is filled with water, the envelope sides, in unbonded regions, distend outwardly, thereby constricting the air passages between the layers which leads to reduced air flow through the passage and reduces humidification efficiency. In attempts to overcome this problem a reinforcing fabric or other support has been laminated to the outer surface of the hydrophobic porous membrane. This solution results in somewhat less distortion of the envelope surface, however, it adds cost to the construction and further reduces humidification efficiency by increasing the distance over which water vapor must permeate before entering the moving air stream.

Additional problems are encountered when hydrophobic porous membranes are used with water containing contaminants or other impurities. For example, when the membranes are used with water that contains oil components, such as cutting oils used in piping construction, the oil components attach to the membrane surface and then penetrate to the membrane interior. This can result in plugging or dogging the membrane pores, and an attendant loss in efficiency; or can result in changing the surface energy characteristics of the internal membrane structure, lead to leakage of liquid water through the oil-penetrated sections, and thus introduce noxious water-borne materials into the air stream. Also, after long periods of operation, organic and inorganic impurities (such as minerals and mineral salts, etc,) present in the water can attach and collect on the membrane surface resulting in accumulations and buildups that lower humidification efficiency. To avoid problems associated with low quality water it may become necessary to pretreat the water to remove contaminants and impurities present in it. Such pretreatment can involve extensive additional equipment and is impractical due to high cost.

A method to provide resistance to staining and contamination of hydrophobic porous membranes by low quality water is to coat the surfaces to be water-wetted with a non-porous water-vapor-permeable coating of a hydrophilic polymer. Such materials and methods are disclosed in U.S. Patent No. 5,273,689 (to Hamasaki) and also in U.S. Patent No. 5,318,731 (cited above). These coatings, however, significantly lower the water-vapor-transmission rate (WVTR) from that of the porous membrane. The coatings, furthermore, are air-impermeable and require that means be added to the humidifying element for removal of air from the interior of the element when it is filled with water, and for removal of air bubbles entrained in the water during operation. Such methods require additional materials, increase the number of manufacturing steps, and add complexity and cost to the construction of a humidifier assembly.

This invention provides an assembly for use in a humidifier. The assembly, comprising at least one humidification element, resists harmful influence by water-borne contaminants and impurities, and can be efficiently operated using feed water of variable or relatively low quality.

Each element has a porous wall, which encloses and defines an interior region, and an outer surface. The element has at least one port which provides access to the interior region for passage of air or water, and is sealed at its edges, ends, and ports to prevent leakage. Each element comprises a porous water-vapor permeation layer of porous polymeric material. The porous wall is formed by the water-vapor permeation material, which has a structure defining interconnected pores and passageways wherein at least a portion of the structure is coated with a water- and oil-repellent organic polymer so as to substantially maintain the porosity of the material. Each element is positioned in the assembly so that water, on one side of the wall, and air, on the other side of the wall, can fully contact the porous surface of the wall on their respective sides.

In a preferred embodiment, the humidification element has a planar envelope form, in which the planar length and width dimensions are greater than the thickness dimension. The element further comprises, in its interior region, a core layer of porous material selected from the group consisting of nonwoven fabric, knit fabric, and woven fabric or mesh of synthetic polymers. The porous core layer material has continuous interconnected pores and passageways throughout so that liquid water can penetrate to fill the pore volume of the layer. The porous polymeric water-vapor permeation layer encloses, and is laminated to, the porous core layer, thereby forming the porous wall. The envelope-type element also has at least one port accessing the core layer for passage of liquid water into or out of the core, and is sealed at its edges, ends, and water ports to prevent leakage of water from the core layer. The element is disposed in the assembly so that the outer surface of the element is spaced apart from an adjacent outer surface to form a gap between the layers for passage of air. For example, in the assembly, an element can be arranged in a spiral configuration, a folded configuration, or a number of elements can be arranged in essentially parallel relationship.

In another embodiment of the invention, the humidification element is in the form of a hollow tube.

An embodiment of the invention will now be described with reference to the drawings, in which:-

Figure 1 is a cross-sectional view of a section of an embodiment of a humidification element.

Figure 2 is an exploded perspective view of selected components of an assembly.

Figure 3 illustrates components depicted in Figure 2 assembled in an essentially parallel relationship.

Figure 4 is a perspective view of an assembly in which the humidification elements are arranged in essentially parallel relationship.

Figure 5 is a perspective view of an assembly in which the humidification element is arranged in a spiral configuration.

Figure 6 is a perspective view of an assembly in which the humidification element is arranged in a folded configuration.

Figure 7 is a cross-sectional view of another embodiment of a humidification element.

Figure 8 is a perspective view depicting a method of making the element shown in Figure 7.

Figure 9 is a graph of the humidification performance of a humidifier assembly of the type depicted in Figure 4.

With reference to the figures, the invention will be described in detail.

Figure 1 is a cross-sectional view of a section of an embodiment of a platter envelope-type humidification element. The element 10 comprises a porous core layer 1, on each side of which is laminated a layer 2 of a porous water-vapor permeation material. Over a sealed region 4, seal 3 joins the layers 2 of water-vapor permeation material at the edge 12 of the element 10.

A planar article or form, as used herein, is an essentially flat article or form having length and width dimensions much greater than the thickness direction.

By porous, as used herein, is meant a structure of interconnected pores or voids such that continuous passages and pathways throughout a material are provided.

Figure 2 is an exploded view of components of an assembly having a plurality of elements 10 arranged in essentially parallel relationship. Element 10 is shown having a port 13a therethrough, which provides access to the core layer 1, for passage of water into or from the interior region of the element. Figure 2 further depicts plates 15 having openings 13b therethrough for passage of water. Plates 15 are positioned so that element ports 13a are aligned with plate openings 13b. Plates 15 are tightly bonded to the outer surfaces of elements 10 by adhesive 16, which also forms a seal around the openings 13a, 13b between the plates 15 and elements 10, and a unitary sub-assembly of elements and plates is formed. Corrugated spacers 14 are interposed between adjacent elements 10 to maintain a gap for passage of air to be humidified.

Figure 3 illustrates a sub-assembly 20, formed of the components of Figure 2, prior to installation into a frame or housing. A completed assembly, depicted in Figure 4, includes a housing 21 in which the sub-assembly 20 of humidifier elements is bed and supported, and a connector 22 for passage of water into or from the humidification elements.

Figures 5 and 6 depict embodiments of the invention in which the assembly comprises a single element 10. In Figure 5, element 10 is wound in a spiral configuration beginning at a center winding support 18 and ending near a wall of housing 21 where it is connected to connector 22 for passage of water into or from the humidifcation element. Corrugated spacer 14 is interposed between adjacent outer surfaces of the element 10 to provide a gap for passage of air. Figure 6 shows the element 10 in a folded configuration begininning at one end of housing 21 and extending to the opposite

end where it is connected to connector 22. Corrugated spacer 14 is interposed between adjacent outer surfaces of the element 10 to provide a gap for passage of air.

The frames and housings in which to mount the humidification elements, as well as the spacers, fittings, and hardware required for mounting, can be of materials and designs well known in the an, and are selected and fashioned according to the needs of the end-use application and design of the equipment in which an assembly is used. No particular limitations are imposed on the materials and designs, and none are particularly preferred.

The porous water-vapor permeation material is a composite material comprising a porous polymeric film or membrane which has been treated with a water and oil-repellent organic polymer. The porous membrane can be made of any of a number of synthetic polymers which can withstand long-term continuous contact with liquid water. Polymers such as, but not limited to, polyethylene, polypropylene,or other polyolefins, polyvinyl chloride, polyvinylidene chloride, polyester, fluoropolymers, and the like, are suitable. Fluoropolymers, including tetrafluoroethylene/(perfluoroalkyl) vinyl ether copolymer (PFA), tetrafluoroethylene/hexafluoropropylene copolymer (FEP), and polytetrafluoroethylene (PTFE), polyvinyl fluoride (PVF), polyvinylidene fluoride (PVDF), and the like,are preferred for their processing characteristics, temperature resistance, and chemical inertness. Most preferred are porous membranes of polytetrafluoroethylene.

Porous polytetrafluoroethylene sheet or film suitable for use in the invention can be made by processes known in the art, for example, by stretching or drawing processes, by papermaking processes, by processes in which filler materials are incorporated with the PTFE resin and which are subsequently removed to leave a porous structure, or by powder sintering processes. Preferably the porous polytetrafluoroethylene membrane is porous expanded polytetrafluoroethylene film having a structure of interconnected nodes and fibrils, as described in U.S. Patent Nos. 3,953,566 and 4,187,390 which describe the preferred material and passes for making them.

The porous membrane of the water-vapor permeation material should nave a thickness in the range 5 to 1000 micrometers, preferably in the range 30 to 100 micrometers; and a pore volume in the range 50 to 95 percent, preferably in the range 80 to 95 percent. If the membrane is thicker than about 1000 micrometers, the water-vapor-transmission rate (WVTR) through the membrane may be reduced to undesirable levels. If the membrane is less than about 5 micrometers thick, it may have strength problems which can make it difficult to handle and be relatively easily damaged. Likewise, a pore volume less than about 50 percent may reduce the WVTR to undesirable levels, and a pore volume greater than about 95 percent can result in problems due to diminished strength. The pore size of the membrane must be sufficiently large to permit penetration and coating of its internal structure by the particles of an aqueous latex of a water- and oil-repellent organic chemical, yet should be kept small enough to prevent leakage of water while in operation. The nominal pore size of the membrane should, therefore, be in the range 0.05 to 10 micrometers, preferably in the range 0.1 to 1 micrometer.

As noted above, the structure defining the pores of the porous membrane of the water-vapor permeation material are coated with a water- and oil-repellent organic polymer. No particular limitations are imposed on the polymer as long as it provides acceptable levels of water- and oil-repellency, and can be applied so as to form a coating, on at least a portion of the structure defining the pores of the porous membrane, without causing substantial reduction of the are volume of the membrane, or significantly diminishing air flow through the membrane. Preferred polymers, or copolymers, are those having recurring pendant fluorinated organic side chains, or those having fluorine-containing main chains.

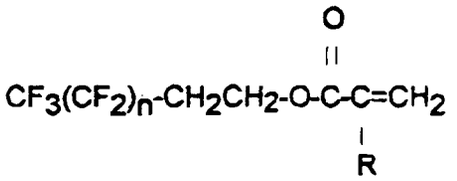
Many such fluorinated polymers are known in the art, and use of such polymers to coat the surface of porous substrates to increase their hydrophobicity is also disclosed in the literature. However, the processes normally used to produce such fluorinated polymers require expensive and/or environmentally-hazardous fluorinated solvents, such as chlorinated fluorocarbon solvents (CFC's). Many of the fluorinated polymers can be prepared by water-based emulsion polymerization, however, water-based emulsion polymerization of such polymers usually yields particles with sizes in the range of 0.1 to 10 micrometers, which are not suited for coating the structure of the porous membrane comprised in the element of the instant invention. It is difficult to obtain uniform coatings on substrates having submicron pore structures with such large particles and, furthermore, such coatings can clog the pores of the submicron pore structures.

The structure defining the pores of the porous membrane can be effectively coated with latex particles of organic polymers having recurring pendant fluorinated organic side chains produced by an aqueous microemulsion polymerization system. The latex particles produced by the microemulsion polymerization system have an average diameter between 0.01 and 0.5 micromoter, preferably between 0.01 to 0.1 micrometer. Such organic fluorinated polymers and the micoemulsion polymerization method used to produce the particles are disclosed in International Patent Application PCT/US93/08884, included herein by reference.

As disclosed in PCT/US93/08884, monomeric microemulsions to produce suitably sized latex particles of organic polymers having recurring pendant fluorinated organic side chains are prepared by mixing water, unsaturated organic monomers having fluoroalkyl groups, fluorosurfactants, and optionally, co-solvents or inorganic salts. The amounts employed are 1-40 weight percent, preferably 5-15 wt.%, organic monomer; 1-40 weight percent, preferably 2-25 wt.%, of the surfactant; with the remainder water.

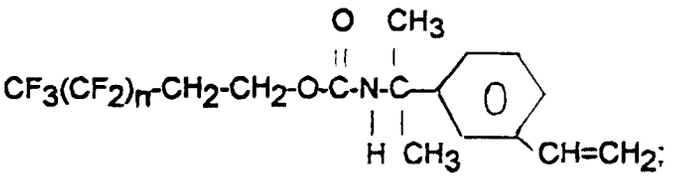
Additional monomers can be present to make the polymers, but the monomers having perfluoroalkyl groups should comprise at least 30 weight percent, preferably 50 wt.%, of the total monomer content Suitable additional monomers include epoxides, carboxyl acids, amines, etc., which have unsaturated moieties.

Representative perfluoroalkyl-containing monomers include fluoroalkyl acrylates and fluoroalkyl methacrylates of the formula:



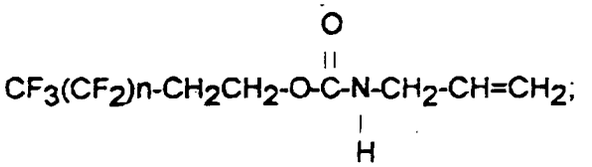
(Formula 1)

fluoroalkyl aryl urethanes, for example



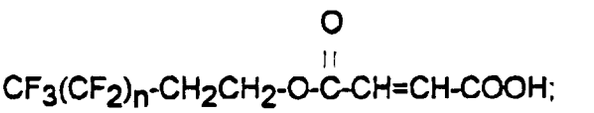
(Formula 2)

fluoroalkyl allyl urethanes, for example



(Formula 3)

fluoroalkyl maleic acid esters, for example



(Formula 4)

wherein n is a cardinal number of 3-13, and R is H or $CH_3$;
fluoroalkyl urethane acrylates; fluoroalkyl acrylamides; fluoroalkyl sulfonamide acrylates and the like. Preferably the fluorinated alkyl moieties will have 6-16 carbon atoms and most preferably 6-12 carbon atoms.

The fluorinated surfactants used have the general formula

$$R_f\ R\ Y\ X,$$

Where $R_f$ is a perfluoroalkyl group or a perfluoroalkylether group with carbon number from 1 to 15 and preferably from 6 to 9, and R is, for example, an alkylene group or an alkylene thioether ($-CH_2-S-CH_2-$) linkage with carbon number from 0 to 4. For fluorinated anionic surfactants, Y is, for example, a carboxylate group (COO-), sulfonic group ($SO_3$-), or sulfate group ($SO_4$-), and X is an alkaline metal ion or ammonium ion. For fluorinated nonionic surfactants, Y is for example an oxyethylene $(OCH_2CH_2)_m$ linkage where m is an integer from 1 to 15 and preferably from 3 to 9 and X is a hydroxyl group. For fluorinated cationic surfactants, YX is, for example, a quaternary ammonium salt.

To make the polymerized microemulsions in a single batch using the monomeric microemulsions described above, the temperature of the emulsion is adjusted to between 5 an 100°C, preferably to between 5 and 80°C, and a free radical producing polymerization initiator is added. Preferred initiators include persulfates; azo initiators, for example, 2,2-azobis; (2-amidopropane) dihydrochloride; peroxides, or photopolymerization initiators such as ultraviolet initiators and gamma ray initiators. The amount of initiators used can range from 0.01 to 10 percent by weight based on monomer content.

Cosolvents such as an alcohol, amine or other amphiphilic molecule or salt can be employed, if desired, to facilitate formation of the microemulsion.

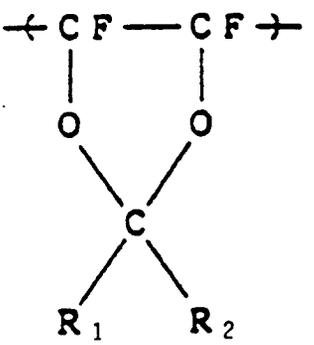
Introduction of the initiator generally causes polymerization of the monomer to begin and the reaction proceeds. The resulting polymer particle latex has an average particle size of between 0.01 to 0.5 micrometer and a polymer average molecular weight of over 10,000, preferably over 20,000 or 50,000. The unusually small particle size provides a polymer system with a number of advantages over systems containing larger particles. The system is a colloidal dispersion and is usually clear rather than turbid. The small latex particle size aids in producing thin coatings of uniform thickness which maintains good gas permeability of porous substrates. The highly fluorinated nature of the pendant groups in the polymer chain aids in increasing the hydrophobicity and oleophobicity of the substrates to which the polymer is applied.

The polymer is manufactured in such a way that the polymer concentration of the aqueous latex is usually in the range 2 to 25 percent, preferably about 5 to 10 percent. Application of the dispersion to the porous membrane can be carried out directly from the aqueous colloidal dispersion by immersion, by roll coating, by painting, by spraying, or other conventional method; and it can be diluted, if desired, to facilitate application to the porous substrate.

It is also possible to apply the monomeric microemulsion containing a photopolymerization initiator to a substrate, and polymerize the microemulsion after the substrate has been coated.

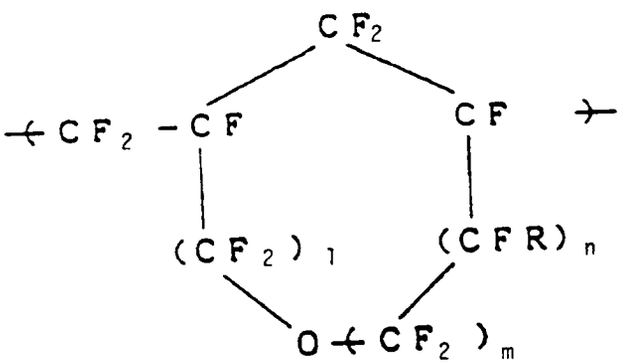
After the dispersion has been applied to the membrane or other porous substrate, any water, surfactant, or initiator remaining can be drawn off by any convenient means, such as steam stripping, vacuum evaporation, or the like; or by heating, using forced hot air, infrared radiation, heated rolls, and the like, to a temperature of about 150 to 250°C. The heat treatment can also be used to melt any latex particles remaining in the pores and cause them to flow onto the structure defining the pores.

Other fluorinated organic polymers, when prepared in aqueous dispersions having latex particle diameters in the range of 0.01 to 0.5 micrometer, can also be used as the water- and oil-repellent organic polymer. For Example, fluorinated polymers that have alicyclic structures in their main chains, exemplified by Formulas 5, 6, and 7, can be used.



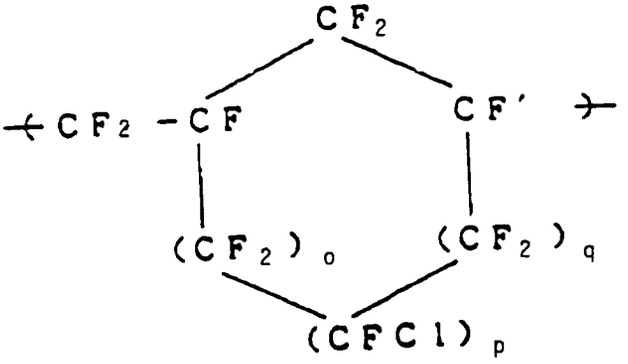
(Formula 5)

wherein $R_1$ is F or $CF_3$, and $R_2$ is F or $CF_3$;



(Formula 6)

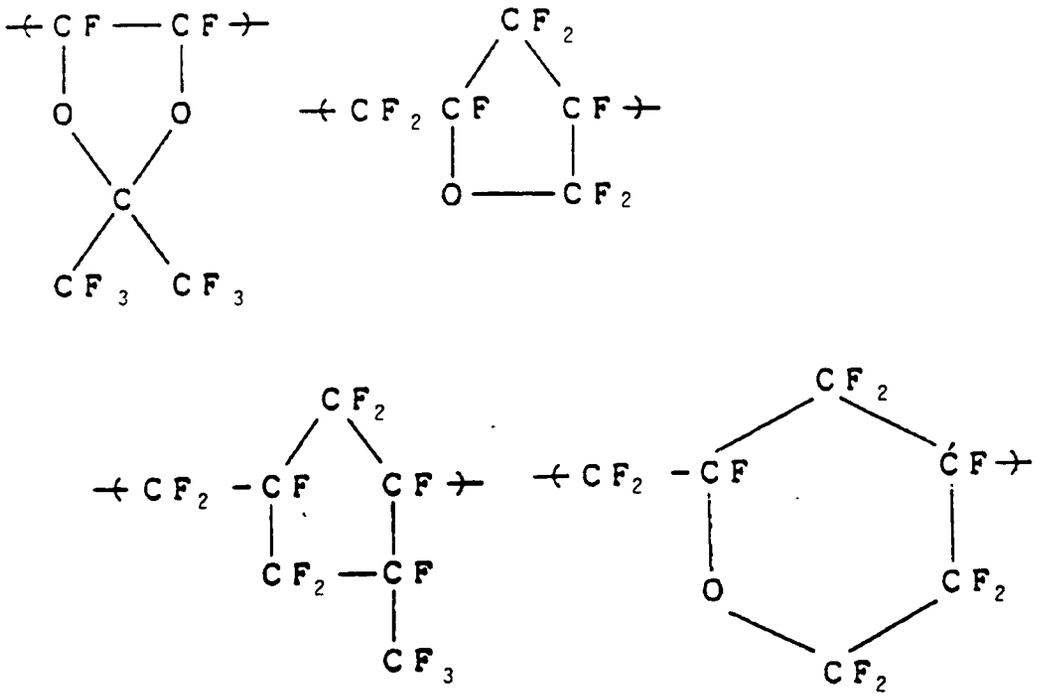
wherein l is 0 to 5, m is 0 to 4, n is 0 to 1, l + m + n is 1 to 6, and R is F or CF3;



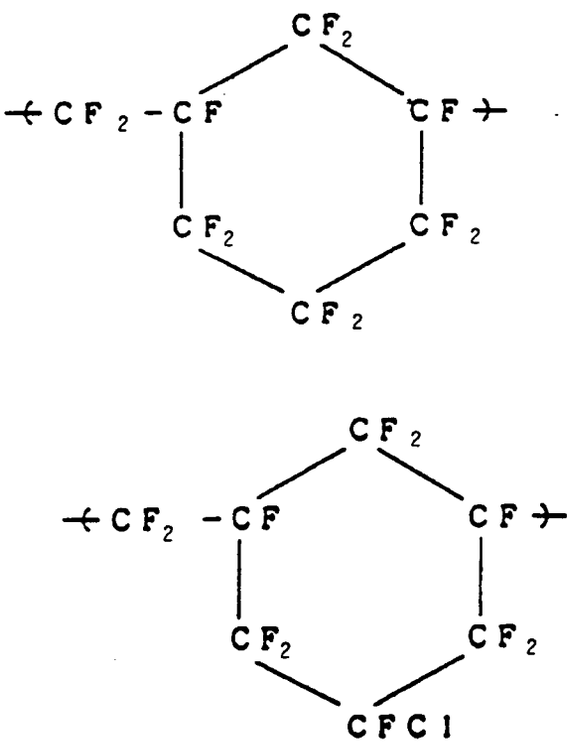
(Formula 7)

wherein o, p, and q are each 0 to 5, and o + p + q is 1 to 6;
Also suitable are fluorine-containing polymers having cyclic structures, such as those expressed by Formulas 8 and 9.

(Formula 8)



(Formula 9)



There are also commercially available fluorinated polymers which can be used. For example, TEFLON AF® Amorphous Fluoropolymer, manufactured by DuPont Co, and CYTOP® Fluoropolymer, made by Asahi Glass Co.

The core layer 1 of the embodiment of the envelope-type element 10 shown in Figure 1 forms and defines the interior region of the element after a layer 2 of the water-vapor permeation material has been laminated to each side of the core layer, and a seal 3 formed around it. The corn layer, also, can be made of any of a number of synthetic polymers which can withstand long-term continuous contact with liquid water. Polymers such as, but not limited to, acrylics, acetates, polyamides, polyesters, polyolefins, and the like, are suitable. The core layer 1 has a planar form and should have a structure that provides strength, compliance and flexibility in the x, y, and z directions (respectively length, width, and thickness directions). Examples of such structures are nonwoven fabrics, knit fabrics, and woven fabrics or mesh. The core layer 1 should be in the range 1 to 10 mm thick, preferably 2 to 5 mm thick. Non-woven fabrics are preferred, and should have a fabric weight in the range 20 to 1000 g/m$^2$, preferably in the range 200 to 300 g/m$^2$.

Lamination of the water-vapor permeation material 2 to the core layer 1 can be done using conventional methods and equipment, for example, by adhesive bonding. The adhesive can be applied to the surface to be bonded of either layer, and should be applied in a non-continuous pattern. A non-continuous pattern of adhesive is used herein to indicate a layer of adhesive which is applied to a surface so as to not form a non-porous continuous film. For example, a layer applied to a surface as a pattern of discrete dots, a porous non-woven web or mesh, or the like.

The adhesive maybe selected from many known in the art. The adhesive can be a thermoplastic, thermosetting, or reaction curing type, in liquid or solid form, selected from the classes including, but not limited to, polyamides, polyacrylamides, polyesters, polyolefins, polyurethanes, and the like. The adhesive should be applied so that it forms a porous (non-continuous) gas-permeable layer which minimizes resistance to air flow while strongly adhering the porous outer water-vapor permeation layer 2 to the porous core layer 1. Preferably, the adhesive is applied so as to ever about 30 percent or less of the surface. Suitable application means include gravure printing, spray coating, powder coating, interposing a non-woven web of adhesive, and the like.

The seal 3 in the seal region 4 around the periphery 12 of the element can also be accomplished using conventional methods and equipment, except in this case bonding of the materials to be joined is done in such a way as to form a non-porous seal region to prevent leakage of water contained in the core layer. The seal can be effected, for example, by application of a continuous bead or film of adhesive in the seal region and pressing the layers together. Adhesives of the types described above can also be used for this purpose. Alternatively, if heat-bondable materials are used in the element construction, by application of heat and pressure in the seal region to thermally fuse the materials together, a non-porous seal region can be formed.

The planar core layer 1, adhered on each side to the inward facing surfaces of the water-vapor permeation layers 2 by a large number of small, relatively closely spaced bend sites, provides uniform support to the water-vapor permeation layers and prevents the water-vapor permeation layers from distending or ballooning into the air passage gap when subjected to normal hydrostatic operating pressure. Thus, additional outer layers of reinforcing fabrics to restrain the water-vapor permeation layers are not needed. Furthermore, the porous core layer of non-woven fabric, knit fabric or woven fabric, provides more uniform support in all directions and is inherently more flexible and compliant in the z-direction than a longitudinal parallel array of ribs of solid polymeric rods. This is particularly advantageous for elements prepared in long lengths for use in an assembly in a spriral-wound, folded or pleated configuration, since, when bending the elements around a small radius to maximize space utilisation of such configurations, bending stresses are largely accommodated by the core layer and not transmitted to the water-vapor permeation layers. Solid polymeric ribs, although bendable in their longitudinal direction, provide no compliance in the z-direction (thickness) which can lead to damaging stresses in the water-vapor permeation layers when bent around a small radius curve when an element is formed in a folded or pleated configuration. The ribs, spaced relatively far apart, provide little support to the water-vapor permeation layers in the y-direction (width) in the space between the ribs, which can lead to distending or ballooning of the water-vapor permeation layers into the air passage spaces when water pressure is applied to the element.

In another embodiment, the humidification element has a hollow tubular form, as shown in Figures 7 and 8. Figure 7 is a cross-sectional view of a hollow tubular humidification element. The hollow tubular humidification element 30 depicted is formed by wrapping a porous composite laminated material 37 so as to form a tube having a hollow inner region 39 surrounded by a porous wall. The porous composite laminate 37 comprises an outer layer 32 of a porous polymeric membrane, treated with a water-and oil-repellent organic polymer, laminated to an inner porous support material layer 31. The material forming the porous wall of the tube is overlapped to form a bonding region 34. A seal 33 can be formed between the overlapped sections.

In Figure 8 is shown a method of forming a hollow tubular element in which a tape of the porous composite laminate 37 is helically wrapped on a mandrel 38 so as to form a helical overlap in which to form a bonded region 34. Another method of forming a hollow tubular element is to wrap a sheet of the porous composite laminate, as in a cigarette wrap, so that the overlapped and sealed regions are parallel to the longitudinal axis of the tube. Figures 7 and 8, for simplicity, depict tubes formed by a single wrap, however, multiple wraps can also be used to form a porous tubular humidification element. In the case of tubular elements formed by multiple wraps, a continuous watertight seal in the overlap of at least one layer must be formed, but need not be formed in each layer.

The porous polymeric membrane used in the hollow tubular element can be made of the same materials described hereinabove in the section relating to the envelope-type element. Likewise, the treatment of the porous membrane with

a water-and oil-repellent organic polymer is done using the same polymers and methods described earlier. The porous membrane of the tubular element can be coated with the organic polymer before or after it is laminated to the porous support material. The porous support material of the hollow tubular element, in like manner, is preferably made of the materials described above relating to the core layer of the envelope-type humidification element.

Assemblies comprising hollow tubular elements can be of the same general forms described for those comprising envelope-type humidification elements, i.e., single or multi-tube element arrangements in spiral-wound, folded, or parallel configurations. Moreover, the assemblies can be configured so that water is contained inside the hollow element, with air passing over the outer surface; or vice versa, so that water is contained within the assembly housing, and air passes through the hollow tubular element. As with the assemblies described earlier, the frames and housings in which to mount the humidification elements, as well as the spacers, fittings, and hardware required for mounting, can be of materials and designs well known in the art, and are selected and fashioned according to the needs of the end-use application and design of the equipment in which an assembly is used. No particular limitations are imposed on the materials and designs, and none are particularly preferred.

Test Procedures

Waterproofness Test

Samples of materials are tested for waterproofness by using a hydrostatic test method, JIS L1092, para 5.1 Technique B, which is a water entry pressure (WEP) challenge. The test consists essentially of forcing water against one side of a test piece, and observing the other side of the test piece for indications of water penetration through it.

The pressure at which the first appearance of water through the specimen is noted and recorded. The hydrostatic resistance of the sample material is the average of the results obtained from the specimens tested, and is reported in $kg/cm^2$.

In a modification of the test, referred to hereinbelow as the Cutting Oil Test, a 10% solution of a water-soluble cutting oil (Miyagawa 50W, made by Miyagawa Co.) is used in lieu of water.

Air Permeability Test (Gurley Number)

The air permeability of samples was measured using an Oken-type air permeability tester, in accordance with Standard Test Method JIS L1096, Technique B, para. 6.27.

The results are reported in terms of Gurley Number, which is the time in seconds for 100 cubic centimeters of air to pass through 1 square inch (6.45 $cm^2$) of a test sample at a pressure drop of 4.88 inches of water (12.4 cm).

Moisture Permeability Test

The water-vapor transmission rate (WVTR) through a sample was measure in accordance with Standard Test Method JIS L1099, Method B of item 4.2 (Potassium Acetate Method). Test results are reported in $g/m^2/24$ hours.

Particle Size Determination

Quasielastic light scattering was used to determine particle size. Microemulsion samples obtained as described in the examples were diluted with water to 100 times the original volume to eliminate interparticle interactions. Quasielastic light scattering cumulant functions were measured at a scattering angle of 90°. Correlation functions were used to determine the apparent diffusion coefficent, which was assumed to correspond to the reported particle size via the Stokes-Einstein relation. The solvent viscosity was assumed to be that of water.

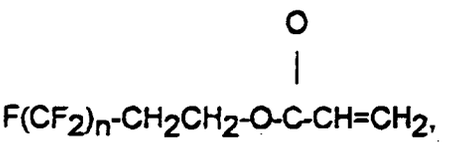
Molecular Weight

Molecular weight was determined after precipitating and washing the polymer with acetone. The washed polymer was dissolved in Fluorinert® FL-75 at 50°C. Molecular weight and polymer concentration were determined at room temperature using a differential refractometer instrument. The instrument records the light scattered intensity at a scattering angle of 90°, and this value is related to polymer molecular weight using the principles of classical light scattering.

**Example 1**

Forming a microemulsion latex of a fluorinated organic polymer:

In a 100 milliliter glass reactor, 10 gram of fluoroacrylate, namely,



(Zonyl® TA-N, manufactured by DuPont Co.), 15 gram of ammonium perfluorooctanoate, and 70 gram of distilled water were charged and heated to 70°C with stirring. A clear microemulsion with a light green color formed. Then, 0.1 gram of potassium persulfate in 5 gram of distilled water was charged into the reactor to initiate polymerization. Polymerization proceeded for about one hour at 70°C. At that time the mixture was cooled to room temperature. A clear latex was produced which was stable for at least 24 hours at room temperature. The average particle size of the latex was determined to be about 0.03 miorometer by quasielastic light scattering. The weight average molecular weight of the polymer produced was determined to be above 1,000,000 by classical light scattering techniques.

**Example 2**

Forming a microemulsion latex of a fluorinated organic polymer:

In a 100 milliliter glass reactor, 10 gram of fluoromethacrylate (Zonyl® TM from Du Pont Co), 20 gram of ammonium perfluorooctanoate, and 65 gram of distilled water were charged and heated to 75°C with stirring. A clear microemulsion with a light green color formed. Then, 0.1 gram of ammonium persulfate in 5 gram of distilled water was charged into the reactor to initiate polymerization. Polymerization proceeded for about one hour at 75°C at which time the mixture was allowed to cool to room temperature. A clear latex was produced which was stable for at least 24 hours at room temperature. The average particle size of the latex was determined to be about 0.03 micrometer by quasielastic light scattering. The weight average moleoular weight was determined to be over 1,000,000 by classical light scattering techniques.

**Example 3**

Forming a microemulsion latex of a fluorinated organic polymer:

A mixture of fluorinated monomer, hydrogenated monomer, fluorinated surfactant, and hydrogenated surfactant was employed.

In a 100 milliliter glass reactor, 4 gram of fluoroaoylate (Zonyl® TA-N, from Du Pont Co., trade name), 2 gram of styrene (from Aldrich Chemical Co.), 3 gram of ammonium perfluorooctanoate and 7 gram of sodium dodecylsulfate (from Aldrich Chemical) and 80 gram of distilled water were charged and heated to 70°C with stirring. A microemulsion formed. Then, 0.07 gram of a cationic initiator (from Wako Co., trade name V-50) in 5 gram of distilled water was charged into the reactor to initiate polymerization. Polymerzation proceeded for about two hours at 70°C. A translucent latex was produced and on cooling was stable for at least 24 hours at room temperature.

**Example 4**

Preparing a water-vapor permeation material:

A porous polytetrafluoroethylene (PTFE) membrane (expanded microporous PTFE membrane, provided by Japan Gore-Tex Inc.) was coated with the latex produced in Example 1 which had been diluted threefold with distilled water. The PTFE membrane had a pore volume of 80 percent, a nominal pore size of 0.2 micrometer, and was 50 micrometers thick. Air permeability of the PTFE membrane was Gurley Number 10.

The coating procedure was to immerse the porous membrane into the diluted latex and let excess fluid drip off. Then the coated membrane was placed in an oven at 225°C for 3 minutes. During the drying process, water and the fluorinated surfactant were removed from the membrane and the fluorinated polymer melted and flowed to coat the

structure forming the pores of the membrane. The coated membrane had a Gurley number of 11 seconds, indicating that the porosity was substantially unchanged by the coating.

Samples of the coated membrane and an uncoated, but otherwise identical, membrane were tested as follows:

Test pieces of each membrane were subjected to the Cutting Oil Test described earlier.

A bag, about 10 cm long by 10 cm wide, was formed from each membrane. The bag was filled with tap water, after which 60°C heated air was passed over the bag surface to entrain water vapor evaporated through the porous wall of the bag. Tap water was supplied continuously to the bag until 50 liters of water had been evaporated (approximately 250 cc water per square centimeter of wall surface). Portions of the bag wall on which substances contained in the water were deposited were subjected to the Waterproofness Test and Moisture Permeability Test described hereinabove. The test results are shown in the following table.

| | Treated Membrane | Untreated Membrane |
|---|---|---|
| Cutting Oil Test, kg/cm$^2$ | 0.152 | 0.000 |
| Waterproofness, kg/cm$^2$ | 4.105 | 0.013 |
| Moisture Permeability, g/m$^2$/day | 71005 | 70210 |

**Example 5**

Preparing a humidification element and a spiral-wound assembly:

A water-vapor permeation membrane, prepared as described in Example 4 was laminated to each side of an acrylic fiber nonwoven fabric (thickness: 3 mm; weight: 50 g/m$^2$). A pattern of discrete dots of a polyurethane adhesive, covering about 30 percent of the surface, was gravure printed on one side of the water-vapor permeation membrane. The nonwoven fabric was superposed on the printed surface of the membrane and the two layers were press-bonded together using a roller at about 3 kg/cm$^2$ applied pressure and a speed of about 5 m/min. The lamination steps were repeated to bond a water-vapor permeation membrane to the opposite side of the nonwoven fabric. A tube for passage of water was attached at one end, and the edges were sealed by application of heat and pressure to fuse the materials together to form a non-porous seal region and complete the humidification element. In use as a humidification element, i.e., with water contained in the nonwoven fabric core layer, the structure described had a water-vapor-transmission rate (WVTR) of 50,000 g/m$^2$/24 hrs.

A humidification element having the above structure, 46 mm wide and 15 meters long, was combined with a corrugated polyethylene spacer having the same width and length to form a spiral-wound assembly of the type shown in Figure 5. The corrugated space interposed between adjacent surfaces of the element, had corrugations 2.5 mm high and a pitch of 6.2 mm.

Hot, dry air (40°C, 15% relative humidity) was passed through the assembly across the surfaces of the humidification element at a speed of 2 meters/ second. The air pressure drop across the assembly was stable at 5 micrometers of water, and a humidification rate of 1 kg (water)/hour was maintained. Water containing 0.1% cutting oil (Miyagawa 50W) was fed into the element and no leaks were noted.

**Example 6**

Preparing an assembly having multiple parallel elements:

Referring to Figures 1, 2, 3 and 4, humidification elements 10 (width: 46 mm; length: 990 mm; thickness 2 mm) were prepared as described in Example 5. A seal 3 was formed by application of heat and pressure around the perimeter 12 of the element Water passage ports 13a (6 mm diameter) through each element were made near an end of each element Polyvinyl chloride (PVC) plates 15 (width: 45 mm; length: 46 mm; thickness: 3 mm) were attached to each side of each element 10 with water passage ports 13a aligned with openings 13b through the PVC plates, except for the end plate which had no opening for water passage. The elements 10 and plates 15 were bonded, and a seal formed around the water passage ports, by PVC adhesive 16. Polyethylene corrugated spacers 14 (width: 45 mm; length: 945 mm; height: 2.5 mm; pitch 6.2 mm) were placed on rich side of the elements to provide a gap for passage of air across the element surfaces. A sub-assembly 20 having 25 humidification elements was thus prepared.

The sub-assembly 20 was mounted in a housing 21, made of galvanized steel sheet and having outer dimensions of about 1000 mm x 150 mm x 50 mm. A tube connector 22 was provided in the housing for connection and passage of water to the sub-assembly.

Water was supplied to the completed assembly and the unit was tested by directing air (45°C; 20% RH) through the unit at a speed of 1.5 meters/second. A humidification capacity of 1.5 liters (water)/ hour was recorded. Air pressure drop across the unit did not exceed 7 Pa. The unit was also tested at other conditions and the results are shown in Figure 9, which is a graph of humidification capacity versus air temperature.

**Example 7**

Preparing a hollow tubular humidification element:

A nonwoven fabric of polypropylene fibers (thickness: 100 micrometers; weight: 125 g/m$^2$) was bonded to a porous membrane of PTFE (thickness: 50 micrometers; pore volume: 80 percent; nominal pore size: 0.2 micrometer) by application of heat and pressure in passing through the nip between heated rolls to form a laminated composite sheet. The laminated composite sheet was slit to form 25 mm wide tape. The tape was wrapped on a mandrel in a helical fashion to form the first layer of a tube, each wrap overlapping a portion of the preceding wrap. The nonwoven polypropylene fabric in the overlapping region was heat bonded and sealed to the underlying wrap by hot forced air from a heated nozzle. Two successive layers of the composite tape were applied in the same way to form a porous tube with an inside diameter of 12 mm and a wall thickness of 0.5 mm. The porous portions of the tube were then impregnated with an aqueous latex of the type described in Example 1, and dried at 225°C, thereby completing the hollow tubular humidification element.

For comparative purposes, a second tube was made in the same manner and of the same materials, except that it was not treated with a water- and oil-repellent organic polymer.

Sections of each tube were cut, and slit axially to provide flat samples for testing. The samples were subjected to the Cutting Oil Test, Moisture Permeability Test, and Air Permeability Test. The results are shown in the following table.

| | Treated Membrane | Untreated Membrane |
|---|---|---|
| Cutting Oil Test, kg/cm$^2$ | 0.201 | 0.006 |
| Moisture Permeability, g/m$^2$/day | 24,100 | 20,100 |
| Air Permeability, Gurley No. | 152 | 150 |

## Claims

1. An assembly for a humidifier unit, said assembly having at least one humidification element,

   each said element having an interior region, a porous wall enclosing and defining said interior region, an outer surface, and having at least one port which provides access to said interior region for passage of air or water, said element sealed at its edges, ends, and ports to prevent leakage;

   each said humidification element comprising a porous water-vapor permeation layer of porous polymeric material, said water-vapor permeation material having a structure defining interconnected pores and passageways wherein at least a portion of said structure is coated with a water- and oil-repellent organic polymer, and wherein the porosity, of said water-vapor permeation material is substantially maintained;

   each said element disposed in said assembly so that water, on one side of said wall, and air, on the opposite side of said wall, fully contact the porous surface of said wall on their respective sides.

2. The assembly for a humidifier unit as recited in Claim 1, wherein each said element has essentially a planar envelope form, the planar length and width dimensions greater than the thickness dimension;

   each said element further comprising a core layer of porous material selected from the group consisting of nonwoven fabric, knit fabric, woven fabric or mesh of synthetic polymers, said porous core material having continuous interconnected pores and passageways throughout whereby liquid water can penetrate to fill the pore volume of the layer;

   said porous water-vapor permeation layer of porous polymeric material being laminated to the opposed planar surfaces of said porous core layer,

   said element having at least one port which provides access to said core layer for passage of water, and said

element sealed at its edges, ends, and water ports to prevent leakage of water;

said element disposed in said assembly so that said outer surface is spaced apart from an adjacent outer surface so as to form a gap between said surfaces for passage of air.

3. The assembly for a humidifier unit as recited in Claim 2, wherein the water- and oil-repellent organic polymer is an aqueous latex in which particles of an organic polymer having recurring pendant perfluorinated organic side chains are present and in which the particles have an average size between 0.01 and 0.5 micrometers.

4. The assembly for a humidifier unit as recited in Claim 3, wherein the organic polymer comprises a polymer selected from the group consisting of polymers derived from fluoroalkyl acrylates, fluoroalkyl methacrylates, fluoroalkyl aryl urethanes, fluoroalkyl allyl urethanes, fluoroalkyl maleic acid esters, fluoroalkyl urethane acrylates, fluoroalkyl acrylamides, and fluoroalkyl sulfonamide acrylates.

5. The assembly for a humidifier unit as recited in Claim 2, wherein the porous water-vapor permeation material comprises porous expanded polytertrafluoroethylene.

6. The assembly for a humidifier unit as recited in Claim 3, wherein the porous water-vapor permeation material comprises porous expanded polytetrafluoroethylene.

7. The assembly for a humidifier unit as recited in Claim 4, wherein the porous water-vapor permeation material comprises porous expanded polytetrafluoroethylene.

8. The assembly for a humidifier unit as recited in Claim 1, wherein each said element has essentially a hollow tubular form.

9. The assembly for a humidifier unit as recited in Claim 8, wherein the water- and oil-repellent organic polymer is an aqueous latex in which particles of an organic polymer having recurring pendant perfluorinated organic side chains are present and in which the particles have an average size between 0.01 and 0.5 micrometers.

10. The assembly for a humidifier unit as recited in Claim 9, wherein the organic polymer comprises a polymer selected from the group consisting of polymers derived from fluoroalkyl acrylates, fluoroalkyl methacrylates, fluoroalkyl aryl urethanes, fluoroalkyl allyl urethanes, fluoroalkyl maleic acid esters, fluoroalkyl urethane acrylates, fluoroalkyl acrylamides, and fluoroalkyl sulfonamide acrylates.

11. The assembly for a humidifier unit as recited in Claim 8, wherein the porous water-vapor permeation material comprises porous expanded polytetrafluoroethylene.

12. The assembly for a humidifier unit as recited in Claim 9, wherein the porous water-vapor permeation material comprises porous expanded polytetrafluoroethylene.

13. The assembly for a humidifier unit as recited in Claim 10, wherein the porous water-vapor permeation material comprises porous expanded polytetrafluoroethylene.

14. The assembly for a humidifier unit as recited in Claim 1 wherein said element is disposed in a spiral configuration.

15. The assembly for a humidifier unit as recited in Claim 1 wherein said element is disposed in a folded configuration.

16. The assembly for a humidifier unit as recited in Claim 1 wherein a plurality of said elements is disposed in essentially parallel relationship.

17. The assembly for a humidifier unit as recited in Claim 2, wherein a plurality of said elements is disposed in essentially parallel relationship,

each said element having, on each planar surface facing an adjacent element, at least one port accessing said interior region for passage of water,

said ports being in linear alignment throughout said assembly;

said assembly further comprising a plurality of flat plates, each said plate having an opening therethrough for passage of water,

said plates interposed between said ported element surfaces with said openings in alignment with said ports,

said plates tightly bonded to each adjacent element surface, thereby forming a seal around each said port, and providing a unitary sub-assembly of joined elements and plates to facilitate installation in said assembly.

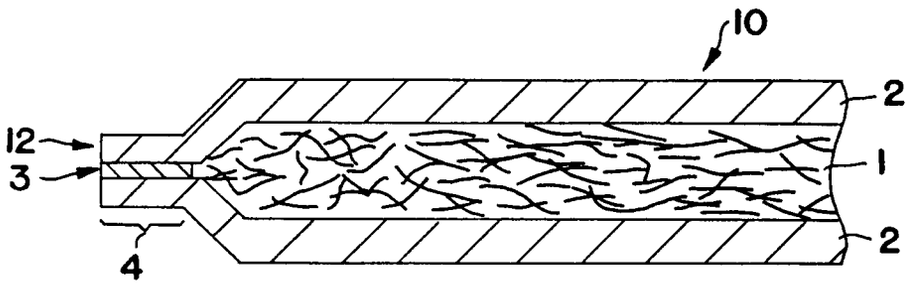



FIG. 1

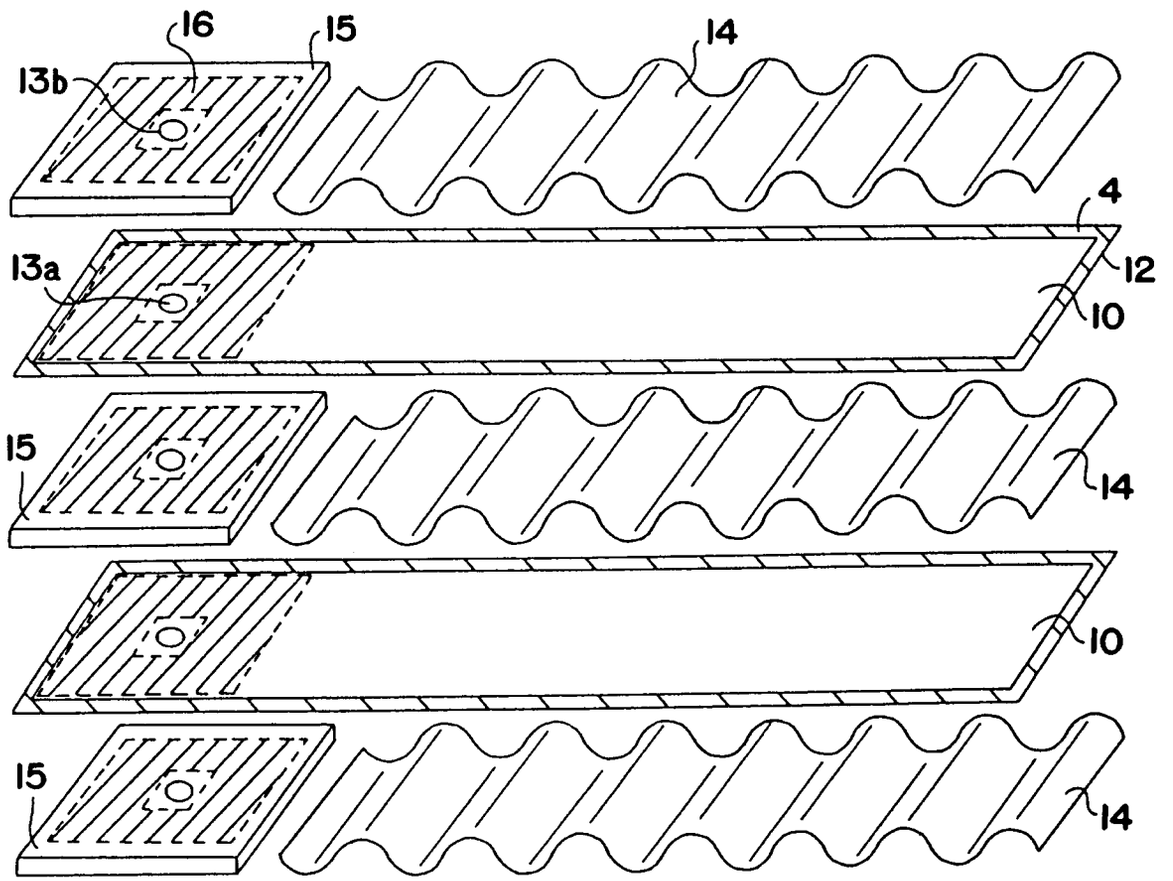



FIG. 2

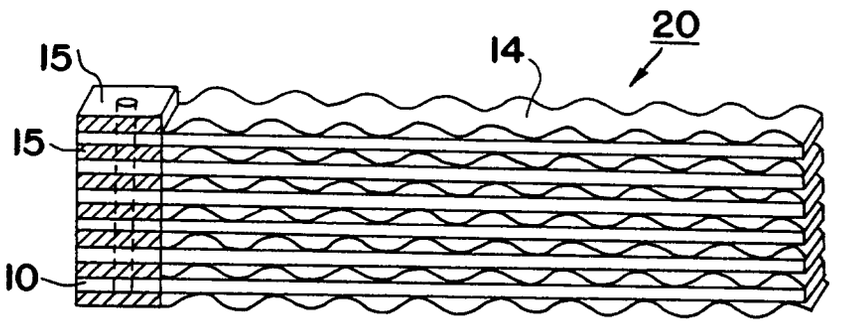



FIG. 3

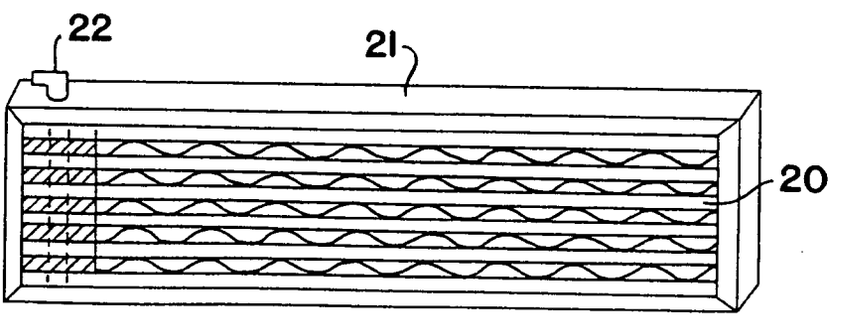



FIG. 4

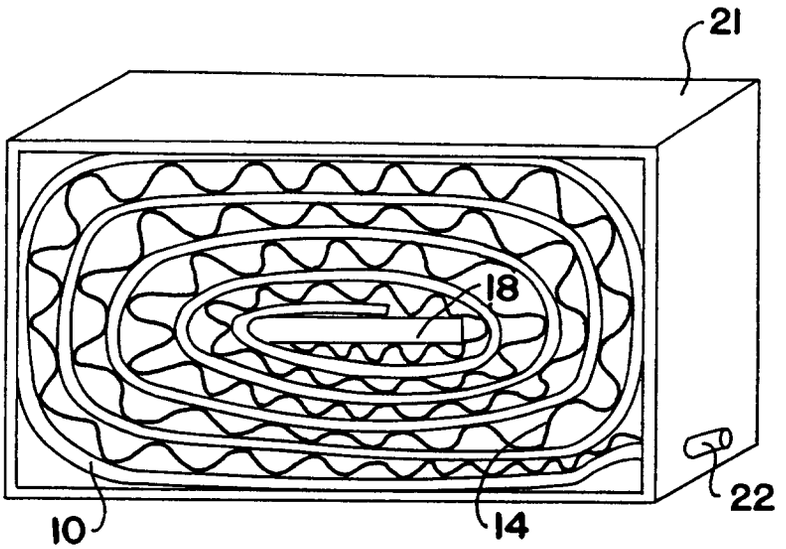



FIG. 5

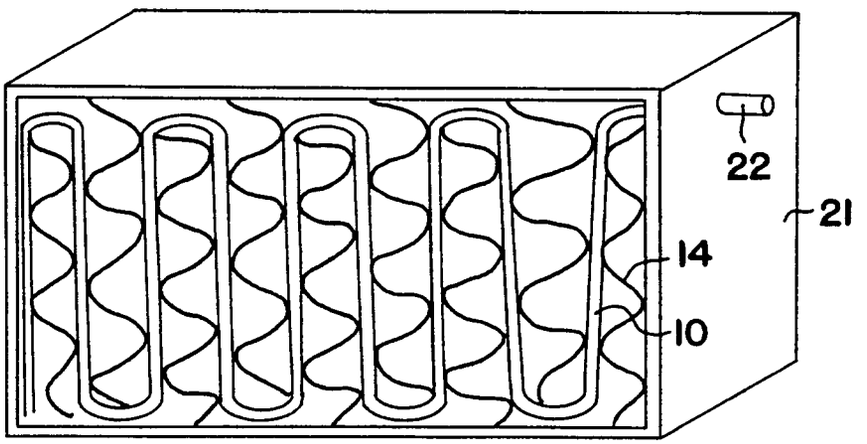



FIG. 6

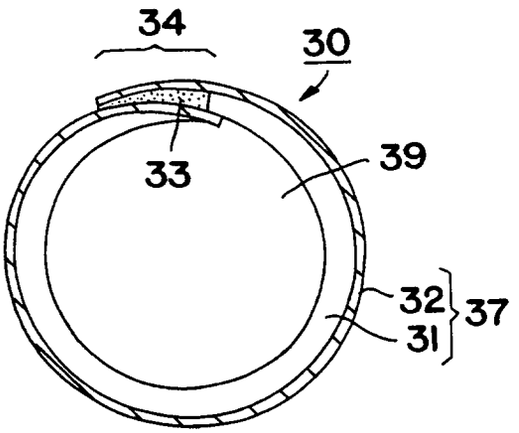



FIG. 7

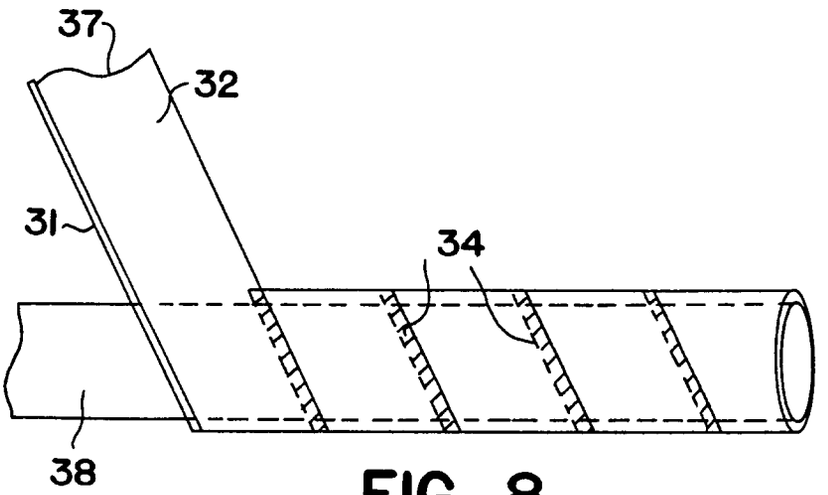



FIG. 8

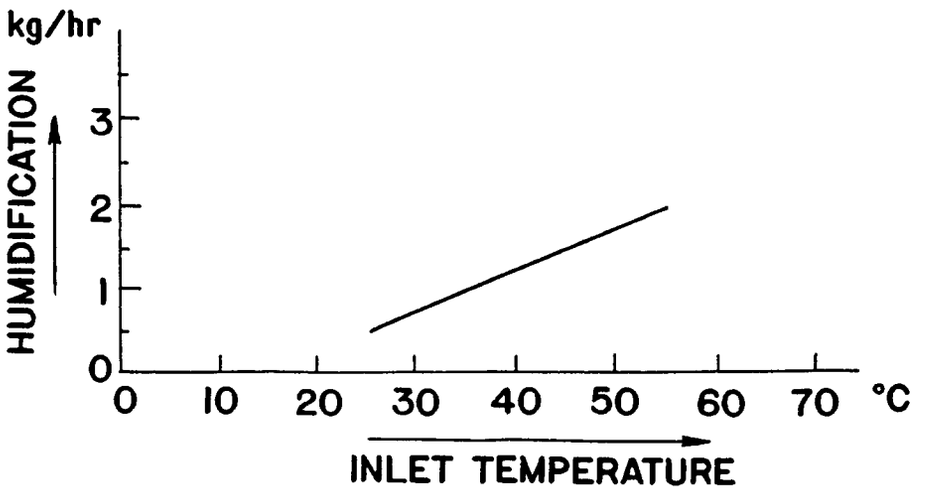



FIG. 9