

IMPREGNATED FILTER ELEMENTS, AND METHODS

This application is being filed on 25 August 2005, as a PCT International Patent application in the name of Donaldson Company, Inc., a U.S. national corporation, applicant for the designation of all countries except the US, and Andrew
5 James Dallas, a citizen of the U.S., Lefei Ding, a citizen of China, and Jon Dennis Joriman, a citizen of the U.S., and claims priority to U.S. Utility Application No. 10/928,776, filed August 27, 2004, U.S. Utility Application No. 10/927,708, filed August 27, 2004, and U.S. Utility Application No. 11/016,013, filed December 17, 2004.

10 **Field**

The present invention relates to a low-pressure drop filter element for removing contaminants from a gas stream, such as an air stream. More particularly, the invention relates to removal of a contaminant from a gas stream, by using a filter element impregnated with a material selected to specifically remove that
15 contaminant.

Background

Gas adsorption articles, often referred to as elements or filters, are used in many industries to remove airborne contaminants to protect people, the environment, and often, a critical manufacturing process or the products that are manufactured by
20 the process. A specific example of an application for gas adsorption articles is the semiconductor industry where products are manufactured in an ultra-clean environment, commonly known in the industry as a "clean room". Gas adsorption articles are also used in many non-industrial applications. For example, gas adsorption articles are often present in air movement systems in both commercial
25 and residential buildings, for providing the inhabitants with cleaner breathing air.

Typical airborne contaminants include basic contaminants, such as ammonia, organic amines, and N-methyl-2-pyrrolidone, acidic contaminants, such as hydrogen sulfide, hydrogen chloride, or sulfur dioxide, and general organic material contaminants, often referred to as VOCs (volatile organic compounds) such as
30 reactive monomer or unreactive solvent. Silicon containing materials, such as silanes, siloxanes, silanols, and silazanes can be particularly detrimental contaminants for some applications. Additionally, many toxic industrial chemicals and chemical warfare agents must be removed from breathing air.

The dirty or contaminated air is often drawn through a granular adsorption
35 bed assembly or a packed bed assembly. Such beds have a frame and an adsorption

medium, such as activated carbon, retained within the frame. The adsorption medium adsorbs or chemically reacts with the gaseous contaminants from the airflow and allows clean air to be returned to the environment. The removal efficiency and the length of time at a specific removal efficiency are critical in order to adequately protect the processes and the products for extended periods.

The removal efficiency and capacity of the gaseous adsorption bed is dependent upon a number of factors, such as the air velocity through the adsorption bed, the depth of the bed, the type and amount of the adsorption medium being used, and the activity level and rate of adsorption of the adsorption medium. It is also important that for the efficiency to be increased or maximized, any air leaking through voids between the tightly packed adsorption bed granules and the frame should be reduced to the point of being eliminated. Examples of granular adsorption beds include those taught in U.S. Patent Nos. 5,290,345 (Osendorf et al.), 5,964,927 (Graham et al.) and 6,113,674 (Graham et al.). These tightly packed beds result in a torturous path for air flowing through the bed.

However, as a result of the tightly packed beds, a significant pressure loss is incurred. Current solutions for minimizing pressure loss include decreasing air velocity through the bed by increased bed area. This can be done by an increase in bed size, forming the beds into V's, or pleating. Unfortunately, these methods do not adequately address the pressure loss issue, however, and can create an additional problem of non-uniform flow velocities exiting the bed. Additionally, packed beds are fairly heavy.

Although the above identified packed bed contaminant removal systems are sufficient in some applications, what is needed is an alternate product that can effectively remove contaminants such as acids, bases, or other organic materials, while minimizing pressure loss and providing uniform flow velocities exiting the filter.

One example of a non-packed bed adsorbent article is disclosed in U.S. Patent No. 6,645,271 (Seguin et al.). The articles described in this patent have a substrate having passages therethrough, the surfaces of the passages coated or covered with an adsorbent material. The adsorbent material can be held onto the substrate by a polymeric material.

U.S. Patent No. 6,071,479 (Marra et al.) has attempted to provide a suitable article for removal of contaminants from a gas stream, however, various disadvantages and undesirable features are inherent in the article of Marra et al. For example, the media is not designed for long-term and/or high purity filtration applications. In accordance with the invention of Marra et al., citric acid impregnated paper media is supposedly a suitable contaminant removal article;

however, when in actual use, such a product does not provide acceptable performance. Marra et al. include a humectant or an organic amine in order to increase the water content of the adsorptive material, to aid in the reaction between the acidic impregnant and basic materials to be removed. Additionally, Marra et al. uses binders and glues to retain the structure of the formed media. Such adhesive materials are known to off-gas contaminants, some may which react with or bind with the contaminant-removal material, thus decreasing the amount available for removing contaminants from the gas flowing therethrough.

Better contaminant removal systems are needed.

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Summary of the Invention

The present invention is directed to a contaminant-removal filter having a contaminant removal active material present within and throughout a fibrous substrate. The active material present in the filter is selected for the particular contaminant to be removed.

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In one design, the filter includes an acidic material and a preservative or stabilizer, configured for the removal of basic contaminants. Applicants have found that prior to the present invention, acidic materials in a filter element generally did not have an acceptable contaminant-removal life; the life of prior art filters is shortened by the presence of moisture within the filter. Applicants found that inclusion of a preservative or stabilizer with the acidic material increases the useful life of the filter. Although not being bound by theory, Applicants believe that the preservative or stabilizer inhibits the growth of microbial organisms such a mold, bacteria and viruses on the filter substrate, thus extending the use life of the filter.

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A preferred acidic material is citric acid. The acidic material reacts with or otherwise removes basic contaminants from air or other gaseous fluid that contacts the filter. Also present on at least the surface, and preferably within the substrate, is at least one of a preservative or a stabilizer. Generally, this preservative and/or stabilizer is homogeneously present with the acidic material. A preferred stabilizer is polyacrylic acid (PAA). A preferred preservative is sodium benzoate.

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In another design, the filter includes a basic or alkaline material and a promoter, configured for the removal of acidic contaminants. Applicants have found that prior to the present invention, basic materials in a filter element generally did not have an acceptable contaminant-removal life; the life of prior art filters is shortened by the presence of moisture within the filter. Applicants found that inclusion of a promoter with the basic material increases the useful life of the filter. Although not being bound by theory, Applicants believe that the promoter enhances

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the oxidation reaction between an acid gas (the contaminant being removed) and the basic or alkaline material of the filter, thus extending the use life of the filter.

5 A preferred basic material is potassium carbonate (K_2CO_3). The basic material reacts with or otherwise removes acidic contaminants from air or other gaseous fluid that contacts the filter. Also present on at least the surface, and preferably within the substrate, is a promoter. Generally, this promoter is homogeneously present with the basic material. A preferred promoter is potassium iodide (KI).

10 In yet another design, the filter includes a substrate having reactive material or reactant present therein and thereon, the reactive material being a sulfite, bisulfite, oxidant, or derivative of ammonia, specifically high molecular weight and stable amines, configured for the removal of carbonyl-containing compounds, which includes ketones and aldehydes. Strong alkali (basic) materials are particularly suitable for aldehyde removal.

15 An example of a preferred material for removing carbonyl-containing compounds is activated carbon, such as in granular or fibrous form, impregnated with a reactant such as a sulfite, bisulfite, oxidant, or derivative of ammonia, specifically high molecular weight and stable amines. Activated carbon granules or fibers impregnated with strong alkali is specifically suitable for aldehydes removal.

20 In still another design, the filter includes a substrate that includes activated carbon fibers therein, the fibers being a structural component of the substrate. Such a filter design is configured for the removal of VOCs, such as methanol, toluene, ethanol, and the like. Activated carbon fibers are particularly suitable for removing VOCs present at low concentration (e.g., less than 100 ppm). Any of the previously summarized designs may be used with such a substrate, having carbon fibers therein. The carbon fibers are particularly suited for impregnation with a reactant such as a sulfite, bisulfite, oxidant, or derivative of ammonia, specifically high molecular weight and stable amines, for the removal of carbonyl-containing compounds and VOCs.

30 The substrate forming the filter is a fibrous or porous material, such as cellulosic or polymeric material, or a combination thereof. For VOC removal, the substrate includes activated carbon fibers. The body of the filter, formed by the substrate, is preferably configured with a plurality of passages extending from an inlet face to an outlet face, the passages providing a pathway for gas flow therethrough. Present at least on the surface of the substrate, and preferably within
35 the substrate, is the active material.

The active material, either the acidic material, alkaline or basic material, or reactive material, is applied to the substrate as a mixture or solution of active material. Typically, the mixture or solution is applied by impregnation.

5 The contaminant-removal filter of the present invention can be used in a variety of high purity applications that desire the removal of basic contaminants from a gas stream, such as an air stream. By use of the term "high purity" and modifications thereof, what is meant is a contaminant level, in the cleansed gas stream, of less than 1 ppm of contaminant. In many applications, the level desired is less than 1 ppb of contaminant. The contaminant-removal filter of the present
10 invention is a "high purity element" or includes "high purity media". In this application, such terms refer to materials that not only remove contaminants from the air stream but also do not diffuse or release any contaminants. Examples of materials that are generally not present in high purity elements or high purity media include adhesives or other polymeric materials that off-gas. It should be understood
15 that in some applications, the presence of adhesives in the contaminant-removal filter is acceptable.

Generally, the filter can be used in any application such as lithographic processes, semiconductor processing, and photographic and thermal ablative imaging processes. Proper and efficient operation of a fuel cell also desires oxidant
20 (e.g., air) that is free of unacceptable chemical contaminants. Other applications where the contaminant-removal filter of the invention can be used include those where environmental air is cleansed for the benefit of those breathing the air. Often, these areas are enclosed spaces, such as residential, industrial or commercial spaces, airplane cabins, and automobile cabins.

25 **Brief Description of the Drawings**

Referring now to the drawings, wherein like reference numerals and letters indicate corresponding structure throughout the several views:

Figure 1 is a schematic, perspective view of one embodiment of a contaminant-removal filter according to the present invention;

30 Figure 2 is a schematic, perspective view of a second embodiment of a contaminant-removal filter according to the present invention;

Figure 3 is a schematic, perspective view of a third embodiment of a contaminant-removal filter according to the present invention;

35 Figure 4 is a schematic, perspective view of a fourth embodiment of a contaminant-removal filter according to the present invention;

Figure 5 is a schematic depiction of a system incorporating multiple contaminant-removal filters according to the present invention, in conjunction with a particulate filter;

Figure 6 is a schematic, perspective view of a fifth embodiment of a contaminant-removal filter according to the present invention;

Figure 7 is a graphical representation of test results for various contaminant-removal filters according to the present invention;

Figure 8 is a graphical representation of test results for a contaminant-removal filter according to the present invention; and

Figure 9 is a graphical representation of test results for various contaminant-removal filters according to the present invention.

Figure 10 is a graphical representation of test results for various contaminant-removal filters according to the present invention;

Figure 11 is a photograph of the inlet side of a filter element according to the present invention, after testing with Breakthrough Test 3; and

Figure 12 is a photograph of the inlet side of a comparative example filter element, after testing with Breakthrough Test 3; and

Figure 13 is a graphical representation of the results from testing Example 11 and Comparative Example F.

Detailed Description

Referring now to the Figures, specifically to Figure 1, a first embodiment of a contaminant-removal filter or element according to the present invention is shown at 10. Contaminant-removal filter 10 is defined by a body 12 having a first face 17 and an opposite second face 19. Generally, gas to be cleansed of basic contaminants enters filter 10 via first face 17 and exits via second face 19. In this embodiment, body 12 is formed by alternating a corrugated layer 14 with a facing layer 16. Corrugated sheet 14 has a rounded wave formation, with each of the valleys and peaks being generally the same. Facing layer 16 can be a corrugated layer or a non-corrugated (e.g., flat) sheet; in this embodiment facing layer 16 is a flat sheet. Layer 14 and layer 16 together define a plurality of passages 20 through body 12 that extend from first face 17 to second face 19. Filter 10 has "straight-through flow" or "in-line flow", meaning that gas to be filtered enters in one direction through first face 17 and exits in generally the same direction from second face 19. The length of passages 20, "L", is measured between first face 17 and second face 19; this dimension L generally also defines the thickness of body 12 and of filter 10, in the direction of airflow.

A second configuration of a contaminant-removal filter according to the present invention is shown at 10' in Figure 2. Similar to the article of Figure 1, contaminant-removal filter 10 is defined by a body 12' having a first face 17' and an opposite second face 19'. The distance between first face 17' and second face 19' is the thickness of filter 10'. Body 12' is formed by alternating a corrugated layer 14' with a facing layer 16'. Corrugated sheet 14' has an angular wave formation, with each of the valleys and peaks being generally the same height. Facing layer 16' can be a corrugated layer or a non-corrugated (e.g., flat) sheet; in this embodiment facing layer 16' is a flat sheet. Layer 14' and layer 16' together define a plurality of passages 20' through body 12' that extend from first face 17' to second face 19'.

Body 12 of Figure 1 and body 12' of Figure 2 have a similar construction in that they both include a corrugated layer 14, 14' and a facing layer 16, 16'. For body 12, two layers 14, 16 are alternatingly stacked, providing a generally planar filter 10. For body 12', two layers 14', 16' are alternatingly coiled, providing a generally cylindrical filter 10'. Filter 10' illustrated has a non-circular cross-section, such as an oval, elliptical, or racetrack shape; other shapes, particularly a circle, could also be formed by coiling layers 14', 16'. Additionally, a shape having two parallel sides, two other parallel sides orthogonal to the first two parallel sides, and four rounded corners therebetween, could also be coiled. Any coiled construction could include a central core to facilitate winding of the layers.

A third configuration of a contaminant-removal filter according to the present invention is shown at 30 in Figure 3. Contaminant-removal filter 30 is defined by a body 32 having a first face 37 and an opposite second face 39. Generally, gas to be cleansed enters filter 30 via first face 37 and exits via second face 39. The distance between first face 37 and second face 39 is the thickness of filter 30. Body 32 is formed by spiral winding a substrate layer 35. Spacers may be used to obtain the desired spacing between adjacent wraps of layer 35. The adjacent wraps of layer 35 form a passage through filter 30. Similar to filter 10' of Figure 2, filter 30 can have a circular or non-circular cross-section, and can include a central core to facilitate winding of the layers.

A fourth configuration of a contaminant-removal filter according to the present invention is shown at 50 in Figure 4. As with the previous configurations, filter 50 is defined by a body 52 having a first face 57 and an opposite second face 59. The distance between first face 57 and second face 59 is the thickness of filter 50. Body 52 is formed by multiple individual sheets 65 of substrate arranged to form a generally spiraling configuration. For example, body 52 has a first sheet 65a, an adjacent second sheet 65b, and subsequent sheets. These sheets 65, although generally flat, may be corrugated. Adjacent sheets 65, such as 65a and 65b, together

define a plurality of passages 60 through body 52 that extend from first face 57 to second face 59. As with the previous configurations, element 50 can have a circular or non-circular cross-section and can include a core to facilitate placement of sheets 65.

- 5 Another anticipated configuration for a contaminant-removal filter according to the present invention is to have concentric layers, formed by multiple, individual sheets.

Specific features of the contaminant-removal filters are described below. For ease, although generally only the reference numerals from the first embodiment, filter 10, are used, it is understood that the description of the features applies to all configurations, unless specifically indicated.

Body of the Filter

Body 12 provides the overall structure of contaminant-removal filter 10; body 12 defines the shape and size of filter 10. Body 12 can have any three-dimensional shape, such as a cube, cylinder, cone, truncated cone, pyramid, truncated pyramid, disk, etc., however, it is preferred that first face 17 and second face 19 have at least close to the same surface area, to allow for equal flow into passages 20 as out from passages 20. The cross-sectional shape of body 12, defined by first face 17, second face 19, or any cross-section taken between faces 17 and 19, can be any two dimensional shape, such as a square, rectangle, triangle, circle, star, oval, ellipse, racetrack, and the like. An annular shape can also be used. Preferably, the cross-section of body 12 is essentially constant along length "L" from first face 17 to second face 19.

25 Typically, first face 17 and second face 19 have the same area, which is at least 1 cm². Additionally or alternatively, first face 17 and second face 19 have an area that is no greater than about 1 m². In most embodiments, the area of faces 17, 19 is about 70 to 7500 cm². Specific applications for filter 10 will have preferred ranges for the area. The thickness "L" of body 12, between first face 17 and second face 19, is generally at least 0.5 cm, and generally no greater than 25 cm. In most embodiments, "L" is about 2 to 10 cm. Two particular suitable thicknesses of body 12 are 2.5 cm and 7.5 cm. The dimensions of body 12 will effect the residence time of gas in the filter and the resulting removal of contaminant from the gas stream.

Body 12 typically has a plurality of passages 20 extending therethrough; see, for example, elements 10 and 10' of Figures 1 and 2. Passages 20 may have any shape, for example square, rectangular, triangular, circular, trapezoidal, hexagonal (e.g., "honeycomb"), but a preferred shape is generally domed, such as those illustrated in Figure 1. Preferably, the shape of passages 20 does not appreciably

change from first face 17 to second face 19, and each of passages 20 within filter 10 has a similar cross-sectional shape.

Each passage 20 generally has a cross-sectional area typically no greater than about 50 mm^2 ; this cross-sectional area is generally parallel to at least one of first face 17 and second face 19. Alternately or additionally, passages 20 typically have a cross-sectional area no less than about 1 mm^2 . Generally the cross-sectional area of each passage 20 is about 1.5 to 30 mm^2 , often about 2 to 4 mm^2 . In one preferred embodiment, the cross-sectional area of a domed passage 20, such as passage 20 illustrated in Figure 1, is about 7 to 8 mm^2 . In another preferred embodiment, the area of passage 20 is 1.9 mm^2 .

The longest cross-sectional dimension of passages 20 is typically no greater than 10 mm , often no greater than 6 mm . Additionally, the shortest dimension of passages 20 is no less than 0.25 mm , often no less than 1.5 mm .

The total, internal surface area of each elongate passage 20 is generally no less than about 5 mm^2 , and is generally no greater than about 200 cm^2 . The total surface area of filter 10, as defined by the interior surface area of passages 20, is at least about 200 cm^2 or about 250 cm^2 to 10 m^2 .

In the third configuration, Figure 3, element 30 has a single passage, formed by the subsequent and adjacent winds of layer 35. In such a configuration, the total internal surface area of element 30 is at least about 200 cm^2 and is usually about 250 cm^2 to 10 m^2 .

The passage walls, which define the shape and size of passages 20, are defined by the substrate that forms body 12. The substrate is generally at least 0.015 mm thick. Alternately or additionally, the passage walls are generally no thicker than 5 mm . Typically, the passage walls are no greater than 2 mm thick. The thickness of the walls will vary depending on the size of passage 20, the substrate from which body 12 is made, and the intended use of filter 10. For those configurations where layer 14 and facing layer 16 define passages 20, the passage walls are defined by layer 14 and facing layer 16.

In most embodiments, each of passages 20 has a continuous size and shape along its length. Generally, the length of each passage 20 is essentially the same as the thickness "L" between first face 17 and second face 19. It is contemplated that passage 20 is not a straight line from face 17 to face 19, however, this is generally not preferred, due to the potential of undesirable levels of pressure drop through passage 20.

Body 12 (e.g., layers 14, 16) is formed from a porous or permeable substrate; a fibrous material is a preferred material. Examples of suitable substrates for body 12 include natural (e.g., cellulosic materials) and polymeric based materials. The

substrates can be nonwoven fibrous materials (such as spun-bonded), woven fibrous materials, knitted fibrous materials, or open or closed cell foam or sponge materials. Specific examples of suitable substrates include glass fiber papers, crepe papers, Kraft papers, wool, silk, cellulosic fiber fabrics (such as cotton, linen, viscose or rayon) and synthetic fiber fabrics (such as nylon, polyester, polyethylene, polypropylene, polycarbonate, polyvinylalcohol, acrylics, and polyamides). Porous ceramic materials may also be used for body 12.

Activated carbon fibers in body 12 are desired for the removal of VOCs, particularly at low concentration (less than about 100 ppm). The fibers may be present at levels of 20 wt-% up to 100 wt-%, although levels of 30 to 80 wt-% are most common. The activated carbon fibers are generally mixed with at least one other fiber to form body 12; combination with thermoplastic fibers is preferred. The thermoplastic fibers add strength and stiffness to the material. The carbon fibers may be present in one or both of layers 14, 16.

The activated carbon fibers suitable for use in body 12 for the removal of VOCs typically having nominal BET surface areas of approximately 800 to 3000 m²/gram, micro-pore volumes of approximately 0.3 to 0.8 cm³/gram, fiber diameters of 5 to 100 micrometers, and average fiber length of 0.1 to 10 mm.

The materials used for body 12 should not produce deleterious off-gassing or emissions of contaminants that might affect the functioning of the active material (i.e., the acidic, basic, or other reactive material) present on body 12. Examples of materials that are preferably avoided include adhesives and other such materials that off-gas. There are some adhesives that are acceptable in certain applications, adhesives that have levels, amounts and types of off-gassing that are not harmful to the application, but that are acceptable.

A preferred substrate for body 12 has thermoplastic polymeric fibers combined with cellulose fibers. The two fibers can be homogeneously combined or intermingled and formed into a sheet-like substrate. Upon heating, the polymeric fibers soften and at least partially melt, binding the fibers together. Upon cooling, the polymeric fibers resolidify. Using a substrate that includes thermoplastic materials allows joining multiple sheets or layers of substrate without using an adhesive. A specific example of a suitable substrate has about 40 wt-% polyethylene terephthalate (PET) fibers and about 60 wt-% cellulose fibers. Another specific example of a suitable substrate has about 60 wt-% activated carbon fibers and about 40 wt-% polyester fibers. Other combinations of thermoplastic and non-thermoplastic fibers would also be suitable.

An example of a preferred body 12, such as illustrated in FIG. 2, can be made from a corrugated sheet 14 and a facing sheet 16, both having thermoplastic

polymeric fibers combined with cellulose fibers. The sheets 14, 16 can be passed through an ultrasonic welder, which uses high frequency sound to locally heat the sheets. Pressure is applied at the areas where sheets 14, 16 contact each other, thus bonding sheets 14, 16 together. Sheets 14, 16 made with activated carbon fibers and thermoplastic polymeric fibers can also be welded in such a manner.

Methods for making body 12, from a corrugated sheet 14 and a facing sheet 16 are taught, for example, are taught in U.S. Patent No. 6,416,605 and in WO 03/47722, which are incorporated herein by reference. Body 12 is a carrier for the acidic material that removes contaminants from air or other gaseous fluid passing through filter 10.

As provided above, contaminant-removal filter 10 includes at least one active material, such as an acidic material, basic or alkaline material, or a reactive material, which are selected for the removal of bases, acids, and carbonyl-containing compounds, respectively. Contaminant-removal filter 10 can alternately or additionally include activated carbon fibers in body 12, for the removal of VOCs.

To produce filter 10 having active material provided in and on body 12 rather than as fibers in body 12, the active material is provided in a liquid carrier and is impregnated into or onto the substrate that forms the contaminant-removal filter. Typically and preferably, the active material is impregnated into the substrate while in the form of a solution. It is understood that some materials may not dissolve in the solvent, but rather, are dispersed. Water is the preferred solvent for the solution, dispersion, or any other mixture form.

The level of active material within the impregnate solution is selected based on the specific active material and the substrate being used. The amount of active material in the solution is at least about 0.5 wt-% and is no more than about 75 wt-%. Preferably, the amount of active material is 5-50 wt-% or 10-50 wt-%.

Although the terms "impregnation", "impregnate", and the like have been used, it should be understood that the method of application of the active material to the substrate is not limited to impregnation. Other methods may be used to provide the active material into the substrate. Other alternate and suitable methods for applying the active material into the substrate include immersion, spraying, brushing, knife coating, kiss coating, and other methods that are known for applying a liquid onto a surface or substrate. The impregnation or other application method can be done at atmospheric conditions, or under pressure or vacuum.

In a preferred method, the substrate is formed into body 12 prior to application of the active material. It is understood, however, that body 12 could be formed after the substrate has been formed into body 12. For inclusion of activated

carbon fibers in body 12, it is understood that the substrate would be formed with the fibers therein.

After being impregnated, the substrate is at least partially dried to remove solvent (e.g., water), leaving active material in and on the substrate. Preferably, at least 90% all free water or other solvent is removed, and most preferably, at least 95% of all free water or other solvent is removed.

The active material is present on and within at least 50% of the surface area of the passages 20 of the element. Preferably, the active material is present on and within at least 55 to 75% of the passage wall surfaces, more preferably at least 90% of the surfaces, and most preferably, is continuous and contiguous with no areas without the active material. The active material is present through at least 10% of the thickness of the substrate. Preferably, the active material is present through at least 50% of the substrate, and more preferably through at least 80%. When the active material is activated carbon fibers in the substrate, it is preferred that the substrate has at least 30 wt-% activated carbon fiber, preferably at least 60 wt-%, homogeneously distributed throughout layer 14 or layer 16. In some embodiments, only one of layer 14, 16 includes the carbon fibers.

The active material generally does not generally increase the thickness of the substrate. The active material, may however, alter the characteristics of the substrate, such as making it more rigid, or more flexible.

Acidic Material as the Active Material

In one design, contaminant-removal filter 10 includes acidic material as the active material. The acidic material removes basic contaminants from the air passing through the passages by reacting with or otherwise removing the contaminants.

Examples of suitable acidic materials for use in the element of the invention include carboxylic acids (mono-, di-, tri-, and multi-acids; linear, branched, and cyclic forms) such as citric acid, oxalic acid, malonic acid, and higher homologs, aromatic carboxylic acids; sulfonic acids (linear, cyclic, and aromatic); inorganic acids such as sulfuric acid, phosphoric acid, nitric acid, hydrochloric acid; heteropolyacids (superacids). Citric acid is the preferred acidic material.

The level of acidic material within the impregnate solution is selected based on the acidic material and the substrate being used. The amount of acidic material in the solution is at least about 0.5 wt-% and is no more than about 75 wt-%. Preferably, the amount of acidic material is 10-50 wt-%. For the preferred acidic material, citric acid, the amount of citric acid is about 10-50 wt-%, preferably 15-35 wt-%. Other levels of acid would also be suitable.

It has been found that lower concentrations of acidic material are generally preferred over higher concentrations. For example, a solution having 5-15 wt-% citric acid is preferred over a solution having 20-35 wt-% citric acid. In a particular example, it was found that impregnating a substrate with a 5% aqueous citric acid solution, drying the substrate, and then impregnating with a 12% aqueous citric acid solution provided better basic-contaminant removal than a single step impregnation with a 25% citric acid solution. This lower concentration, double-step impregnation process is also preferred over a single step impregnation process.

10 Additives to be Avoided When Acidic Material is Active Material

It is theorized that increased levels of moisture in the substrate decrease the suitable life of an acid-impregnated element. Thus the use of humectants, which increase the amount of water content in the dried substrate, is undesired. Examples of humectants to be avoided include urea, glycerol, glycerin, alcohols, polyvinylpyridine, polyvinylpyrrolidone, polyvinylalcohols, polyacrylates, polyethylene glycols, and cellulosic acetates. Also, the use of organic amines, which increase the amount of water content in the dried substrate, is undesired. Examples of organic amines to be avoided include alkanol amines, hydroxyl amines, and polyamines.

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Additives Acceptable When Acidic Material is Active Material

Although not being bound by theory, Applicants believe that moisture present in the substrate of the filter element facilitates the growth of microbial organisms such as mold, bacteria and viruses on the filter; the microbial organisms react with or otherwise deteriorate the acidic material. Applicants have found that adding at least one of a preservative or stabilizer to the acidic material improves the effectiveness of the acidic material over the life of the element and extends the life of the filter element.

The level of stabilizer and/or preservative within the impregnate solution is selected based on the acidic material and the stabilizer or preservative being used. The amount of stabilizer and/or preservative in the solution is at least about 0.01 wt-% and is no more than about 20 wt-%. Preferably, the amount of stabilizer and/or preservative is 0.1-10 wt-%, and more preferably about 0.1-10 wt-%, depending on the additive. Other levels of stabilizer and/or preservative would also be suitable.

35 An example of a suitable stabilizer is polyacrylic acid. The preferred level of polyacrylic acid in the solution, if present, is about 1-10 wt-%, preferably 6-10 wt-%. These levels are particularly suitable when the acidic material is citric acid. The

preferred level of polyacrylic acid, as a ratio to citric acid, is about 1:1 to 1:10, more preferably about 1:2 to 1:4.

Examples of suitable preservatives include benzoic acid, sodium benzoate, potassium nitrate, potassium nitrite, sodium nitrite, sodium nitrate, methyl paraben, ethyl paraben, methyl paraben, ethyl paraben, propyl paraben, butyl paraben, propionic acid, sodium propionate, calcium propionate, sorbic acid, potassium sorbate, acetic acid, phosphoric acid, sodium sorbate, calcium sorbate, potassium benzoate, calcium benzoate, ethyl para-hydroxybenzoate, sodium ethyl para-hydroxybenzoate, propyl para-hydroxybenzoate, biphenyl, diphenyl, orthophenyl phenol, sodium orthophenyl phenol, sodium sulfite, and sodium sulfate. The preferred level of sodium benzoate in the solution, if present, is about 0.01-5 wt-%, preferably 0.1-1 wt-%, and even more preferably about 0.1-0.5 wt-%. These levels are particularly suitable when the acidic material is citric acid. The preferred level of sodium benzoate, as a ratio to citric acid, is about 1:5 to 1:1000, more preferably about 1:50 to 1:700.

Alkaline or Basic Material as the Active Material

In another design, contaminant-removal filter 10 includes basic material as the active material. The basic material removes acidic contaminants from the air passing through the passages by reacting with or otherwise removing the contaminants.

Examples of suitable basic materials for use in the element of the invention include basic salts such as carbonates, bicarbonates, hydroxides, quaternary ammonium compounds (generally the hydroxide forms); and metal oxides such as copper oxides, manganese oxides, and iron oxides. Ion-exchange resins, such as those that include polystyrene quaternary ammonium (hydroxide forms), polystyrene tertiary amine, grafted polyethylene, and grafted polypropylene, are also suitable for removal of basic-contaminants. For basic salts of alkali and alkaline earth metals; typically the lithium, sodium, and potassium versions are used. Potassium carbonate is the preferred basic material for use in contaminant-removal element 10. Examples of other preferred basic materials include potassium bicarbonate, sodium carbonate, and sodium bicarbonate.

The level of basic material within the impregnant solution is selected based on the basic material and the substrate being used. The amount of basic material in the solution is at least about 0.5 wt-% and is no more than about 75 wt-%. Preferably, the amount of basic material is 10-50 wt-%. For the preferred basic material, potassium carbonate, the amount is about 10-50 wt-%, preferably 15-35 wt-%. Other levels of basic material would also be suitable.

Additives to be Avoided When Alkaline Material is the Active Material

It is theorized that increased levels of moisture in the substrate decrease the suitable life of the element. Thus the use of humectants, which increase the amount of water content in the dried substrate, is undesired. Examples of humectants to be avoided include urea, glycerol, glycerin, alcohols, polyvinylpyridine, polyvinylpyrrolidone, polyvinylalcohols, polyacrylates, polyethylene glycols, and cellulosic acetates. Also, the use of organic amines, which increase the amount of water content in the dried substrate, is undesired. Examples of organic amines to be avoided include alkanol amines, hydroxyl amines, and polyamines.

Additives Acceptable When Alkaline Material is the Active Material

Applicants have found that adding a promoter to the basic or alkaline material improves the effectiveness of the basic or alkaline material over the life of the element and extends the life of the filter element.

The level of promoter within the impregnant solution is selected based on the basic material and the promoter being used. Examples of suitable promoters are alkali and alkaline earth metal iodides and iodates, such as potassium iodide, sodium iodide, lithium iodide, potassium iodate, sodium iodate, and sodium iodate. A preferred promoter is potassium iodide; this promoter is particularly suitable for use with potassium carbonate material.

The amount of promoter in the solution is at least about 0.01 wt-% and is no more than about 20 wt-%. Preferably, the amount of promoter is 0.1-10 wt-%, and more preferably about 0.1-5 wt-%. These levels are particularly suitable when the basic material is about 5 wt-%. Other levels of promoter would also be suitable.

The preferred level of promoter, as a ratio to the basic material, is about 1:1 to 1:50, more preferably about 1:3 to 1:10.

Reactant Material as the Active Material

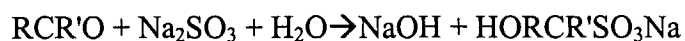
In another design, contaminant-removal filter 10 includes reactant material as the active material. The reactant material removes carbonyl-containing compounds from the air passing through the passages by reacting with or otherwise removing the compounds.

Examples of suitable reactant materials for use in the filter element of the invention include sulfites, bisulfites, oxidants, or derivatives of ammonia, specifically high molecular weight and stable amines. For removal of aldehydes, strong alkali (basic) materials are preferred.

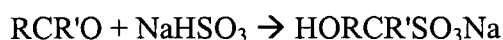
More specific examples of suitable reactants include: for sulfites, sodium sulfite and potassium sulfite; for bisulfites, sodium bisulfite and potassium bisulfite;

for derivatives of ammonia, specifically suitable high molecular weight and stable amines, 2,4 dinitrophenyl hydrazine (DNPH), 2-hydroxymethyl piperidine (2-HMP), and tris(hydroxymethyl) aminomethane; for strong alkali, sodium hydroxide and potassium hydroxide. Various examples of the mode of carbonyl-containing
 5 compound removal are provided below.

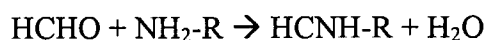
An example reaction of a sulfite with a carbonyl-containing compound is:



10 An example reaction of a bisulfite with a carbonyl-containing compound is:



An example reaction of a high molecular weight and stable amine with an
 15 aldehyde is:



An example reaction of a strong alkali with an aldehyde is:
 20



The level of reactant material within the impregnant solution is selected based on the reactant material and the substrate being used. The amount of reactant
 25 material in the solution is at least about 0.5 wt-% and is no more than about 75 wt-%. Preferably, the amount of reactant material is 5-50 wt-%. For example, when tris(hydroxymethyl) aminomethane is used, the preferred level of is about 5 wt-% in the impregnant solution. When sodium hydroxide is used, the preferred level of is about 5 wt-%. Other levels of reactant material, such as 10-50 wt-%, would also be
 30 suitable.

Additives to be Avoided

It is theorized that increased levels of moisture in the substrate decrease the suitable life of the element. Thus the use of humectants, which increase the amount
 35 of water content in the dried substrate, is undesired. Examples of humectants to be avoided include urea, glycerol, glycerin, alcohols, polyvinylpyridine, polyvinylpyrrolidone, polyvinylalcohols, polyacrylates, polyethylene glycols, and cellulosic acetates.

Any of the active materials described above can be impregnated or otherwise applied to activate carbon fibers.

Regeneration

5 It has been found the contaminant-removal filter of this invention, whether having acidic, basic, or reactive material, can be regenerated. After use, or after a prolonged duration of non-use, the element can be again impregnated with the acidic material, with alkaline material, or with reactant material. This second or any subsequent impregnation can be done with or without cleansing the previous
10 contaminants from the filter; cleansing the filter could be done, for example, by a water rinse. It is foreseen that the substrate can be impregnated any number of times, any limitation being the physical intactness of the substrate.

Applications for Contaminant-Removal Filter 10

15 Contaminant-removal filter 10 of the present invention can be used in any variety of applications that desire the removal of contaminants from a gas stream, such as an air stream. Contaminant-removal filter 10 is particularly suitable for high purity applications that desire the removal of chemical contaminants from a gas to a level of less than 1 ppm of contaminant. In many high purity applications, the level
20 desired is less than 1 ppb of contaminant. Filter 10 itself generally adds no contaminants, such as due to off-gassing.

Examples of common airborne basic contaminant compounds that can be removed by an acid-impregnated filter 10 include organic bases such as ammonia, amines, amides, N-methyl-1,2-pyrrolidone, sodium hydroxides, lithium hydroxides,
25 potassium hydroxides, volatile organic bases and nonvolatile organic bases. Examples of common airborne acidic contaminant compounds that can be removed by an alkaline-impregnated filter 10 include oxides of sulfur, oxides of nitrogen, HCl (hydrochloric acid), HNO₃ (nitric acid), H₂S (hydrogen sulfide), H₂SO₄ (sulfuric acid) and HCN (hydrogen cyanide). Examples of common airborne carbonyl-
30 containing compounds include ketones, including acetone, and aldehydes, including formaldehyde. Carbonyl-containing compounds, in general, are fairly malodorous and cause discomfort to many people. Some people have allergic reactions to carbonyl-containing compounds.

Generally, contaminant-removal filter 10 can be used in any application
35 where a packed granular bed has been used; such applications include lithographic processes, semiconductor processing, photographic and thermal ablative imaging processes. Proper and efficient operation of a fuel cell would benefit from intake air that is free of unacceptable basic contaminants. Other applications where

contaminant-removal filter 10 can be used include those where environmental air is cleansed for the benefit of those breathing the air. Filter 10 can be used with personal devices such as respirators (both conventional and powered) and with self-contained breathing apparatus to provide clean breathing air. Contaminant-removal
5 filter 10 can also be used on a larger scale, for enclosed spaces such as residential and commercial spaces (such as rooms and entire buildings), airplane cabins, and automobile cabins. At other times, it is desired to remove contaminants prior to discharging the air into the atmosphere; examples of such applications include automobile or other vehicle emissions, exhaust from industrial operations, or any
10 other operation or application where chemical contaminants can escape into the environment.

Filter 10 is typically positioned in a housing, frame or other type of structure that directs gas flow (e.g., air flow) into and through passages 20 of filter 10. In many configurations, filter 10 is at least partially surrounded around its perimeter by
15 a housing, frame or other structure.

When a contaminant-removal filter 10, made by any process described herein, is positioned within a system, a pre-filter, a post-filter, or both may be used in conjunction with contaminant-removal filter 10. A pre-filter is positioned upstream of filter 10 to remove airborne particles prior to engaging filter 10. A post-
20 filter is positioned downstream of filter 10 to remove residual particles from filter 10 before the air is released. These filters are generally placed against or in close proximity to first face 17 and second face 19, respectively, of contaminant-removal filter 10. An example of a system including a pre-filter is illustrated in Figure 5.

In Figure 5, a system 100 is illustrated for removing contaminants from a
25 dirty gas stream 101. System 100 includes a particulate filter 105, a first contaminant-removal filter 110, and a second contaminant-removal filter 110'. Particulate filter 105 is configured to remove solid particles, such as dust and smoke, from gas stream 101. Typically, if particulate filter 105 is used, particulate filter 105 is positioned upstream of contaminant-removal filters 110 and 110', to decrease the
30 potential of filters 110, 110' being clogged or laden with particulate. In one example, first contaminant-removal filter 110 is configured to remove basic contaminants from gas stream 101 and second contaminant-removal filter 110' is configured to remove acidic contaminants from gas stream 101. It is understood that in alternate embodiments, filters 110, 110' can be configured in any fashion to
35 remove acidic contaminants, basic contaminants, or carbonyl-containing compounds. After passing through each of particulate filter 105, contaminant-removal filter 110, and contaminant-removal filter 110', the resulting cleaned gas stream is designated as 102.

Any or all of particulate filter 105, filter 110, and filter 110' may be retained in a housing, such as housing 120. Filters 105, 110, 110' may be positioned adjacent one another, or may have spacing therebetween.

5 An alternate configuration for a combined base-contaminant-removal filter and particulate filter is illustrated in Figure 6 as filter 70. Contaminant-removal filter 70 is defined by a body 72 having a first face 77 and an opposite second face 79. Generally, gas to be cleansed of contaminants enters filter 70 via first face 77 and exits via second face 79. Body 72 is similar to body 12 of filter 10' of Figure 2, having alternating corrugated layer 74 and facing layer 76. Layer 74 and layer 76
10 together define a plurality of passages 80. A first set of passages 80 are blocked or sealed at first face 79; these are illustrated as seals 85. At the opposite end of seals 85, at second face 79, passages 80 are open. Additionally, a second set of passages 80 are blocked or sealed at the second face 79 and are open at the first face 79.

15 In use, particulate laden gas enters open passage 80 at first face 79. The particulates become trapped in passages 80 due to the sealed second face 79, whereas the gas passes through the passage walls, formed by the fibrous substrate. The active material in and on the substrate removes airborne contaminants. The cleaned gas exits via second face 79.

20 Filter 70 is referred to a z-filter, a straight-through flow filter, or an in-line filter. The particulate removal features of such a filter as filter 70 are disclosed, for example, in U.S. Patent Nos. 5,820,646; 6,190,432; 6,350,291.

Positioned downstream of filter 10 or any of the other embodiments can be an indicator or indicating system to monitor the amount, if any, of contaminant that is passing through filter 10 without being removed. Such indicators are well known.

25 The shape and size of filter 10 is selected to remove the desired amount of contaminants from the gas or air passing therethrough, based on the residence time of the gas in filter 10. For example, preferably at least 90%, more preferably at least 95% of contaminants are removed. In some designs, as much as 98%, or more, of the contaminant is removed. It is understood that the desired amount on
30 contaminants to be removed will differ depending on the application and the amount and type of contaminant. As an example, for a semiconductor processing facility, the residence time of the incoming air in filter 10 is usually about 0.06 to 0.36 seconds, which can be accomplished with an element having a thickness of about 7.6 to 15 cm.

35

Examples

The following non-limiting examples will further illustrate the invention. All parts, percentages, ratios, etc., in the examples are by weight unless otherwise indicated.

5 Two different bodies were used for the example contaminant-removal elements:

Body 1: Body 1 was similar to that of Figure 2, formed by alternating a flat facing sheet and a sinusoidal corrugated sheet. Each of the sheets was made from 100% cellulose fibers. The sheets were wrapped to form a cylinder. The resulting
10 domed passages had an approximate height of 3.4 mm and width of 5.0 mm. The cross-sectional area of each passage was about 8.5 mm^2 . The sheets were held together with a urethane adhesive.

Body 2: Body 2 was similar to Body 1, except that Body 2 had domed passages with an approximate height of 1.05 mm and width of 2.90 mm. The cross-
15 sectional area of each passage was about 1.5 mm^2 . The sheets were made from 60% cellulose fibers and 40% PET fibers. The sheets were held together by the thermoplastic material, which had been melted with heat created by ultrasonic energy.

20 Acidic-Impregnated Examples

The bodies were impregnated with acidic material by the following method. A volume of acidic solution was placed in a beaker. The fibrous body was placed into the beaker, so that entire body was immersed in the solution. After approximately 60 seconds, the body was removed and allowed to dry in an oven for
25 1 hour. After drying, the resulting filter element was tested to determine its estimated life.

Breakthrough Test 1

The filter element was placed in a test chamber and sealed to provide an
30 upstream side of the filter and a downstream side. An air stream that contained 50 ppm of ammonia was delivered to the upstream side of the filter element at a flow rate of 30 liters/minute. The upstream and downstream ammonia concentrations were monitored using an ammonia detector.

35 Comparative Example A: A solution of 35 wt-% citric acid in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Comparative Example A was tested with Breakthrough Test 1, and the results are illustrated in the graph of Figure 7.

Example 1: A solution of 35 wt-% citric acid and 6 wt-% polyacrylic acid in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Example 1 was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 7.

5 Example 2: A solution of 35 wt-% citric acid and 1 wt-% polyacrylic acid in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Example 2 was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 7.

10 Example 3: A solution of 35 wt-% citric acid and 0.5 wt-% sodium benzoate in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Example 3 was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 7.

15 Figure 7 shows that over time (along the x-coordinate), the number of minutes at which the 10% threshold level was reached decreased for both Comparative Example A and Example 2, but not as quickly as for Comparative Example A. For the duration of the test, Examples 1 and 3 indicated no decrease in performance.

20 Comparative Example B: A solution 15 wt-% citric acid and 15 wt-% urea in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Comparative Example B was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 8.

25 Example 4: A solution of 15 wt-% citric acid and 10 wt-% polyacrylic acid in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Example 4 was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 8.

30 Figure 8 shows that over time (along the x-coordinate), the number of minutes at which the 10% threshold level was reached decreased for Comparative Example B, which included a humectant. For the duration of the test, Example 4 indicated no decrease in performance.

35 Example 5: A solution of 35 wt-% citric acid and 0.5 wt-% sodium sulfate in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 2.5 cm, was impregnated with the solution. Example 5 was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 9.

Example 6: A solution of 35 wt-% citric acid and 0.5 wt-% sodium benzoate in water was made. Body 2, having a diameter of about 3.8 cm and a length of about

2.5 cm, was impregnated with the solution. Example 6 was tested with Breakthrough Test 1 and the results are illustrated in the graph of Figure 9.

Example 7: A solution of 50 wt-% citric acid and 0.5 wt-% sodium benzoate in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 2.5 cm, was impregnated with the solution. Example was tested with the breakthrough test, and the results are illustrated in the graph of Figure 9.

Example 8: A solution of 35 wt-% citric acid and 0.5 wt-% sodium sulfate in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 2.5 cm, was impregnated with the solution. Example 8 was dried over the weekend (approximately 48 hours) and then tested according to Breakthrough Test 1. The results are illustrated in the graph of Figure 9.

Figure 9 shows that for the duration of the test, Examples 5, 6 and 8 indicated no decrease in performance. Example 7 had an increase in breakthrough time. This is possibly due to the small area of test data available as well as the small area of the filter tested. With the diameter of 3.8 cm, the center of the filter can become damaged and cause minor fluctuations in the 10% breakthrough time, but the overall capacity are good.

Alkaline-Impregnated Examples

The bodies were impregnated with basic material by the following method. A volume of basic solution was placed in a beaker. The fibrous body was placed into the beaker, so that entire body was immersed in the solution. After approximately 60 seconds, the body was removed and allowed to dry in an oven for 1 hour. After drying, the resulting filter element was tested to determine its estimated life. The filter element was placed in a test chamber and sealed to provide an upstream side of the filter and a downstream side.

Breakthrough Test 2

For Breakthrough Test 2, an air stream that contained 500 ppb SO₂ and 50% relative humidity was delivered to the upstream side of the filter element at a flow rate of 30 liters/minute. The upstream and downstream sulfur dioxide concentrations were monitored using an SO₂ detector.

Breakthrough Test 3

For Breakthrough Test 3, an air stream that contained 50 ppm SO₂ and 50% relative humidity was delivered to the upstream side of the filter element at a flow rate of 30 liters/minute. The upstream and downstream sulfur dioxide concentrations were monitored using an SO₂ detector.

Comparative Example C: A solution of 20 wt-% potassium carbonate (K_2CO_3) in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Comparative Example C was tested with Breakthrough Test 2, and the results are illustrated in the graph of Figure 10.

Comparative Example D: A solution of 20 wt-% K_2CO_3 in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Comparative Example D was tested with Breakthrough Test 2, and the results are illustrated in the graph of Figure 10.

Example 9: A solution of 20 wt-% K_2CO_3 and 6.6 wt-% KI in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Example 9 was tested with Breakthrough Test 2, and the results are illustrated in the graph of Figure 10.

Figure 10 shows the SO_2 levels passing through the tested filter elements over time. It is seen that Example 9, which included a promoter, provides better SO_2 removal than the Comparative Examples C and D.

Comparative Example E: A solution of 20 wt-% K_2CO_3 in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Comparative Example E was tested with Breakthrough Test 3. A photograph of the tested sample is illustrated in Figure 12.

Example 10: A solution of 20 wt-% K_2CO_3 and 6.6 wt-% KI in water was made. Body 2, having a diameter of about 3.8 cm and a length of about 7.5 cm, was impregnated with the solution. Example 10 was tested with Breakthrough Test 3. A photograph of the tested sample is illustrated in Figure 11.

The quantitative test results for Comparative Example E and Example 10, from Breakthrough Test 3, showed that the filter element life of the two was similar. However, comparison of Figures 11 and 12 show that even though the two samples adsorbed the same amount of SO_2 , there was a significant difference in the pressure drop across the filters. As seen in Figure 12, the inlet face of Comparative Example E has significant build-up of material, thus reducing the available volume for air flow therethrough. The crystal build-up on the inlet side of Comparative Example E was identified as K_2SO_3 . This build-up was not seen on Example 10, Figure 11. This build-up was not seen with Breakthrough Test 2, under lower concentration.

Reactant Impregnated Examples

The bodies were impregnated with reactant material by the following method. A volume of reactant solution was placed in a beaker. The fibrous body was placed into the beaker, so that entire body was immersed in the solution. After approximately 60 seconds, the body was removed and allowed to dry in an oven for 1 hour.

After drying, the resulting filter element was tested to determine its estimated life.

Breakthrough Test 4

For Breakthrough Test 4, the filter element was placed in a test chamber and sealed to provide an upstream side of the filter and a downstream side. An air stream that contained 0.7 ppm formaldehyde and 50% relative humidity was delivered to the upstream side of a filter element at a flow rate of 30 liters/minute. The filter element had a diameter of about 3.8 cm and a length of about 2.54 cm. The downstream formaldehyde concentrations were monitored using a detector.

Comparative Example F: A filter element was made from Body 1, having a diameter of about 3.8 cm and a length of about 2.54 cm. There was no surface or substrate treatment of the body substrate.

Example 11: A solution of 5% tris(hydroxymethyl) aminomethane in water was made. Body 1, having a diameter of about 3.8 cm and a length of about 2.54 cm, was impregnated with the solution.

Example 11 and Comparative Example F were tested according to Breakthrough Test 4, and the results are shown in Figure 13. The graph of Figure 13 illustrates that the impregnated filter element, Example 11, had a drastically extended life. The formaldehyde levels reached 0.5 ppm for Comparative Example F almost immediately, whereas Example 11 had at least 5000 minutes before 0.5 ppm formaldehyde was reached.

It is to be understood, however, that even though numerous characteristics and advantages of the present invention have been set forth in the foregoing description, together with details of the structure and function of the invention, the disclosure is illustrative only, and changes may be made in detail, especially in matters of shape, size and arrangement of parts within the principles of the invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

What is claimed:

1. A contaminant-removal filter comprising:
a body comprising a fibrous substrate, and throughout the substrate, active
5 material being one of:
 - (a) citric acid and at least one of a preservative or a stabilizer;
 - (b) basic material and a promoter, with the filter being free of any humectants; or
 - (c) a reactant selected from the group of sulfites, bisulfites, derivatives of
10 ammonia, specifically high molecular weight and stable amines, and strong alkali.
2. The filter according to claim 1 wherein, if present, the preservative is selected from the group consisting of sodium benzoate, benzoic acid, potassium
15 nitrate, potassium nitrite, sodium nitrite, sodium nitrate, methyl paraben, ethyl paraben, methyl paraben, ethyl paraben, propyl paraben, butyl paraben, propionic acid, sodium propionate, calcium propionate, sorbic acid, potassium sorbate, acetic acid, phosphoric acid, sodium sorbate, calcium sorbate, potassium benzoate, calcium benzoate, ethyl para-hydroxybenzoate, sodium ethyl para-hydroxybenzoate, propyl
20 para-hydroxybenzoate, biphenyl, diphenyl, orthophenyl phenol, sodium orthophenyl phenol, sodium sulfite, sodium sulfate, and combinations thereof.
3. The filter according to claim 1 wherein, if present, the stabilizer is polyacrylic acid.
25
4. The filter according to claim 1 wherein, if present, a ratio of citric acid to preservative is 1:1 to 5000:1.
5. The filter according to claim 1 wherein, if present, a ratio of citric acid to
30 stabilizer is 1:1 to 50:1.
6. The filter according to claim 1 wherein, if present, the basic material is an alkali metal or alkaline earth metal selected from the group consisting of carbonates, bicarbonates, and hydroxides, a quaternary ammonium compound, a metal oxides, a
35 basic anion ion- exchange resin, or combination thereof.
7. The filter according to claim 6, wherein the basic material is potassium carbonate.

8. The filter according to claim 1 wherein, if present, the promoter is potassium iodide, sodium iodide, lithium iodide, potassium iodate, sodium iodate, or lithium iodate.
- 5 9. The filter according to claim 8, wherein the promoter is potassium iodide.
10. The filter according to claim 1 wherein, if present, a ratio of the promoter to the basic material is 1:1 to 1:5000.
- 10 11. The filter according to claim 10, wherein the ratio of the promoter to the basic material is 1:1 to 1:10.
12. The filter according to claim 1 wherein, if present, the derivative of ammonia is one of 2,4 dinitrophenyl hydrazine (DNPH), 2-hydroxymethyl piperidine (2-
15 HMP), and tris(hydroxymethyl) aminomethane.
13. The filter according to claim 12, wherein the derivative of ammonia is tris(hydroxymethyl) aminomethane.
- 20 14. The filter according to claim 1 wherein, if present, the sulfite is sodium sulfite or potassium sulfite.
15. The filter according to claim 1 wherein, if present, the bisulfite is sodium bisulfite or potassium bisulfite.
- 25 16. The filter according to any of claims 1-15, wherein the fibrous substrate has a first face and a second face, and a plurality of passages extending from the first face to the second face.
- 30 17. The filter according to any of claim 1-16, wherein the filter is configured for straight-through flow.
18. The filter according to any of claims 1-17, wherein the fibrous substrate comprises thermoplastic fibers.
- 35 19. The filter according to any of claims 1-18, wherein the fibrous substrate comprises activated carbon fibers.

20. The filter according to claim 1 being free of any humectant.
21. A method of making a contaminant-removal filter according to any of claims 1-15, the method comprising:
- 5 (a) providing the substrate;
- (b) applying a mixture of active material to the substrate by impregnation.