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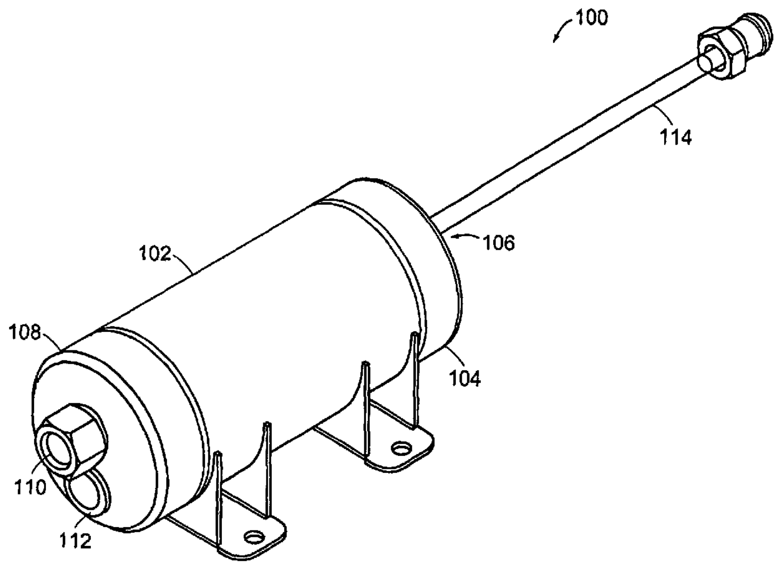

(57) Abstract: In preferred embodiments, the invention provides a gas filter for a reactive gas used in semiconductor processing tools and processes that are sensitive to molecular contamination. The reactive gas filters of the invention have improved pressure drop and can supply an output gas stream having concentrations of less than about 1 ppbv for both ammonia and sulfur dioxide for an input gas stream with ammonia and sulfur dioxide concentrations, respectively, of no greater than about 10 ppbv and 5 ppbv. In one aspect the invention provides a reactive gas filter with an improved pressure drop that can supply an output gas stream having concentrations of less than about 1 ppbv for both ammonia and sulfur dioxide for an input gas stream with ammonia and sulfur dioxide concentrations, respectively, of no greater than about 10 ppbv and 5 ppbv, using a filter media volume of no greater than about 0.5 liters.

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REACTIVE GAS FILTER

CROSS REFERENCES TO RELATED APPLICATIONS

The present application is a continuation–in–part of U.S. Patent Application No. 10/653,430, filed September 2, 2003. The entire contents of the above application is incorporated herein by reference.

BACKGROUND OF THE INVENTION

Gas filtration is critical in semiconductor manufacturing environments. Tremendous efforts are made to eliminate yield-reducing contaminants from the gases used in semiconductor processing tools. Contaminants can generally be classified as either particulate or molecular. Common particulate contaminants include dust, lint, dead skin, and manufacturing debris. Examples of yield-reducing contaminants include: acids, such as hydrobromic acid, nitric acid, sulfuric acid, phosphoric acid, hydrochloric acid; bases, such as ammonia, ammonium hydroxide, tetramehtlyammonium hydroxide, trimethylamine, triethylamine, hexamethyldisilazane, NMP, cyclohexylamine, diehtylaminoethanol, methylaamine, dimethylamine, ethanolamine, morpholine, condensables such as silicones and hydrocarbons with a boiling point greater than or equal to 150 (C; and dopants such as boron (usually as boric acid), phosphorous (usually as organophosphate), and arsenic (usually as an arsenate).

In semiconductor photolithography tools gas is supplied for generally two purposes: the actuation of tool pneumatics; and the purging of tool optics. Although purified dry air, nitrogen, or the like is generally used to drive pneumatics and purge optics, small amounts of contaminants are still liable to be present in the gas at concentrations sufficient to damage tool optics (for example, illuminator optics and projection lenses). Contaminating substances may adhere onto the optical elements to form molecular films. Molecular films on optical surfaces physically absorb and scatter incoming light. Scattered or absorbed light in photolithography optical surfaces causes distortion of the spherical quality of wavefronts. When the information contained in the spherical wavefront is distorted, the resulting image is also misformed or abberated. Image distortions, or in the case of photolithography, the inability to accurately reproduce the circuit pattern on the reticle, cause a loss of critical dimension control and process yield.

Contaminating substances may also chemically react with the optical surfaces of the photolithography tool and/or the wafers being processed in the tool. For example, sulfur dioxide may combine with water in the tool to produce sulfuric acid, which can irreversibly damage tool optics. In addition, ammonia may react with wafer surface materials, such as the resist, gate-insulating films, and the like, interfering with the photolithography processing step and reducing process yield. Thus, the purity of the gases supplied to semiconductor processing tools is of critical concern.

SUMMARY OF THE INVENTION

The invention includes a gas filter for a reactive gas used in semiconductor processing tools and processes that are sensitive to molecular contamination. Gas filters in accordance with the invention can be used, for example, to purify a gas such as the clean dry air used to run tool pneumatics or a gas used to purge the exposure area, the area between the final optical element and the wafer, commonly called the free working area, in processing tools such as 248 nm wavelength photolithography tools and I-line or 365 nm wavelength photolithography tools.

A preferred embodiment of the invention utilizes a gas filter for filtering a gas for use in a semiconductor processing system in combination with a gas monitor that measures contaminants entering, passing through, and/or exiting the filter. The gas monitoring device can be an active or passive sampling device that collects contaminants over time in a trap, for example, whose contents can be measured using analytical techniques. The gas flow can also be measured with a sensor such as a surface acoustic wave detector.

The gas filter can be used to purify synthetic air and clean dry air, gas streams used in photolithography equipment and in semiconductor processing tool pneumatics. It may be, however, advantageous to filter synthetic air prior to mixing, for example, filter oxygen and nitrogen separately, before mixing them together to make synthetic air.

In preferred embodiments, the gas filters of the invention remove particulates and molecular contamination, which may include acids, bases, condensables, or dopants, for example. The gas filter can include a chemically active or chemically catalytic filtering material in combination with an inert polymer (such as PTFE), activated carbon, or both. The gas filter can include a porous metal high purity particle filter, such as, for example, a porous nickel cup or porous nickel concentric tube.

Typically, filters are used to remove particulate and molecular contamination from gases supplied to semiconductor processing tools. Although purity of the supplied gas is a critical concern, it is not the only criteria for a useful gas filter. In addition to output purity, a gas filter must fit in the application for which it is intended and provide a sufficient flow of gas (with an acceptable pressure drop across the filter) for its intended purpose. Excessive pressure drop is undesirable for multiple reasons. For example, it increases fan load and power consumption, reduces airflow through a processing tool and positive pressure inside enclosures.

For example, for an optics purge gas, a gas flow rate from 150 to 250 standard liters per minute (slpm) may be required to sweep contaminants away from optical surfaces. Whereas for pneumatic actuation, a gas flow rate of 20 to 50 slpm may be required. In both situations, it is desirable to use a filter with a low pressure drop across the filter (generally the lower the better). However, factors that increase gas purity (for example, increased filter media density, volume, and/or filter size) also tend to increase the pressure drop across the gas filter.

The present invention provides a reactive gas filter with an improved pressure drop that can also supply. It is to be understood that pressure drop varies with both flow rate and input gas stream pressure. Typically, the pressure drop decreases with increasing input gas stream pressure and increase with increasing flow rate. In addition, pressure from varies with filter media volume and density. For example, gas purity can be increased by increasing the total media volume, media density, or both. It is particularly problematic, however, to provide a gas filter with reduced filter media volume and reduced pressure drop that can still provide an output gas stream having concentrations of less than about 1 ppbv for both ammonia and sulfur dioxide for an input gas stream with ammonia and sulfur dioxide concentrations, respectively, of no greater than about 10 ppbv and 5 ppbv.

Accordingly, in one aspect the present invention provides a gas filter with an improved pressure drop and a filter media volume of no greater than about 0.5 litters that can also supply an output gas stream having concentrations of less than about 1 ppbv for both ammonia and sulfur dioxide for an input gas stream with ammonia and sulfur dioxide concentrations, respectively, of no greater than about 10 ppbv and 5 ppbv.

In another aspect, the present invention provides a gas filter with an improved pressure drop and a filter media volume of no greater than about 3 litters that can also supply an output gas stream having concentrations of less than about 1 ppbv for both ammonia and sulfur dioxide for an input gas stream with ammonia and sulfur dioxide concentrations, respectively, of no greater than about 10 ppbv and 5 ppbv.

In accordance with one aspect of the present invention, the filter media volume is no greater than about 0.5 liters. In various preferred embodiments, for an input gas stream pressure in the range from about 100 pounds per square inch gauge (psig) to about 150 psig, a gas filter in accordance with the invention can be as follows: (i) in one embodiment, the gas filter has a pressure drop of no greater than about 9 pounds per square inch (psi) for an outlet flow rate in the range from about 3 slpm to about 20 slpm; (ii) in another embodiment, the gas filter has a pressure drop of no greater than about 20 psi for an outlet flow rate in the range from about 20 slpm to about 50 slpm; (iii) in another embodiment, the gas filter has a pressure drop of no greater than about 50 psi for an outlet flow rate in the range from about 50 slpm to about 100 slpm; In various other embodiments of a gas filter having a filter media volume of no great than about 0.5 liters, for an input gas stream pressure in the range from about 70 psig to about 100 psig a gas filter in accordance with the invention can be as follows: (i) in one embodiment, the gas filter has a pressure drop of no greater than about 13 psi for an outlet flow rate in the range from about 3 slpm to about 20 slpm; (ii) in another embodiment, the gas filter has a pressure drop of no greater than about 35 psi for an outlet flow rate in the range from about 20 slpm to about 50 slpm; (iii) in another embodiment, the gas filter has a pressure drop of no greater than about 80 psi for an outlet flow rate in the range from about 50 slpm to about 100 slpm;

In various other embodiments of a gas filter having a filter media volume of no great than about 0.5 liters, for an input gas stream pressure in the range from about 30 psig to about 70 psig a gas filter in accordance with the invention can be as follows: (i) in one embodiment, the gas filter has a pressure drop of no greater than about 18 psi for an outlet flow rate in the range from about 3 slpm to about 20 slpm; (ii) in another embodiment, the gas filter has a pressure drop of no greater than about 50 psi for an outlet flow rate in the range from about 20 slpm to about 50 slpm; (iii) in another embodiment, the gas filter has a pressure drop of no greater than about 100 psi for an outlet flow rate in the range from about 50 slpm to about 100 slpm; In accordance with one aspect of the present invention, the filter media volume is no greater than about 3 liters. In various preferred embodiments, for an input gas stream pressure in the range from about 100 pounds per square inch gauge (psig) to about 150 psig, a gas filter in accordance with the invention can be as follows: (i) in one embodiment, the gas filter has a pressure drop of no greater than about 5 pounds per square inch (psi) for an outlet flow rate in the range from about 3 slpm to about 20 slpm; (ii) in another embodiment, the gas filter has a pressure drop of no greater than about 16 psi for an outlet flow rate in the range from about 20 slpm to about 50 slpm; (iii) in another embodiment, the gas filter has a pressure drop of no greater than about 47 psi for an outlet flow rate in the range from about 50 slpm to about 100 slpm; (iv) in another embodiment, the gas filter has a pressure drop of no greater than about 93 psi for an outlet flow rate in the range from about 100 slpm to about 150 slpm; and (v) in another embodiment, the gas filter has a pressure drop of no greater than about 230 psi for an outlet flow rate in the range from about 150 slpm to about 250 slpm.

In various other embodiments of a gas filter having a filter media volume of no great than about 3 liters, for an input gas stream pressure in the range from about 70 psig to about 100 psig a gas filter in accordance with the invention can be as follows: (i) in one embodiment, the gas filter has a pressure drop of no greater than about 6.5 psi for an outlet flow rate in the range from about 3 slpm to about 20 slpm; (ii) in another embodiment, the gas filter has a pressure drop of no greater than about 25 psi for an outlet flow rate in the range from about 20 slpm to about 50 slpm; (iii) in another embodiment, the gas filter has a pressure drop of no greater than about 80 psi for an outlet flow rate in the range from about 50 slpm to about 100 slpm; (iv) in another embodiment, the gas filter has a pressure drop of no greater than about 165 psi for an outlet flow rate in the range from about 100 slpm to about 150 slpm; and (v) in another embodiment, the gas filter has a pressure drop of no greater than about 420 psi for an outlet flow rate in the range from about 150 slpm to about 250 slpm.

In various other embodiments of a gas filter having a filter media volume of no great than about 3 liters, for an input gas stream pressure in the range from about 30 psig to about 70 psig a gas filter in accordance with the invention can be as follows: (i) in one embodiment, the gas filter has a pressure drop of no greater than about 12 psi for an outlet flow rate in the range from about 3 slpm to about 20 slpm; (ii) in another embodiment, the gas filter has a pressure drop of no greater than about 30 psi for an outlet flow rate in the range from about 20 slpm to about 50 slpm; (iii) in another embodiment, the gas filter has a pressure drop of no greater than about 60 psi for an outlet flow rate in the range from about 50 slpm to about 100 slpm; (iv) in another embodiment, the gas filter has a pressure drop of no greater than about 90 psi for an outlet flow rate in the range from about 100 slpm to about 150 slpm; and (v) in another embodiment, the gas filter has a pressure drop of no greater than about 150 psi for an outlet flow rate in the range from about 150 slpm to about 250 slpm.

In preferred embodiments, the gas filter of the present invention comprises a container having a substantially cylindrical tube portion, which has an inlet end with an inlet port, an outlet end with an outlet port, and an internal chamber. The inlet port has an inlet particle filter that extends into the internal chamber and the outlet port has an outlet particle filter that extends into the internal chamber. A filter media fills the internal chamber.

The filter media can be bedded, graded, mixed or a combination of both. For example, a granulated activated charcoal (GAC), material can be bedded to form a first bed and an acid treated GAC and base treated GAC mixed and bedded to form a second bed. In another example, the base treated GAC is bedded to form a first bed and the acid treated GAC may be graded in the GAC to form a second bed where the concentration of acid treated GAC varies across the second bed.

In preferred embodiments, the filter media includes porous adsorptive materials such as zeolites, activated carbons, molecular sieves, etc. In one embodiment, the filter media incorporates treated GAC materials which are designed to remove ammonia and sulfur dioxide. In another embodiment, the filter media incorporates zeolites and/or highly acidic porous materials which are designed to remove ammonia and amines, to which chemically amplified deep ultraviolet (DUV) photoresists are sensitive.

The filter media can incorporate materials which are designed to remove condensable organic compounds, for example, organic molecules with a molecular weight of greater than about 90 g/mol. and a boiling point greater than about 150 (C. Typically, condensable organics include organic compounds including carbon atoms within the range of approximately six to thirty carbon atoms ($C_6 - C_{30}$) and high molecular weight organics with an inorganic component which is not volatilized through combination with oxygen, such as, for example, C_6 silanes, C_6 siloxanes and C_6 iodates.

In a preferred embodiment, the present invention provides a gas filter with improved pressure drop that can also supply an output gas stream having a total condensable organic concentration of less than about 10 ppbv for an input gas stream with a total condensable organic concentration of no greater than about 100 ppbv. In accordance with another preferred embodiment, the present invention provides a gas filter with improved pressure drop that can also supply an output gas stream where about 99% or greater of the condensable organic contaminants have been removed from an input gas stream with a total condensable organic concentration of no greater than about 100 ppbv.

In preferred embodiments, the filter media is selected to purify compressed dry air. In one embodiment of a compressed dry air filter, filter media comprises granulated activated charcoal (GAC), an acid treated GAC for removal of ammonia, and a base treated GAC for removal of sulfur dioxide. The filter media can also include inorganic adsorbents (such as, for example, zeolites and molecular sieves, such as, for example, SiO_2/Al_2O_3) and inorganic adsorbents treated with a chemically active or chemically catalytic filtering material.

In preferred embodiments, the gas filter of the present inventions incorporates particle filters for removal of particulates from the input and output gas streams. The particulate filters are disposed in the internal chamber, although more difficult to construct, it is believed that such placement facilitates improved flow distribution. In preferred embodiments, the gas filter includes porous nickel particle filters that can effectively remove particulates with an average size of about 0.003 microns and greater. In one preferred embodiment, the particle filter is a porous nickel concentric tube high purity particle filter such as supplied by Mott Corporation (84 Spring Lane, Farmington, CT, 06032-3159) under part number 2390804. In another preferred embodiment, the particle filter is a porous nickel cup high purity particle filter such as supplied by Mott Corporation under part number 1204380. In preferred embodiments, the particle filter removes 99.9999999% or greater of all particles down to about 0.003 microns.

In other embodiments, a gas filter in accordance with the invention can be cooled using a thermoelectric cooling device. Organics can be condensed and collected using such a low temperature embodiment. The low temperature embodiment can include heat sinks to dissipate the heat energy generated.

A controlled humidification source can be coupled to the gas filter to provide a humidity controlled gas supply. The controlled humidification source can comprise an ultrapure deionized (DI) water source to add water to the gas and a dryer to remove water from the gas stream. The controlled humidification source can further comprise a sensor system to sense gas stream humidity (inlet, outlet or both) and feedforward and/or feedback a signal to the controlled humidification source. Preferably, a gas filter of the present invention is brought into equilibrium with a desired humidity level before it is incorporated into a reactive gas supply line.

The foregoing and other objects, features and advantages of the invention will be more fully understood from the following descriptions of various embodiments of the invention and the accompanying drawings. In the drawings like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are described with reference to the following drawings, wherein:

Figure 1 is an isometric illustration of a preferred embodiment of a reactive gas filter in accordance with the present invention;

Figures 2A-2W illustrate various detailed views of a preferred embodiment of a reactive gas filter in accordance with the present invention, where the various parts in Figures 2A-2I, 2K-2O, 2R-2S, and 2U-2W are to scale, and Figures 2J, 2P-2Q, and 2T are various isometric views not necessarily drawn to scale;

Figures 3A-3D illustrate various detailed views of a preferred embodiment of a reactive gas filter of Figures 2A-2W where square bracket dimensions are in millimeters and unbracketed dimensions in inches;

Figure 4A is an isometric illustration of another preferred embodiment of a reactive gas filter in accordance with the present invention;

Figure 4B is a side view of the gas filter of Figure 4A;

Figure 5A is an isometric illustration of another preferred embodiment of a reactive gas filter in accordance with the present invention;

Figures 5B-5D illustrate various detailed views to scale of a preferred embodiment of a reactive gas filter in accordance with the present invention, where the unbracketed dimensions in inches;

Figure 6 illustrates a schematic diagram of a system for determining the pressure drop of a gas filter in accordance with the present invention;

Figures 7A-7C are plots of pressure drop versus flow rate at various inlet gas stream pressures for gas filters substantially similar to those illustrated in Figures 1-5D, the plots were determined using a system substantially similar to that illustrated in Figure 6;

Figures 8A-8V illustrate various detailed views of a preferred embodiment of a reactive gas filter in accordance with the present invention, where the various parts in Figures 8B-8G, 8J-8L, 8O-8P, and 8R-8T are to scale, and Figures 8A, 8H-8I, 8M-8N, 8Q and 8U-8V are various isometric views not necessarily drawn to scale;

Figure 9 is a plot of pressure drop versus flow rate at various inlet gas stream pressures for a prior art clean dry air filter;

Figures 10 is a plot of pressure drop versus flow rate at various inlet gas stream pressures for gas filters substantially similar to those illustrated in Figures 8A-8V;

Figures 11A-11Z, 11AA-11AZ, and 11BA-11BJ illustrate various detailed views of a preferred embodiment of a reactive gas filter in accordance with the present invention, where the various parts in Figures 11B-11F, 11H-11J, 11L-11N, 11P-11R, 11T-11V, 11X-11Z, 11AB-11AD, 11AF-11AG, 11AJ-11AL, 11AN-11AP, 11AR-11AT, 11AV-11AX, 11AZ, 11BB, 11BD, 11BF, 11BH, and 11BJ are to scale, and Figures 11A, 11G, 11K, 11O, 11S, 11W, 11AA, 11AE, 11AI, 11AM, 11AQ, 11AU, 11AY, 11BA, 11BC 11BE, 11BG, and 11BI are various isometric views and non-isometric views not necessarily drawn to scale;

Figures 12A-12B are plots of pressure drop versus flow rate at various inlet gas stream pressures for gas filters substantially similar to those illustrated in Figures 11A-11Z, 11AA-11AZ, and 11BA-11BJ;

Figures 13A-13C are plots of pressure drop versus flow rate at various inlet gas stream pressures for a Mott Corporation high purity concentric tube particle filter part number 2390804;

Figure 14 illustrates an embodiment of an apparatus for determining a contaminant;

Figure 15 illustrates an embodiment of a refractory trap in accordance with the present invention;

Figure 16 illustrates an embodiment of a filtering system in accordance with the invention;

Figures 17A-17C illustrate schematic representations of an apparatus that functions as a concentrator in an embodiment of a filter system;

Figure 18 illustrates a schematic representation of a system that includes a filter and detection apparatus in accordance with the present invention;

Figures 19A-19C illustrates an embodiment of a detector for monitoring contaminants;

Figures 20A and 20B illustrate embodiments of detectors in accordance with an embodiment of the invention;

Figure 21 illustrates a method for using a detector in accordance with an embodiment of the invention;

Figure 22 illustrates an embodiment of a portable dry sampling system;

Figure 23A illustrates a schematic representation of a handheld dry sampling device in accordance with an embodiment of the invention;

Figure 23B illustrates a handheld dry sampling device;

Figures 24A-24C illustrate a method for using a dry sampler to monitor contaminants in a gas supply;

Figure 25 illustrates a schematic representation of an exemplary computer in accordance with an embodiment of the invention; and

Figure 26 illustrates a schematic representation for monitoring a contaminant in a gas supply in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a gas filter for a reactive gas used in semiconductor processing tools and processes that are sensitive to molecular contamination. Contaminants in a gas can come from many sources including the cleanroom environment itself. Table 1 illustrates various species in a cleanroom environment, such as, for example, a fabrication environment using photolithography systems. The low molecular weight species, such as acetone, isopropyl alcohol and low molecular weight siloxanes are the most prevalent in manufacturing environments. In addition, even so called clean gases, such as clean dry air, can contain contaminants at concentrations sufficient to negatively impact semiconductor processing and reduce yield.

Compounds that are most likely to reduce the performance of optics are compounds having a high contamination coefficient or a high molecular weight; examples can include, but are not limited to, methoxytrimethyl silane, trimethyl silane and trimethyl silanol. These compounds appear in italics in Table 1 and have a higher molecular weight, higher contamination coefficient and an inorganic component. Compounds that negatively impact optical systems can also include refractory compounds such as silanes, siloxanes and iodates, in particular hexamethyldisiloxane (HMDSO or C_6-siloxane). Refractory materials are compounds containing atoms forming nonvolatile or reactive oxides, for example, but not limited to, phosphorous (P), silicone (Si), sulfer (S), boron (B), tin (Sn), aluminum (Al). These contaminants may be exposed to deep ultraviolet (DUV) light and may form refractory compounds resistant to active oxygen treatment.

TABLE 1

Compound (in cleanrooms)	Typical concentration, ppbv
Isopropyl Alcohol	610.0
Acetone	330.0
Ethanol	134.0
Silane,Methoxytrimethyl-	*35.0*
Heptane,Hexadecafluoro-	28.0
2-Pentanone	17.0
2-Butanone(MEK)	9.8
Hexane,Tetradecafluoro-	8.9
Butanoic Acid,Heptafluoro-	5.2
Tetrahydrofuran	3.3
3-Buten-2-one	2.5
4-Methyl-2-pentanone(MIBK)	1.9
Silane,Trimethyl(1-Methylethoxy)-	*1.7*
n-Pentane	1.4
Silanol,Trimethyl-	*1.4*

Photochemical decomposition reactions occur when high-energy photons interact with organic vapors. These reactions form extremely reactive free radicals from otherwise neutral and relatively inert organic molecules. Irrespective of where radical formation occurs, in the gas phase or on the surface of optical elements, the resulting free radicals may react to form much larger organic compounds, which can contaminate optical elements. In severe cases, a polymer layer may be formed on the optical surface. The relationship between the chemical nature of the organic species and wavelength of light it absorbs can affect the nature and severity of optics contamination. For example, I-line or 365 nm wavelength light is energetic enough to break down only a few iodated components, which are not commonly found in clean room air. 248 nm wavelength light, typically used in deep ultraviolet (DUV) lithography for fabricating 250 to 150 nm linewidth devices, is more efficient and reacts with most halogenated organics and may even interact with some common hydrocarbons. 193 nm light, required for less than 130 nm geometries, reacts very efficiently with a wide range of airborne or gaseous molecular organic contaminants.

As the wavelength of light used in the lithography exposure tool decreases, the energy per unit photon increases. These progressively higher energy photons stand a better chance of breaking the bonds of a number of commonly present molecular species, ultimately rendering them into reactive species that stick to optical surfaces. 157 nm optical elements are even more sensitive to environmental conditions than 193 nm optics because this wavelength of light is efficiently absorbed or interacts with nearly all organic species plus oxygen and atmospheric moisture, requiring the exposure area, the area between the final optical element and the wafer, commonly called the free working area, to be purged with an inert, clean, dry, oxygen-free gas.

In accordance with a preferred embodiment of the present invention, the gas filter includes a substantially cylindrical housing having an internal chamber filled with a filter media. Figure 1 is an exterior isometric view of a gas filter 100 in accordance with a preferred embodiment of the invention. The housing comprises a substantially cylindrical potion 102, an outlet end 104 having an outlet port 106, and an inlet end 108 having an inlet port 110. The housing can also have a fill port 112 for loading the internal chamber with the filter media. The gas filter can also include, for example, an inlet assembly, outlet assembly 114, or both that facilitate connecting the gas filter to a reactive gas source, reactive gas line, manifold, or tool.

Preferably, the housing and any assemblies are constructed of a low sulfur metal such as 316 stainless steel and 304 stainless steel, which are suitable for use in the present invention. It is to be understood that the housing and any assemblies are to be free of lubricants, grease, dirt, etc. Accordingly, it is preferred that the components be degreased, and cleaned with, for example, a 20% aqueous alcohol solution, preferably in an ultrasonic cleaner. Such cleaning methods are known to the art. In addition, it is preferred that all welds that may communicate with the interior of gas filter are performed in an inert gas environment, such as, for example argon, and preferably all welds are performed in an inert gas environment to facilitate producing gas free welds. Preferably, all "welds" are gas, turgsten are welds with welds on curved surfaces made with an orbital welder. Prior to use, it is also preferred that the gas filters of the present invention be purged, for example, by a flow of an inert gas, such as, nitrogen, at elevated temperatures (for example, 100°C) for 24 to 72 hours. It is also preferred that prior to use that the gas filters of the present invention are brought into equilibrium with the humidity of the gas to be filtered.

The filter media in the internal chamber can include an inert polymer, carbon, activated carbon, and inorganic material in the form of, for example, pellets or granules. Preferably, the pellets or granules have an average mesh size in the range from about 16 U.S. mesh to about 50 U.S. mesh. These pellets or granules may be untreated or treated with a chemically active or chemically catalytic filtering material to facilitate adsorption of one or more types of organic and inorganic compounds, including, for example, acids, such as hydrobromic acid, nitric acid, sulfuric acid, phosphoric acid, hydrochloric acid; bases, such as ammonia, ammonium hydroxide, tetramehtlyammonium hydroxide, trimethylamine, triethylamine, hexamethyldisilazane, NMP, cyclohexylamine, diehtylaminoethanol, methylaamine, dimethylamine, ethanolamine, morpholine, condensables such as silicones and hydrocarbons with a boiling point greater than or equal to 150 °C; and dopants such as boron (usually as boric acid), phosphorous (usually as organophosphate), and arsenic (usually as an arsenate).

A wide variety chemically active or chemically catalytic filtering material can be used to pellet or granule to form a filter media. Example of materials for adsorption of basic amines include, but are not limited to, phosphoric acid (H_3PO_4), sulfonated styrene divinyl benzene. Example of materials for adsorption of acids (such as, for example sulfuric acids) include, but are not limited to, potassium carbonate (K_2CO_3), quaternary amines. In addition to acids and bases, certain compounds are of particular concern in photolithography systems, such as HMDSO. Examples of materials for adsorption of HMDSO include, but are not limited to, untreated granulated activated carbon (GAC), zeolites.

In accordance with a preferred embodiment, the filter media includes a GAC with a minimum surface area per gram of about 1200 m^2/g and a density in the range from about 0.45 to about 0.50 g/ml, a phosphoric acid treated GAC with a minimum surface area per gram of about 1000m^2/g and a density in the range from about 0.66 to about 0.69 g/ml, and a potassium carbonate treated GAC with a minimum surface area per gram of about 1000 m^2/g and a density in the range from about 0.7 to about 0.9 g/ml.

Additional chemically active or chemically catalytic filtering materials for contamination control are described in U.S. Application No.: 10/205,703, filed on July 26, 2002 entitled “Filters Employing Porous Strongly Acidic Polymers and Physical Adsorption Media”, U.S. Application No.: 09/969,116, filed on October 1, 2001 entitled “Protection of Semiconductor Fabrication and Similar Sensitive Processes”, and U.S. Application No. 09/783,232, filed on February 14, 2001 entitled “Detection of Base Contaminants In Gas Samples”, the entire teachings of the above referenced applications are being incorporated herein by reference in their entirety.

Figures 2A-2W present detailed views of a preferred embodiment of a gas filter in accordance with the present invention for use with a reactive gas such as clean dry air (CDA). Figures 2A-2C show external scale views of the gas filter 200, having a substantially cylindrical central portion 202. The outlet end 204 is shown end on in Figure 2C and has an outlet port 206. The outlet end 204 can also include an outlet interface assembly 208, 210, 212, to facilitate connection to a gas line, manifold etc. The inlet end 214 is shown end on in Figure 2B and includes an inlet port 216 and can also include a fill port 220. The inlet end 216 can include an inlet interface assembly 218, to facilitate connection to a gas line, manifold etc., and the central portion 202 can include mounting brackets 219.

Figures 2D-2F show scale views of the inlet end 214 with interface assemblies, where the unbracketed dimensions shown are for a preferred embodiment and are in inches. Figure 2D shows an end view of the inlet end 214 with the inlet port 216 and a fill port 220. Figure 2E shows the components of an inlet interface assembly 222, 224, 226, and a porous nickel cup particle filter 228 that in a preferred embodiment is welded to sub-assembly 224. Figure 2E is a hidden-line side view of an inlet end 214 with an inlet interface assembly and a fill port assembly 230 with plug 232. Figure 2H shows an end view of the inlet end with assemblies 215 and Figure 2I shows a cross-section along BB of Figure 2H. The unbracketed dimensions in Figure 2I are in inches and the square bracketed dimensions in millimeters (mm).

The cross sectional view also shows a portion of the internal chamber 201 into which the inlet particle filter 228 extends. While Figure 2J shows an exploded assembly drawing (not necessarily to scale) of the inlet end with assemblies 215.

Figures 2K-2M show scale views of the outlet end 202 with interface assembly 208, 210, 212, where the unbracketed dimensions shown are for a preferred embodiment and are in inches. Figure 2K shows an end view of the outlet end 204 with the outlet port 206. Figure 2M and 2L shows the components of an outlet interface assembly 208, 210, 212, and 234, and a porous nickel cup particle filter 226 that in a preferred embodiment is welded to sub-assembly 234. Figure 2L is a hidden-line side view of the outlet end 204 with an outlet interface assembly having a tube 208, an interface fitting 212 with plug 210. Figure 2N shows a cross-section along GG of end view Figure 2O and Figure 2O shows an end view of the outlet end with outlet interface assembly 233. The unbracketed dimensions in Figure 2N are in inches. The cross sectional view Figure 2N also shows another portion of the internal chamber 201 into which the outlet particle filter 236 extends. While Figure 2P shows an isometric view (not necessarily to scale) of the outlet end with interface assembly 233.

Figures 2Q-2S show details of the substantially cylindrical portion 202 where all unbracketed dimensions are given in inches. Figure 2Q shows an isometric view (not necessarily to scale) of the substantially cylindrical portion. Figures 2R and 2S are to scale, showing respectively an end view and a cross section along line HH. The cross sectional view Figure 2S, shows the remaining portion of the internal chamber 201.

Figures 2T-2W show details of a mounting bracket 219, where Figure 2T is an isometric view not necessarily to scale, and Figures 2U-2W are plan views to scale where unbracketed dimensions are in inches.

In one preferred embodiment, the components, materials and hardware of Figures 2A-2W are as follows:

0.083", 2.5" outside diameter (OD) Stainless Steel (SS) Tubing, 202;
2.5" SS Pipe Cap (Swagelok B16W-CAP-37-101), 204;
1.4" Inch OD SS Tubing, 208;
4" VCR Short Tube Weld Gland (Swagelok 6LV-4-VCT-3S-4TB3), 210;

1.4" VCR Male Gland Nut (Swagelok SS-4-VCR-4), 212;

BSP Fitting (Swagelok -4TA-7-4RT), 218;

0.06-304 SS Wall Weld Bracket, 219;

BSP Fitting -4-TA-7-4RT (Swagelok), 222;

Nickel (Ni) High Purity Particle Filter Cup, Mott Corp. (part no. 1204380), 228;

Fill Spout Constructed out of Round Stock, Tapped ¼-20, 230;

Machined Washer, Used as Transition, 224;

2.5" SS Pipe Cap with Fill Spout (Swagelok B16W-CAP-37-101), 214;

BSP Fitting -4-TA-7-4RT (Swagelok), 222;

¼" 20 SS Pipe Plug (Swagelok), 232;

Ni High Purity Particle Filter Cup, Mott Corp. (part no 1204380), 236;

¼" OD SS Tubing, Machined to Length, 238;

4" VCR Short Tube Weld Gland (Swagelok 6LV-4VCT-3S-4TB3), 242;

¼" VCR Male Gland Nut (Swagelok SS-4-VCR-4), 240; and

Machine Washer, Used as Transition, 234.

Figures 3A-3D illustrate various detailed views of a preferred embodiment of the reactive gas filter 200 of Figures 2A-2W including an inlet wit inlet assemblies 215 and an outlet with outlet assembly 233. In Figures 3A-3D, square bracket dimensions are in millimeters and unbracketed dimensions in inches. In a preferred embodiment 300, a the gas filter 200 fits within the three-dimensional footprint 302 illustrated as a shadow-box about the filter.

In accordance with another preferred embodiment, the gas filter of the present invention is substantially as shown in Figures 4A-4B and 5A-5D. Figures 4A-4B present shaded exterior views while Figures 5A-5D provide more detailed views. In accordance with a preferred embodiment of the present invention, the gas filter 400 includes a substantially cylindrical housing having an internal chamber filled with a filter media. The housing comprises a substantially cylindrical potion 402, an outlet end 404 having an outlet port 406, and an inlet end 408 having an inlet port 410. The inlet port 410 and outlet port 406 do not share a common axis, as the inlet port 410 is placed off of the axis of the substantially cylindrical potion 402 while the outlet port 406 is placed on the axis of the substantially cylindrical potion 402. The housing can also have a fill port 412 for loading the internal chamber with the filter media. The gas filter can also include, for example, an inlet assembly, outlet assembly 414, or both that facilitate connecting the gas filter to a reactive gas source, reactive gas line, manifold, or tool. Also illustrated is a concept for a product label 403 on which is an arrow indicating the recommended direction of gas flow through the gas filter.

Figure 5A is an exterior isometric view of a gas filter 500 in accordance with a preferred embodiment of the invention. The housing comprises a substantially cylindrical potion 502, an outlet end 504 having an outlet port 506, and an inlet end 514 having an inlet port 516. The gas filter can also include, for example, an inlet interface assembly 518 and an outlet interface assembly 508 to facilitate connecting the gas filter to a reactive gas source, reactive gas line, manifold, or tool. The housing can also have a fill port 520 for loading the internal chamber with the filter media with a fill port assembly 521 to facilitate filling the internal chamber and readily sealing the chamber. In addition, the gas filter 500 can include mounting brackets. Figures 5B-5D show external scale views of the gas filter 501, having a substantially cylindrical central portion 502. The outlet end 504 is shown end-on in Figure 5D and has an outlet port 506. The outlet end 504 can also include an outlet interface assembly 508, 510, 512, to facilitate connection to a gas line, manifold etc. The inlet end 514 is shown end on in Figure 5C and includes an inlet port 516 and can also include a fill port 520. The inlet end 516 can include an inlet interface assembly 518, to facilitate connection to a gas line, manifold etc., and the central portion 502 can include mounting brackets 519. The various details of the components of the gas filter 501 of Figures 5B-5D are substantially similar to those of Figures 2A-2W, with the exception of the placement of the outlet port 506 on the outlet end 504. As shown in Figures 5A-5D, the outlet port 506 is centered in the outlet end 504 and thus has an axis coincident with that of the central portion 502. Such placement of the outlet port 506, relative to the inlet port 516, is believed to help prevent channeling of a gas flow through the gas filter 501.

In accordance with preferred embodiments of the invention, gas filters substantially in accordance with Figures 2A-2W and 4A-5D can provide improved pressure drop and an output gas stream having concentrations of less than about 1 ppbv for both ammonia and sulfur dioxide for an input gas stream with ammonia and sulfur dioxide concentrations, respectively, of no greater than about 10 ppbv and 5 ppbv, when the internal chamber is filled with a filter media including, for example, about 80% GAC, about 10% acid treated GAC, and about 10% base treated GAC, where the average mesh size of the treated and untreated GAC is in the range from about 20 U.S. mesh to about 50 U.S. mesh. In accordance with a preferred embodiment, the gas filter also provides an output gas stream having a total condensable organic concentration of less than about 10 ppbv of HMDSO for an input gas stream with a total condensable organic concentration of no greater than about 100 ppbv including HMDSO.

In one preferred embodiment, the filter media includes about 80% GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, about 10% potassium carbonate treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, and about 10% phosphoric acid treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh.

Figure 6 illustrates a schematic diagram of a system for determining the pressure drop of a gas filter in accordance with the present invention. The pressure of the inlet gas stream 602 is controlled by a pressure regulator 604. Preferably, the inlet gas is compressed clean dry air, however, inert gases such as nitrogen are also suitable for testing the pressure drop of the gas filter. The inlet gas stream is first passed through a carbon scrubber 606 and the pressure drop across the gas filter 608 measured with a pressure gauge 610 set to measure the differential in pressure between the gas filter 608 inlet and outlet gas streams. The pressure of the outlet gas stream is measured with a pressure gauge 612 to facilitate converting the output gas stream flow rate as measured by a flow meter 614 into standard liters per minute. In these tests, the output gas stream was vented to atmosphere 616.

Figures 7A-7C show pressure drop test results for a gas filter in accordance with the invention that is substantially similar to the preferred embodiment of Figures 5A-5D. The test results shown in Figures 7A-7B are for a gas filter without a filter media and the test results in Figure 7C are for a gas filter with filter media. Tests on other preferred embodiments of the invention predict an additional pressure drop in the range from about 1 psi to about 3 psi for a filter media having a volume of about

0.4 liters (the estimated volume of the internal chamber of the embodiment of Figures 5A-5D) that includes about 80% GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 US mesh, about 10% potassium carbonate treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, and about 10% phosphoric acid treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh.

Referring to Figures 7A and 7B, Figure 7A is a plot 700 pressure drop (in bars) versus outlet flow rate (in slpm) at various inlet gas stream pressures, whereas Figure 7B is a plot 701 pressure drop (in psi) versus outlet flow rate (in standard cubic feet per hour "cfh") at various inlet gas stream pressures. The data shown in Figures 7A and 7B is tabulated in Table 2. Both Figures 7A and 7B show the variation in pressure drop with inlet gas pressure at about 30 psi (2.06 bar) 702, 703; at about 60 psi (4.13 bar) 704, 705; at about 90 psi (6.20 bar) 706, 707; and at about 100 psi (6.89 bar) 708, 709, and the performance of the gas filter at these inlet pressure over a range of outlet flow rates.

TABLE 2

cfh	cfm	lpm	30 psi	2.06 bar	60 psi	4.13 bar	90 psi	6.20 bar	100 psi	6.89 bar
6	0.10	2.83	1.50	0.10	0.90	0.06	0.60	0.04	0.70	0.05
20	0.33	9.44	6.50	0.45	3.00	0.21	2.40	0.17	2.00	0.14
40	0.67	18.88	14.00	0.97	7.00	0.48	5.00	0.34	4.00	0.28
55	0.92	25.96			12.00	0.83	7.40	0.51	7.20	0.50
70	1.17	33.04			14.50	1.00	10.50	0.72	10.60	0.73
85	1.42	40.12					14.00	0.97	12.50	0.86
95	1.58	44.83							14.90	1.03

Figure 7C is a plot 710 pressure drop (in bars) versus outlet flow rate (in slpm) at various inlet gas stream pressures at various inlet gas stream pressures. The data shown in Figure 7C is tabulated in Table 3 and the error on each measurement is estimated to be ± 5%. Figure 7C shows the variation in pressure drop with inlet gas pressure at about 2.06 bar 712; at about 4.13 bar 714; at about 6.20 bar 716,; at about 6.89 bar 718, and at about 7.5 bar 720, and the performance of the gas filter at these inlet pressure over a range of outlet flow rates. The plot 710 also shows polynomial fits 722-730 to the 2.06 bar data 722, the 4.13 bar data 724, the 6.20 bar data 726, the 6.89 bar data 728 and the 7.5 bar data 730.

TABLE 3

lpm	2.06 bar	4.13 bar	6.20 bar	6.89 bar	7.5 bar
2.8	0.1	0.1	0.0	0.0	0.1
9.4	0.4	0.2	0.2	0.1	0.1
18.9	0.7	0.5	0.3	0.3	0.3
26.0	1.0	0.8	0.5	0.5	0.4
29.5	1.4				
33.0		4.0	0.7	0.7	0.6
40.1		1.4	1.0	0.9	0.8
44.8		1.8	1.1	1.0	1.0
47.2		1.9			
56.6			1.7	1.5	1.4
62.5			2.3		
68.4				2.5	
70.8					2.6

Figures 8A-8V present detailed views of another preferred embodiment of a gas filter in accordance with the present invention for use with a reactive gas such as clean dry air (CDA). Figure 8A shows an isometric view not necessarily to scale of the gas filter 800, while Figures 8B-8G show external scale views where unbracketed dimensions are in inches and square bracketed dimensions are in mm. The gas filter 800 comprises a substantially cylindrical central portion 802 an outlet end 804 having an outlet port 806, that can further include an outlet interface assembly 808 to facilitate connection to a gas line, manifold etc. The inlet end 814 is shown end-on in Figures 8D and 8G and includes an inlet port 816 and can also include a fill port 820. The inlet end 814 can include an inlet interface assembly 818, to facilitate connection to a gas line, manifold etc., the central portion 802 can include mounting brackets 819, and the fill port 820 can include a fill port assembly 821 to facilitate adding the filter media and readily sealing the fill port.

Figure 8H shows an isometric view, not necessarily to scale, of the inlet end with assemblies 815 of the gas filter 800, and Figure 8I shows an isometric view 817, not necessarily to scale, of an inlet end without a fill port which is substantially identical to the outlet end with an outlet interface assembly. Figures 8J-8L show scale views of the inlet end with interface assemblies 815. Figure 8J is a hidden-line side view of an inlet end 814 with an inlet interface assembly 818 and a fill port assembly 821; also shown is the a porous nickel cup inlet particle filter 828. Figure 8K shows an end view of the inlet end with assemblies 815 and Figure 8L shows a cross-section along AA of Figure 8K. Figure 8K also shows a portion of the internal chamber 801 into which the inlet particle filter 828 extends. Figure 8M shows an exploded assembly drawing (not necessarily to scale) of the inlet end with assemblies 815. Figure 8M illustrates the assembly of the inlet interface assembly 818 into the inlet port 816 of the inlet end 814, and components 822, 825 of the fill port assembly 812 in relation to the fill port 820.

The outlet end 804 and outlet interface assembly 808 are substantially identical to, respectively, the inlet end and inlet interface assembly as, for example, illustrated in Figure 8I.

Figures 8N-8P show details of the substantially cylindrical portion 802 where all unbracketed dimensions are given in inches. Figure 8N shows an isometric view (not necessarily to scale) of the substantially cylindrical portion 802. Figures 8O and 8P are to scale, showing respectively an end view and a cut-away side view. The cut away view Figure 8P, shows a portion of the internal chamber 801.

Figures 8Q-8T show details of a mounting bracket 819, where Figure 8Q is an isometric view not necessarily to scale, and Figures 8R-8T are plan views to scale where unbracketed dimensions are in inches.

Figures 8U and 8V show further isometric assembly drawings of the gas filter 800, neither of which are necessarily to scale. Figure 8U shows an exploded assembly drawing which illustrates the portion of the internal chamber 801 in the substantially cylindrical portion 802 and the outlet end 804. In addition, Figure 8U provides a view of the outlet particle filter 836. Figure 8V shows an isometric view of a preferred embodiment of a gas filter in accordance with the invention 800 and an exploded assembly view of an inlet interface assembly 816 with plug 831 and an outlet interface assembly (hidden in view) with plug 833.

In one preferred embodiment, the components, materials and hardware of Figures 8A-8V are as follows:

0.083" wall, 4" OD 304 Stainless Steal (SS) Pipe, 802;

4" OD Pipe Cap SS, 804;

0.06 -304 SS Wall Weld Bracket, 819;

4" OD Pipe Cap SS with and without Fill Spout Hole, 814;

High Purity Particle Filter, Mott Corporation (part no.), 828;

Swagelok 8-VCR Gland Fitting SS, 827; and

Swagelok 8-VCR Female Nut SS, 825.

High Purity Particle Filter, Mott Corporation (part no.), 836;

Figure 9, shows, for comparison, plots of pressure drop (in psi) versus outlet flow rate (in slpm) at various inlet gas stream pressures for a gas filter (CDA canister) not in accordance with the present invention. Figure 9 shows a plot 900 for an inlet gas pressure of about 90 psig and the CDA canister (2.5 inches wide by 12 inches long) with 0.003 micron particle filters external to the canister, where the diamonds 902 are actual data points and the line 904 is a linear fit of the data (the formula for the fitted line 906 is given at the top of the plot).

Figure 10 shows pressure drop test results for a gas filter in accordance with the invention that is substantially similar to the preferred embodiment of Figures 8A-8V. Figure 10 plot pressure drop (in psi) versus flow rate (in slpm) at various inlet gas stream pressures, the data shown in Figure 10 is tabulated in Table 4. The test results shown in Figure 10 is for a gas filter with a gas flow meter positioned after the gas filter. The volume of filter media in the test of Figure 10 was about 2.6 liters and comprised about 80% GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, about 10% potassium carbonate treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, and about 10% phosphoric acid treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh.

Figure 10 shows a plot 1000 for of pressure loss for inlet gas pressures of 30 psig, 60 psig and 90 psig. The diamonds 1002 are actual data points for 90 psig, the squares 1004 for 60 psig, and the triangles 1006 for 30 psig inlet gas pressures. Also shown are fits to the data and the formulas for the fitted equations noted on and about the plot. The plot 1000 shows: a linear fit to the 30 psig data 1008 and fitted function 1014; a polynomial fit to the 60 psig data 1010 and fitted function 1016; and a polynomial fit to the 90 psig data 1012 and fitted function 1018.

TABLE 4

Flow (L/min)	Flow (SCFH)	Pressure Loss (PSI) @90 o.p.	Pressure Loss (PSI) @60 o.p.	Pressure Loss (PSI) @30 o.p.
0	0	0	0	0
5.0	10.6			3.1
10.0	21.2	2.75	2.8	5.5
15.0	31.8			8.5
20.0	42.4	4.5	6.2	12.2
30.0	63.5	8.75	11	
35.4	75.0		14.5	
40.0	84.7	11.1		
44.8	94.9	15		

Figures 11A-11BJ present detailed views of another preferred embodiment of a gas filter in accordance with the present invention, for use with a reactive gas such as clean dry air (CDA). Figure 11A shows an isometric view, not necessarily to scale, of a gas filter 1100 in accordance with a preferred embodiment of the invention and a gravity compensator 1101. Figures 11B-11F show external scale views where unbracketed dimensions are in inches and square bracketed dimensions are in mm. The gas filter 1100 comprises a substantially cylindrical portion 1102 an outlet end 1104 having an outlet port 1106, that can further include an outlet interface assembly 1108, in this case to facilitate connection to a gravity compensator 1101. The inlet end 1114 is shown end-on in Figure 11D and includes an inlet port 1116 and can also include a fill port 1120. The inlet end 1114 can include an inlet interface assembly 1118, to facilitate connection to a gas line, manifold etc., the central portion 1102 can include mounting brackets 1119, and the fill port 1120 can include a fill port assembly 1121 to facilitate adding the filter media and readily sealing the fill port 1120.

Figure 11G shows an isometric view, not necessarily to scale, of the outlet end 1104, while Figures 11H-11J show views to scale where indicated dimensions are in inches. Figures 11H and 11I present, respectively, end and side views showing the outlet port 1106 in the outlet end1104, and Figure 11J shows a cross-sectional view along line AA in Figure 11H. Figures 11K-11N show details of an outlet particle filter 1136 and an outlet interface assembly 1137, 1138. Figure 11K shows an isometric view, not necessarily to scale, while Figures 11L-11N show views to scale where indicated dimensions are in inches. Figure 11L shows a side view and Figure

11N shows a cross-sectional view along line AA in Figure 11M. Figure 11O shows an isometric view, not necessarily to scale, of the outlet end with outlet interface assembly 1133 and a portion of the outlet particle filter 1136, while Figures 11P-11R show views to scale where indicated dimensions are in inches. Figures 11P and 11Q present, respectively, side and end views of the outlet end with outlet interface assembly 1133, and Figure 11R shows a cross-sectional view along line AA in Figure 11Q. In addition, Figure 11R shows a portion of the internal chamber 1190 of the gas filter 1100.

Figure 11S shows an isometric view, not necessarily to scale, of the inlet end 1114 with an inlet port 1116 and a fill port 1120, while Figures 11T-11V show views to scale where indicated dimensions are in inches. Figures 11T and 11U present, respectively, end and side views showing the inlet port 1116 and fill port 1120 in the inlet end 1114, and Figure 11V shows a cross-sectional view along line BB in Figure 11T. Figures 11W-11Z show details of an inlet particle filter 1128 and an inlet interface assembly 1118, 1124. Figure 11W shows an isometric view, not necessarily to scale, while Figures 11X-11Z show views to scale where indicated dimensions are in inches. Figure 11X shows a side view and Figure 11Z shows a cross-sectional view along line AA in Figure 11Y. Figure 11AA shows an isometric view, not necessarily to scale, of the inlet end with inlet interface assembly 1115 and a portion of the inlet particle filter 1128, while Figures 11AB-11AD show views to scale where indicated dimensions are in inches. Figures 11AB and 11AC present, respectively, side and end views of the inlet end with inlet interface assembly 1115, and Figure 11AD shows a cross-sectional view along line AA in Figure 11AC. In addition, Figure 11AD shows a fill port assembly 1121 and a portion of the internal chamber 1190 of the gas filter 1100.

Figures 11AE-11BB show details of the end caps of the gravity compensator 1101. Figures 11AE-11AH show details of the outlet cap 1157, where Figure 11AE shows an isometric view, not necessarily to scale, and Figures 11AF-11AH show views to scale where indicated dimensions are in inches. Figure 11AH shows a cross-sectional view along line AA in Figure 11AG. Figures 11AI-11AL show details of the outlet cap interface assembly 1159 and components thereof 1169, 1171, where Figure 11AI shows an isometric view, not necessarily to scale, and Figures 11AJ-11AL show views to scale where indicated dimensions are in inches. Figure 11AL shows a cross-sectional view along line AA in Figure 11AK. Figures 11AM-11AP show details of the outlet cap with interface assembly 1167 and components thereof 1169, 1171, where Figure 11AM shows an isometric view, not necessarily to scale, and Figures 11AN-11AP show views to scale where indicated dimensions are in inches. Figure 11AP shows a cross-sectional view along line AA in Figure 11AO.

Figures 11AQ-11AT show details of the inlet cap 1158, where Figure 11AQ shows an isometric view, not necessarily to scale, and Figures 11AR-11AT show views to scale where indicated dimensions are in inches. Figure 11AT shows a cross-sectional view along line AA in Figure 11AS. Figures 11AM-11AP show details of the inlet cap with interface assembly 1168 and components thereof 1172, where Figure 11AU shows an isometric view, not necessarily to scale, and Figures 11AV-11AX show views to scale where indicated dimensions are in inches. Figure 11AX shows a cross-sectional view along line AA in Figure 11AW.

Figures 11AY-11BB show further details of the components 1169, 1171 of the outlet cap interface assembly. Figures 11AY and 11BA show an isometric views, not necessarily to scale, and Figures 11AZ and 11AB show views to scale where indicated dimensions are in inches. In addition, Figure AZ shows a bas component 1170 prior to modification to produce one of the components 1169 of the interface assembly.

Figures 11BC and 11BD show a portion of the an outlet interface assembly 1108, where Figure 11BC is an isometric view, not necessarily to scale, and Figure 11BD is to scale where indicated dimensions are in inches. Figures 11BE and 11BF show details of a mounting bracket 1119, where Figure 11BE is an isometric view, not necessarily to scale, and Figure 11BF shows plan views to scale where indicated dimensions are in inches. Figures 11BG and 11BH illustrate various weld placements, these figures are not necessarily to scale.

Figures 11BI and 11BJ illustrate various detailed views of a preferred embodiment of the reactive gas filter 1100 with gravity compensator 1101 of Figures 11A-11BH. In Figures 11BI and 11BJ, square bracketed dimensions are in millimeters and unbracketed dimensions in inches. In a preferred embodiment 1180, a the gas filter 1100 and compensator 1101 fit within the three-dimensional footprint 1182 illustrated as a shadow-box about the filter and compensator.

In one preferred embodiment, the components, materials and hardware of Figures 11A-11BJ are as follows:

0.083" wall, 4" OD 304 SS Pipe, 1102;
Swagelok ¼" x ½" Pipe Bushing SS, 1121;
4" OD Pipe Cap Cherry-Burrel (37-103) SS without Fill Spout Hole, 1104;
4" OD Pipe Cap Cherry-Burrel (37-103) SS with Fill Spout Hole, 1114;
½" Tube to Fitting Flange, 1137;
304 SS Flange Weld Assembly, 1171;
304 SS Flange Weld Assembly, 1124;
304 SS Flange Weld Assembly, 1137;
2.5" OD Pipe Cap Cherry Burrell (37-101) SS, 1158;
2.5" OD Pipe Cap Cherry Burrell (37-101) SS, 1157;
Machined 1/8" BSP to 1/8" NPT Swagelok SS Interface, 1118;
Mott Corp., GasShield^{TM} brand Concentric Tube Particle Filter, (part no. 2390804), 1128;
0.06 Wall SS Tube, 1138;
Mott Corp., GasShield^{TM} brand Concentric Tube Particle Filter, (part no. 2390804), 1136;
Machined 1/8" BSP to 1/8" NPT Swagelok SS, 1169;
0.065 wall, 2.5" OD SS pipe, 1152; and
½", 90 degree union elbow swagelok with weld fitting, 1112.

Figures 12A and 12B show pressure drop test results for a gas filter in accordance with the invention that is substantially similar to the preferred embodiment of Figures 11A-11BJ. Pressure drop measurements are for the pressure drop across the gas filter 1100 and the gravity compensator 1101. The gravity compensator 1101 was empty and did not include any filter media. Figures 12A and 12B plot pressure drop (in psi) versus flow rate (in slpm) at various inlet gas stream pressures. The test results shown in Figure 12A are for a gas filter without filter media and the test results shown in 12B are for a gas filter with a filter media. In both Figures 12A and 12B the test was conducted with the gas flow meter positioned after the gas filter/gravity compensator combination. The volume of filter media in the test of Figure 12B was about 2.6 liters and comprised about 80% GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, about 10% potassium carbonate treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh, and about 10% phosphoric acid treated GAC with an average mesh size in the range from about 20 U.S. mesh to about 50 U.S. mesh.

Figure 12A shows a plot 1200 for of pressure loss for inlet gas pressures of 30 psig, 60 psig and 90 psig. The diamonds 1202 are actual data points for 90 psig, the squares 1204 for 60 psig, and the triangles 1206 for 30 psig inlet gas pressures. Also shown are polynomial fits to the data. The plot shows: a polynomial fit to the 30 psig data 1208; a polynomial fit to the 60 psig data 1210; and a polynomial fit to the 90 psig data 1212.

Figure 12B shows a plot 1250 for of pressure loss for inlet gas pressures of 30 psig, 60 psig and 90 psig. The diamonds 1252 are actual data points for 90 psig, the squares 1254 for 60 psig, and the triangles 1256 for 30 psig inlet gas pressures. Also shown are fits to the data and the formulas for the fitted equations noted on and about the plot. The plot shows: a linear fit to the 30 psig data 1258 and fitted function 1264; a polynomial fit to the 60 psig data 1260 and fitted function 1266; and a polynomial fit to the 90 psig data 1262 and fitted function 1268.

Figures 13A-13C show plots of pressure drop (in psi) versus flow rate (in slpm) at various inlet gas stream pressures for a Mott Corporation high purity concentric tube particle filter part number 2390804. Figures 13A and 13B show plots for of pressure loss for inlet gas pressures of 30 psig, 60 psig and 90 psig, where Figure 13A shows a plot 1300 for flow rates up to 280 slpm and Figure 13B shows a plot 1320 of the same data up to 180 slpm. Figure 13C shows a plot 1340 of the same data of Figures 13A and 13B for flow rates up to 80 slpm and also data for inlet gas pressures of atmosphere (ATM or 0 psig) and 120 psig. In Figures 13A-13C, the squares 1302 are actual data points for 30 psig, the triangle 1304 for 60 psig, and the x's 1306 for 90 psig inlet gas pressures; while in Figures 13C the diamonds 1342 are actual data points for atmosphere and the asterisks 1304 for 120 psig inlet gas pressures. Also shown in Figures 13A-13C are lines 1308, 1310, 1312, 1346, 1348 illustrating the linearity of the data.

While embodiments discussed thus far have focused on a reactive gas filter operating without additional components such as detectors, many alternative implementations and embodiments are possible. For example, systems and components capable of determining contamination within a gas flow can be used in conjunction with embodiments of the reactive gas filter. In particular it may be desirable to determine contaminant levels, or concentrations, at the input of a gas filter in order to perform functions such as predicting time-between-changes for the filter and for obtaining data regarding contamination levels prior to filtering. Obtaining measurements of contaminants at the input of a filter is herein referred to as input, or upstream, sampling. Alternatively, it may be desirable to determine contaminant levels at the output of a gas filter in order to evaluate performance of the filter and for identifying exhaustion of the filter media or a malfunction of the filtering device. Output, or downstream, sampling is herein used to refer to obtaining contaminant measurements at the output of a filter system. In still other situations, it may be desirable to monitor contaminant levels at a point somewhere in between the input to the filter and the output of the filter. Sampling at a point within the filter system is herein referred to as mid-point, or inter-stack, sampling. Mid-point sampling can be useful for determining a contaminant level part way through a filtering media. This can be particularly useful when a filter system employs filter stages, or filter cartridges, in series. If desired, a contaminant detection and monitoring apparatus can include an input sampler, one or more mid-point samplers and an output sampler. Sampling at multiple points along the filtering path facilitates overall monitoring of the performance of a filter system.

By way of example, Figure 14 illustrates a collection apparatus 1400 for determining contamination in a gas flow. An apparatus such as that shown in Figure 14 can be used to facilitate upstream, mid-point, or downstream sampling of contaminants contained in a gas flow.

The apparatus, or device, 1400 includes a tubular collection device 1402 having an inlet port 1404 and an outlet port 1406. In a preferred embodiment, the collection device includes, absorptive materials 1408 such as, for example, glass spheres of a given size. Alternatively, apparatus 1400 may contain an absorptive material 1408 made from the polymer Tenax. Tenax has a high capacity for high boiling point compounds, and operating Tenax past low molecular weight breakthrough capacity facilitates capture of a meaningful and analyzable mass of high molecular weight compounds.

To collect a sample, an end cap in the inlet post is removed, allowing gas from a gas source to pass through inlet port 1404. Free radicals of contaminants present in the gas sample may bond with absorptive media 1408 in collection device 1402. If desired, laser light can be directed through the sampling tube to facilitate sample collection.

Contaminant sampling is further facilitated through the use of multiple sample tubes and blank collection devices which may be used in conjunction with reactive gas filter 100. The collection devices or refractory traps are applicable to both high pressure sampling, such as for example, purge gas, venting to the atmosphere. Flow through collection device 1402 can employ multiple sample tubes and refractory traps if desired. Flow through the tubes and traps can be controlled by an easily changeable critical orifice.

In a preferred embodiment, apparatus 1400 contains three sample tubes, one blank and two active sample devices. Chemical analysis of obtained data may be correlated to transmission or image uniformity loss of a lithography tool, for example, using a regression analysis which weights first, second, third and fourth order effects:

$$Uniformity\ or\ Intensity = a\,[C_6\text{-}siloxane] + b[C_6\text{-}C_{30}] + c[C_3\text{-}C_6] + d[C_1\text{-}C_5]$$

herein the parenthetic expressions are indicative of the concentration of species. First and second order contaminating effects have a greater impact on contamination of optical systems than third or fourth order contaminants and typically show a greater contamination coefficient (e.g. $a > b > c > d$).

First order contaminants may comprise high molecular weight refractory organics such as, for example, C_6 siloxanes and C_6 iodide with an inorganic component which is not volatilized through combination with oxygen. Second order contaminants may comprise high molecular weight organics, such as, for example, compounds including carbon atoms within the range of approximately six to thirty carbon atoms ($C_6 - C_{30}$). Third order effects can arise due to the contaminating effects of organics such as $C_3 - C_6$ that have approximately three to six carbon atoms. Further, fourth order contaminants include organics such as, for example, methane, that have approximately one to five carbon atoms.

Figure 15 illustrates an embodiment of a refractory trap system 1520 that utilizes collection device 1402. Refractory compounds may include at least siloxanes such as, for example, hexamethyldisiloxane (C_6), silanes such as, for example, C_3-silane, silanols such as, for example, C_3 and iodates. Refractory trap system 1520 includes a conduit 1521 in communication with a gas source and through which a gas sample is carried with pressures ranging between approximately 1 to 120 psi. The gas sample is carried downstream to a pressure cavity 1522. A pressure relief valve 1523 allows the continuous flow of gas to ensure that the pressure cavity walls are in equilibrium with the gas phase of the gas sample. Refractory trap system 1520 includes active sampling traps or collection devices 1524 and a blank trap 1525 in trap cavity 1526. The active sampling trap elements 1524 may include an absorptive medium such as, for example, the polymer Tenax. The gas sample flow through active elements is approximately 0.11 lpm.

Blank trap 1525 is not in communication with the gas source or pressure cavity and as such is not removing contaminants. The outflow gas stream from active collection devices 1524 flows downstream into a manifold 1527 which is in fluid communication with vacuum line 1530, via orifice 1529. A pressure/vacuum regulator valve 1508 is disposed between manifold 1527 and orifice 1529 to regulate pressure. The refractory trap system 1520 provides for both a low pressure application or a high pressure application using a single design.

The gas supply may include a particular constituent as an additive, such as for example hydrogen gas, which may be used to clean the surfaces of the collection devices or, surfaces of optical systems that have been contaminated by a surface contaminant, for example, SiX. A gas additive combines with the surface contaminant to form a volatile compound that is then purged from the system. For example, SiX combines with hydrogen gas to form silane (SiH_4) which is volatile and is purged. The purge gas, is preferably in the ultra high purity gas level allowing the collection device to be placed upstream and downstream of typical in-line filters.

Figure 16 illustrates an embodiment of a trap system 1600 containing a filtration module based on a selectively permeable membrane 1606 for filtering organic compounds from a gas stream such as, for example, a nitrogen stream. The selectively permeable membrane may be of the type such as supplied by, for example, Membrane Technology & Research, Inc. In the embodiment of Figure 16, the feed flow 1604 is nitrogen that contains some level of organic contamination. The feed flow 1604 may comprise 99-100% nitrogen with any balance in organic contaminants as well as water and oxygen. Assuming a 90% removal efficiency of the membrane, the composition of the residue is purified by a factor of 10. The composition of the permeate stream can be enriched with organic contaminants. Filtering system 1600, in accordance with a preferred embodiment may remove contamination effects of first through fourth order contributors.

Alternatively, the filtering system 1600 may utilize a filtration module based on a selective membrane 1616 for filtering organic compounds from a gas stream 1604 wherein the collection device or pipe 1602 is connected to a vacuum source for increasing the pressure gradient across membrane 1616 thus increasing membrane efficiency. The feed flow 1604 may be nitrogen containing some amount of organic contamination. In a particular embodiment the feed flow, 1604 can include nitrogen with organic contaminants as indicated above. Assuming a 99% removal efficiency of the membrane, the composition of the residue 1606 is again improved by a factor of 10 for nitrogen and the balance in organic contaminants. The composition of the permeate stream 1608 may be further enriched with organic contaminants.

Filtering system 1600 may also comprise a filtration module based on a selective membrane 1616 to filter organic compounds from a gas stream. In this particular embodiment the feed flow is nitrogen containing some amount of organic contamination. Feed flow 1604 comprises 99-100% nitrogen with the balance being organic contaminants. Assuming 90% removal efficiency of the membrane, the composition of the residue 1606 is 99-100% nitrogen and the balance in organic contaminants. The composition of the permeate stream 1608 may be enriched with organic contaminants. The organic contaminant enriched airstream 1608 is then directed to a regenerative adsorption device for purification. The permeate stream 1608, which has been purified by an adsorption bed system, is then returned to the feed flow. This filtering system in accordance with a preferred embodiment of the present invention reduces the loss of feed flow volume.

Figures 17A-17C illustrate schematic diagrams of concentrator 1701 for use in a contaminant and filter monitoring system. A concentration 1701 operates to increase the sensitivity of collection in accordance with implementations described herein. Concentrator module 1704 has a cover 1702 and is inserted in a manifold, manifold 1706 having inlet and outlet interfaces 1705, 1703, respectively. Filter system 1600, including a filter monitoring functionality, can be reduced in size using a coupling device such as, for example, concentrator 1704. Performance can be increased by allowing filter system 1600 to collect a greater volume of gas by reducing the temperature to say 0°C or below. Sensitivity of data collection can also be increased by using an embodiment of concentrator 1701 including absorptive materials such as, for example, Tenax. In an embodiment of concentrator 1701, Tenax is used for organics having high boiling points. In contrast absorptive materials such as, for example, carbon traps can be used in embodiments including low boiling point organics. Alternate embodiments include a combination of filters for high and low boilers which can be arranged in parallel and/or in series.

Figure 18 contains a schematic diagram of a system 1800 for monitoring the performance of a filter system 1600. A gas flow, or airstream, 1802 is input into the filter 1804 and sampled by a detector system 1831. The filter 1804 may contain a physioadsorbent to chemically adsorb contaminants. Air flow 1803 in the middle of the filter bed is also sampled and analyzed using a sampling port 1806 that provides the sample to detection system 1831. The location of sampling port 1806 with respect to outlet 1807 is proportional to the propagation rate of the leading indicator gas. For example, if the propagation rate of the tracer gas is high then the distance of the sampling port 1806 from the outlet 1807 is raised. The discharge flow 1808 at the outlet 1807 of the filter 1804 is also sampled. A position selectable valve 1816 disposed in the inlet of the detection system provides sampling capability for more than one stream. Thus, the sampled flow from inlet 1801 of filter bed 1805, the middle of the filter bed 1805 or the outlet 1807 of the filter bed 1805 can be selected as the input to detection system 1831. A valve 1818 allows for the selection of the flow into a preconcentrator 1820 or into a bypass 1822. A pump 1826 for the preconcentrator provides adequate flow therein. The discharge of the bypass 1822 or the preconcentrator 1820 is then selected by valve 1824 to form an input into a chromatographic column 1830. A heater 1828 is disposed around chromatographic column 1830. The outlet of the column 1830 forms the input of detector 1832 which may include among other things a flame ionization detection system. The spectrum illustrating the abundance of the constituents detected with respect to time is displayed on a graphical user interface 1838. System 1800 and its constituent components are further described in pending patent application 10/662,892 entitled System and Method for Monitoring Contamination which was filed on September 15, 2003, the contents of which are incorporated by reference herein.

The embodiment of Figure 18 may use detection technology which is inherently sensitive to, and can identify and quantify organic species at very low concentrations, for example, below 1 ppb (V) using, for example, gas chromatograph/flame ionization detection (GCFID). These implementations may provide advanced warning of filter failure without actually jeopardizing the process by allowing the actual species of interest to breakthrough. Any breakthrough occurs at a low enough concentration to be meaningful to highly sensitive processes, like optics systems.

Detection system 1831 can be used with filters employing a bed of polymer pellets exposed to the airstream using, for example, a traditional media tray and rack system. For example, the filter may include a honeycomb configuration with the polymer pellets held in a partially filled or completely filled honeycomb structure. Other possible filter constructions may include, but are not limited to, a monolithic porous or honeycomb structure formed from polymer, a mat of polymer fiber, either woven or nonwoven, pleated and arranged in a traditional air filter, a bed of the activated carbon pellets exposed to the airstream using a traditional media tray and rack system, a honeycomb configuration wherein the activated carbon pellets are held in a partially filled or completely filled honeycomb structure, a monolithic porous or honeycomb structure formed from the activated carbon, a mat of activated carbon fiber, either woven or nonwoven, pleated and arranged in a traditional air filter and a carbon based composite filter constructed of woven or nonwovens support structures.

Detection system 1831 may include dry collection devices such as those described thus far or detection system 1831 can employ wet collection devices such as, for example, wet impingers. For example molecular bases and molecular acid samples can be collected using impingers filled with distilled water (10 cc). An air or gas sample may be drawn through the impinger at a rate of, say, 1 L/min for 240 minutes using a programmable sample pump. The total sample volume in a preferred embodiment, without limitation is 240 L.

Further, in an embodiment, molecular condensable high boiling point organic materials and refractory material samples can be collected using Thermodesorbtion Samplers (TDS) filled with porous medium, for example, Tenax. Field blank or empty samples are collected for each type of sample. The field blank is a sample device (impinger of TDS), which is handled in the field the same way as an actual sample but having zero sample volume drawn therethrough. The purpose of the field blank is to detect possible uncontrolled contamination events during sample handling and transportation. Field blanks are analyzed in the same manner as actual samples.

Analyses of molecular bases and molecular acids samples can include using Ion Chromatography methods in detection system 1831. Compounds can be identified by retention time and quantified using individual calibration standards and, for example, a 10-point calibration procedure. For example, the low Detection Limit (LDL) of the corresponding methods is ~ 0.1 ug/m^3 per individual component. In a preferred embodiment, molecular bases and refractory material samples are analyzed using a Gas Chromatograph (GC) equipped with a Mass selective Detector and Thermal Desorption System (TD). The total analytical system (TD/GC/MS) is optimized to separate and quantify analytes with a boiling temperature of hexane and higher with LDL of ~ 0.1 ug/m^3 per individual component. Individual components are identified by a MS library search and chromatographic peak position. Individual component are quantified against two analytical standards, for example, toluene and hexadecane. Analytical results are listed in the Tables 5 and 6.

Table 5

			Concentration, ug/m3			
	N2-facilities before	N2- facilities after	Oil free Air before	Oil free Air after	Fab amblent	Sub Fab
Ammonia (as NH3)	0.4	<0.1	0.4	<0.1	4.2	6.4
Other inorganic acids	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrous acid (as NO2)	<0.1	<0.1	0.8	<0.1	0.8	1
Nitric acid (as NO2)	<0.1	<0,1	<0.1	<0.1	<0.1	<0.1
C6+ Organic Compounds (as toluene)	-1.1	-0.9	-.0.8	-.2.3	-213	H

Table 6

Compound	Concentration, ug/m3	
	as toluene	as hexadecane
Benzene (78)	0.4	0.2
Silane, Dimethoxydimethyl (59)	2.7	1.2
Hexane, 3-Methyl (26)	0.4	0.2
2-Heptane (47)	0.5	0.2
Silane, Trimethoxymethyl (45)	0.4	0.2
Hexane, 2,5-Dimethyl (33)	0.3	0.1
Toluene (82) 1	2.9	1.3
Propanoic acid, 2-hydroxy-ethyl ester (59) 2	1.5	0.7
PGMEA (92) 3	2.2	1
Ethylbenzene (59) 4	3.2	1.3
n-Propylbenzene (56)	0.3	0.1
Cyclohexane (84)	9.5	0.2
Xylenes (48) 5	15.2	6.1
Styrene (59)	0.3	0.1
1,2,3 Trimethylbenzene (72)	1.8	0.7
1,3,5 Trimethylbenzene (60)	0.6	0.2
Cyclohexanone (77) 6	0.6	0.2
3-Heptanone (47)	0.4	0.2
Unknown	0.5	0.2
Unknown	0.7	0.3
Octane, 2,6-Dimethyl (59) 7	0.3	0.1
Cyclohexane, (1-Methylethyl)(40)	0.4	0.2
Nonane (59)	0.4	4.1
Octane, 2,5,6-Trimethyl (53)	4.3	1.7
Octane, 2,2,7,7-Tetramethyl (53)	1.8	0.7
Octane, 2,2,6-Trimethyl (64)	1.4	0.6
Benzene, 1-Ethyl, 3-Methyl (93) 8	3.1	1.2
Decane, 2-Methyl (77)	1.2	0.5
Benzene, 1-Ethyl, 2-Methyl (77)	0.9	0.4
Benzaldehyde (48) 9	2.8	1.1
Carbamic acid, methyl-,phenyl ester (25)	2.1	0.8
Propylene cabonate (86) 10	3.5	1.4
Heptane,2,2,4,6,6-Pentamethyl (64)	2.6	1
Decane,2,2-Dimethyl (64) 11	5.7	4
Decane 2,2,9-Trimethyl (77) 12	10.1	2.3
Nonane,3,7-Dimethyl(67) 13	17	0.2
Decane,5,6-Dimethyl(50)	1.7	0.7
Decane,2,3-Dimethyl(40)	1.9	0.8
Nonane,3-Methyl-5-propyl(64)	3.9	1.6
Decane,2,6,7-Trimethyl(47) 14	15	6
Heptane,4-Ethyl-2,2,6,6-Tetramethyl(72) 15	14	0.2
Undecane,2,5-Dimethyl(59)	1.5	0.2
Undecane,4,6-Dimethyl(59) 16	12	4.8
Undecane,3,5-Dimethyl(53)	1.8	0.7
Undecane,4-methyl(83)	2.4	1

Nonane,3-methyl-5-propyl(64) 17	5.7	2.3
Undecane,5,7-Dimethyl(43)	1.7	0.7
Undecane,3,8-Dimethyl(38)	2.5	1
Dodecane,2,5-Dimethyl(36)	3.6	1.4
Heptane,2,2,3,4,6,6-Hexamethyl(72)	1.5	0.6
Dodecane,2,6,10-Trimethyl(72)	2.3	0.9
Tridecane,5-Methyl(64)	0.7	0.3
Tridecane,4-Methyl(64)	0.4	0.2
Dodecane(50)	0.5	0.2
Benzoic acid (66) 18	9.9	4
Cyclotetrasiloxane, Hexamethyl(39)	0.5	0.2
Cyclotetrasiloxane, Octamethyl (54)	0.4	0.2
2,5 Cyclohexadiene-1,4-dione,2,5,-diphenyl(97) 20	27	10.1
Total	213	73

Numerous types of detectors can be used in conjunction with detection system 1831. For example, sensors that change their output response when contaminants are detected can be utilized. An example of a sensor having this type of characteristic is a surface acoustic wave (SAW) sensor. Sensors such as these can have surface coated materials that facilitate the retention of contaminants thereon. Contaminants retained on the detection surface of a sensor preferably form non-volatile residues which can subsequently be detected. Buildup of non-volatile residues on the detection surface may be representative of the concentration of molecular contamination in the airstream in the vicinity of the detection surface. These sensors can be used at input, or upstream, sampling locations, at output, or downstream, sampling locations, or at mid-point, or inter-stack, sampling locations.

The actual formation rate of non-volatile residue onto the detection surfaces of an upstream and downstream detector not only depends on the varying molecular contamination concentrations in the respective airstreams, but also depends on other factors such as temperature, humidity, and the amount of material previously formed onto the detection surfaces; all of which change over time, creating artifacts in the measured signals. For example, the rate non-volatile residue forms onto the upstream detection surface exposed to upstream air having a constant concentration of molecular contamination may change significantly over time. For example, a significant drop in the formation rate may result from a change in temperature or humidity. Also, a generally decreasing artifact in the formation rate may be observed due to changes in the detection surfaces over time caused by previously formed material.

Similar trends may be observed in the rate of non-volatile residue formation on a downstream detection surface. However, a generally decreasing artifact, similar to an artifact accumulating on an upstream detection surface typically appears at a later time in the measured formation rate on the downstream detection surface because the rate of material formation on the downstream detection surface is less than the formation rate on the upstream detection surface as long as filter system 1600 is operating. Also, superimposed onto these artifacts for the downstream detector are changes in the concentration of molecular contamination in the airstream resulting from changes in filter efficiency; the desired quantity to be determined.

Referring to Figure 19A, a detector 1900, which may be used as upstream detector or downstream detector, includes a detection surface 1902, which is exposed to an incoming air stream 1904 including molecular contamination 1906. In a presently preferred embodiment, detection surface 1902 is formed from a piezoelectric crystal 1908 and is configured as a mass microbalance resonator sensor, as described in W. D. Bowers et al., "A 200 MHz surface acoustic wave resonator mass microbalance," Rev. Sci. Instrum., Vol. 62, June 1991, which is herein incorporated by reference. The frequency of vibration is related to the way the crystal is cut and to the amount of mass formed on detection surface 1902. Leads 1910, 1912 are used to apply time-varying electrical signals to piezoelectric crystal 1908. Leads 1910, 1912 are also used to detect a shift in the resonant frequency of the detector. Alternatively, detector 1900 may be configured as a delay line, as described in H. Wohltjen et al., "Surface Acoustic Wave Probe for Chemical Analysis," Analytical Chemistry, Vol. 51, No. 9, pp. 1458-1475 (August 1979).

Even when detection surface 1902 is exposed to an air stream having a constant concentration of molecular contamination, the measured rate of change of formed non-volatile residue will vary depending on environmental conditions, e.g., temperature and humidity. The amount of deposited (formed) material will also depend on other parameters, e.g., the amount of material previously deposited onto the surface. We believe the detectivity D(t) of a detection surface depends on

$$D(t)=K_1 \cdot S(T, RH, R, A(t)) \qquad (1)$$

where, K_1 is a constant, S(T, RH, R, A(t)) is a "sticking coefficient" that depends on (among other things) the temperature (T), the relative humidity (RH), the reactivity

(R) of the surface with the molecular contamination, and A(t) which is the effective surface area of the detection surface which decreases over time (t). The sticking coefficient (S) represents a probability that molecular contamination in the vicinity of the detection surface will condense from the gas-phase and adhere onto the detection surface.

Molecular contamination 1906 may simply condense from the gas-phase onto the surface of detector 1900 to form a non-volatile residue 1914. Also, selective adsorption of a particular class of molecular contamination may be achieved, e.g., by applying to the detection surface a thin film (coating) of a selectively adsorbing material. Thus, when exposed to molecular contamination, some of the molecular contamination may be adsorbed on the detection surface of the detector as a non-volatile reaction product residue 1916. The deposited non-volatile residue 1914 and non-volatile reaction product residue 1916 increase the mass on the detection surface that is measured as a resonant frequency shift.

The decrease in frequency following an increase in mass (Δm) of an oscillating crystal, is given by:

$$\Delta f = \frac{2.3x10^{-6}}{A} \bullet Fo^2 \bullet Am \qquad (2)$$

where Δf is the change in frequency, F_0 is the fundamental frequency applied to the crystal, Δm is the change in mass of the detection surface caused by formed non-volatile residue, and A is the area of the detection surface (typically on the order of 1 cm^2). This can be summarized by

$$\Delta f = -K \cdot Am \qquad (3)$$

where K is a constant ($K=2.3x10^{-6}F_0^2/A$). The resonant frequency as a function of time (f(t)) can be expressed as

$$f(t)=F_0-K \cdot M(t) \qquad (4)$$

Accordingly, the variation in the mass over time (M(t)) can be expressed in terms of the resonant frequency

$$M(t) = \frac{fo - f(t)}{K} \qquad (5)$$

Therefore, under ideal conditions changes in frequency are proportional to the change in mass of the detection surface. Such piezoelectric sensors are useful, at least in part, because of their small size and low detection limits (the lowest detection level is generally in the ppb region, with linearity to ppm). Low-level detection sensitivity is especially important in an environment in which low levels of molecular contamination are severely detrimental (e.g., in a semiconductor device fabrication area or a work environment that may be subject to gas-phase contaminants that are corrosive or toxic at low concentration levels). Such detectors should typically be replaced after a period of about six months to one year, depending on the molecular contamination concentration exposure level.

Referring to FIGS. 19B and 19C, the measured beat frequency of detector 30 changes over time as non-volatile residues form on surface 1902. The rate of change in the beat frequency provides a measure of the rate of change in the formed mass over time (Δm).

An effective efficiency ($E_{eff}(t)$) may be determined by measuring the resonant frequency f(t) in Figure 19A to determine the amount of non-volatile residue that has formed on a detection surface and by using equation (6), below.

$$E_{eff}(t)) = \frac{M_{upstream}(t) - M_{downstream}(t)}{M_{upstream}(t)} \tag{6}$$

An alternative measure of effective efficiency $E'_{eff}(t))$ may be determined from the measured rate of change of the resonant frequency (Δf; Figure 19B) and by using equation (7), below.

$$E'_{eff}(t)) = \frac{\Delta M_{upstream}(t) - \Delta M_{downstream}(t)}{\Delta M_{upstream}(t)} \tag{7}$$

In all of the following detectors a membrane is used to control exposure of the collecting media to the molecular contamination and makes possible quantitative measurements. The collecting media (e.g., activated carbon, reagent solution, or water) varies, depending on the kind of molecular contamination that is to be monitored.

For monitoring volatile organic contaminants, such as toluene, benzene, and vapors of other low boiling point solvents, a detector 1900 (e.g., an Organic Vapor

Monitor available from 3M Company of St. Paul, Minn., under the Brand Nos. 3500, 3510, 3520, and 3530, and described in H.C. Shields et al., "Analysis of ambient concentrations of organic vapors with a passive sampler," APCA Journal, Vol. 37, No. 9, (September 1987), wherein is herein incorporated by reference), may be used as upstream detector or downstream detector.

Referring to Figure 20A, detector 2000 includes a detection surface 2002, which is exposed to an incoming air stream 2004 including molecular contamination 2006 through a housing 2008 with a perforated face 2010 and through a diffusion barrier 2012 (e.g., a precalibrated semi-permeable membrane). Detector 2000 also includes a spacer 2014, and a charcoal sorbent pad 2016. The diffusion barrier creates a concentration gradient from its surface to the carbon sorbent pad.

In use, detectors are respectively positioned upstream or downstream of a filter to be monitor and left in place for a preselected period of time (t). After the preselected period, the detectors are sealed and typically taken to a lab for extraction of the adsorbed species. The pad is immersed in a solvent containing 1 μL of a 1.0 mg/mL cyclooctane/carbon disulfide solution. After a preselected period, the extract is decanted into a vial and reduced at ambient temperature and pressure in a low velocity fume hood. the final volume typically ranges from 0.5 mL to 5 1 μL. Sample volumes of 1-3 μL are injected into a gas chromatograph/mass spectrometer (e.g., a Hewlett-Packard 5992A GC/MS), which separates and identifies the adsorbed species. The identity of the molecular contamination and the collected masses of the respective components are used to calculate the concentration of the molecular contamination.

Molecular contamination 2006 contacts the detection surface of monitor 2000 by diffusion. At the surface of the screen the molecular contamination concentration is the air concentration (C) and at the sorbent pad the concentration is effectively zero. From Frick's First Law of Diffusion, it can be determined that

$$C = \frac{m}{t \bullet u \bullet r} \tag{8}$$

where C is the molecular contamination concentration, m is the mass of substance adsorbed onto the sorbent pad, t is the sampling interval, u is the uptake rate, and r is the recovery coefficient (a factor used to adjust for incomplete extraction of a substance from the sorbent pad). The uptake rate (u) and the recovery rate (r) have been measured and published for a large number of organic vapors (e.g., 3M #3500 Organic Vapor Monitor Sampling Guide (Occupational Health and Safety Products Division/3M; December 1992) and 3M #3500 Organic Vapor Monitor Analysis Guide (Occupational Health and Safety Products Division/3M; 1981), both of which are herein incorporated by reference).

A filter monitor useful for monitoring formaldehyde has a similar construction as detector 2000, except the adsorbent material is coated with a solution reactive with formaldehyde (e.g., an organic passive monitor available from Advanced Chemical Sensors Co. 4901 North Dixie Hwy. Boca Raton, Fla. 33431). Formaldehyde contamination in an air stream passes through a diffusion barrier and forms a non-volatile residue on the adsorbent material. The mass of formaldehyde formed on the adsorbent material may then be measured after a preselected exposure period in a manner similar to that described above in connection with the 3M filter monitor.

Referring to Figure 20B, a detector 2040, which may be used as upstream detector or downstream detector 2044, includes a detection surface 2042, which is exposed to an incoming air stream 2044 including molecular contamination 2046. Detector 2040 includes a housing 2048 containing adsorbent media 2050 (e.g., activated carbon particles with or without a reagent) and a diffusion barrier 2052 that creates a diffusion gradient between the air stream and the adsorbent media. The adsorbent media is the same as that used in the gas-phase filter to be monitored. In this way detector 2040 adsorbs the same gas-phase contamination as the filter with a similar sensitivity. This provides a highly accurate determination of the filter's performance. The adsorbed contamination is extracted in the same way as described above in connection with other adsorbent detectors. Embodiments of detectors for performing performance monitoring of air filters are further described in U.S. Patent No. 5,856,198 entitled Performance Monitoring of Gas Phase Air Filters, the contents of which are herein incorporated by reference.

Referring to Figure 21, in a presently preferred embodiment, the performance of a gas-phase filter is monitored as follows. The amount of non-volatile residue formed on the upstream detection surface is determined (per step 2100). The amount of non-volatile residue formed on the downstream detection surface is determined (per step 2102). The effective efficiency is determined based on a comparison of the amount of non-volatile residue formed on the upstream and downstream detection surfaces (per step 2103). The determined effective efficiency is compared against a predetermined threshold (per step 2104). If the effective efficiency is greater than the threshold (per step 2105), a flag variable is set to 0 (per step 2106) and the monitoring process is repeated. If the effective efficiency is less than the threshold and the flag variable is currently not equal to 1 (per step 2107), the flag is set to one and the monitoring process is repeated (per step 2108). If, on the other hand, the effective efficiency is less than the threshold the flag variable is equal to 1 (per step 2107), then a signal is produced indicating that the filter should be replaced (per step 2109).

In an alternative embodiment, the flag variable may be compared against an integer greater than 1 (per step 2107) and the flag variable may be increased incrementally (per step 2108) to enhance the accuracy of verification procedure (per steps 2105-2108) before the filter replacement signal is produced (per step 2109).

Embodiments of detection systems for monitoring contaminants can take many forms. For example, a portable detection system can be used that employs dry collection media such as dry traps or Tenax traps and/or wet traps such as wet impingers. Figure 22 contains a perspective view of a portable embodiment of gas sampling unit 2200. Embodiments of the unit are designed to be man-portable and typically weigh less than 20 lbs. The gas sampling unit 2200 of Figure 22 includes a housing 2204, an inlet coupling 2202, a first bypass/purge valve 2204, a second bypass/purge valve 2206, a handle 2208, an ON/OFF switch 2210, an hour meter 2212 and a fan grating 2214.

Housing 2201 is adapted to sealably enclose internal parts and to protect them from incidental contact with foreign objects. In a preferred embodiment, housing 2201 is made of aluminum; however, it can be made of, for example, plastic, composite, glass, and the like. In addition, housing 2201 may be anodized or painted. Inlet coupling 2202 is attached to a gas source and may consist of a NPT connector. First and second bypass/purge valves 2204 and 2206, respectively, are used to allow the input gas flow to bypass sampling components in order to ensure adequate gas flow is present without risking contamination of the sampling components within the gas sampling unit 2200. Handle 2208 provides a convenient and safe way for a person to transport gas sampling unit 2200 without damage to the unit.

Embodiments of gas sampling unit 2200 can be powered using external power sources such as alternating current (AC) obtained from a standard power receptacle or by way of internal power sources such as batteries. ON/OFF switch 2210 is used to turn the unit on before sampling a gas flow proximate to a filter system, and ON/OFF switch 2210 is used to turn the unit off when sampling is complete. Hour meter or clock 2212 is used to indicate how long gas sampling unit 2200 has been run. Hour meter 2212 may serve only as an indicator or it may be configured to automatically turn off gas sampling unit 2200 when a predetermined operating interval has been reached. Fan grating 2214 protects the blades of an internal cooling fan from being damaged.

Figure 23A illustrates a schematic representation of components that can be used in a handheld sampling unit 2300. For example, handheld unit 2300 may include a sample inlet 2302, an overpressure/overflow control 2304, one or more user operated valves 2306, an entry manifold 2308, one or more dry traps 2310A-F, an exit manifold 2312, electrical supply and control components 2314, a battery 2316 and an optional AC power source 2318.

Sample inlet 2302 may consist of a coupling for allowing a gas sample to pass therethrough. For example, sample inlet 2302 may include an NPT connector adapted to mateably receive a gas supply line. An optional overpressure/overflow control 2304 may be inserted between sample inlet 2302 and user operated valves 2306 to prevent an overpressure or overflow condition within handheld unit 2300. User operated valves 2306 can be operated to allow passage of a gas sample into entry manifold 2308, or the valves 2306 can be operated to prevent passage of the gas sample. In addition, valves 2306 can be configured to cause a gas sample to flow directly to exit manifold 2312 without passing through entry manifold 2308 and/or dry traps 2310A-F. Bypassing entry manifold 2308 is useful when purging the gas sample line prior to passing a gas sample through dry traps 2310A-F. In a preferred embodiment of handheld unit 2300, valves 2306 are operated by way of controller 2315 operating within electrical supply and control components 2314.

Entry manifold 2308 receives the gas sample and distributes it to dry traps 2310A-F. The embodiment illustrated in Figure 23A includes six dry traps; however, handheld unit 2300 may operate with substantially any number of dry traps depending on the type and concentration of contaminants being measured. Exit manifold 2312 receives the gas sample that was distributed by entry manifold 2308 and generates a single output gas stream. The output gas stream can be coupled to a sample outlet connector located on the exterior of handheld unit 2300. The sample outlet connector facilitates gas passage through handheld unit 2300 without allowing the gas sample to be exhausted into the ambient environment in which handheld unit 2300 is operating.

Handheld unit 2300 may also include an electrical supply and control components subsystem 2314. The electrical subsystem can include a controller 2315, power regulation and distribution modules, alarm indicators, error sensors, cooling fans, and the like.

For example, in a preferred embodiment of handheld unit 2300, an electrical subsystem measures sample times, measures and controls flow rates, measures gas pressures and temperatures, controls valves 2306, controls entry manifold 2308, controls exit manifold 2312, logs performance data, receives and logs user input data such as date, time, sampling location, and the operator's name. Using electrical subsystem 2314, handheld unit 2300 can be configured such that a user presses a single button to make measurements after connecting a gas line to the input of handheld unit 2300. The controller 2315 operating within handheld unit 2300 can facilitate preprogrammed operation by a user. For example, controller 2315 can be programmed to allow a gas sample to pass through only a subset of dry traps 2310A-F.

Handheld unit 2300 may further include an internal power source such as battery 2316. Battery 2316 may consist of one or more replaceable batteries such as disposable alkaline batteries or it may consist of a rechargeable battery such as a lithium ion, nickel metal hydride, and the like. Handheld unit 2300 may also include a connector for coupling an external power source thereto such as, for example, an AC power source.

Figure 23B illustrates an exemplary embodiment of a handheld unit 2300 that includes some, or all, of the components illustrated in Figure 23A. Handheld unit

2300 includes a case 2320 having an upper surface 2322 and a lower surface 2324 opposedly mounted from the upper surface 2322, a first side 2326 and a second side 2328 opposedly mounted from the first side 2326, a third side 2330 and a fourth side 2332 opposedly mounted from the third side 2330. Upper surface 2322 may include an On/OFF switch 2334 for powering handheld unit 2300 on and for powering the unit off after a sampling interval is completed. An ON LED 2336 and OFF LED 2338 may be used for informing a user about the status of handheld unit 2300. A valve control button 2340 may be located on upper surface 2322 for letting a user place the handheld unit 2300 in a run mode or in a bypass/purge mode. Handheld unit 2300 can also include one or more displays for providing operational information to a user. For example, handheld unit 2300 can have a timer display 2342 for displaying a running time of the unit. A diagnostic display 2344 may provide information as to the unit's operational status such as flow rates, gas sample temperature, valve status, and the like. Handheld unit 2300 also includes a gas sample inlet port 2348 and a gas sample exhaust port 2350.

Embodiments of handheld unit 2300 can also utilize a replaceable dry trap module 2354. Replaceable module 2354 can be inserted into housing 2320 by way of a dry trap receptacle 2352. Receptacle 2352 includes an opening, for example in first side 2326, into which the replaceable module 2354 is inserted. Once inserted into housing 2320, dry traps contained in replaceable module 2354 are positioned so that a gas sample passes therethrough to measure contaminants in the gas sample. A controller 2315 can be adapted to read measurement data from the dry traps for reporting to a user using results display 2346. Portable embodiments of systems for monitoring contaminants are further described in pending U.S. Provisional Patent Application 60/526,862, filed December 3, 2003 and entitled Dry Sampler, the contents of which are herein incorporated by reference.

Figures 24A – 24C contain flowcharts illustrating an exemplary method for using gas sampling unit 2200, 2300 for measuring contaminants present in a cleanroom. In Figure 24A, the method begins when an analysis facility initializes gas sampling unit 2200 for making contamination measurements (per step 2400). Next, a pre-shipment checkout/test of gas sampling unit 2200 may be performed by an analysis facility (per step 2402). The gas sampling unit 2200 is shipped to a customer site via common carrier (per step 2404). Upon receipt, the customer removes gas sampling unit 2200 from a reusable shipping container (per step 2406). The customer places gas sampling unit 2200 in a cleanroom environment (per step 2408) and connects the unit to a gas supply (per step 2410). Embodiments of sampling unit 2200 are designed to be used by relatively unskilled workers and therefore do not require specialized training procedures.

Next, the customer places first and second bypass purge valves 54, 56 in bypass position (per step 2412) to purge gas sampling unit 2200 using a cleanroom gas supply line (per step 2414). The customer then places first and second bypass purge valves into run position (per step 2416) and allows the gas sampling unit 2200 to operate for a determined sampling interval (per step 2418, Figure 24B). Gas sampling unit 2200 may be operated anywhere from a few hours to several weeks depending on the types of contaminant measurements being made and the concentration of contaminants in the gas supply.

Gas sampling unit 2200 receives a gas sample (per step 2420) and passes the sample through dry trap 2310, Tenax traps and/or wet traps (per step 2422). Solid state timer indicates to the customer that the end of the sampling interval has been reached (per step 2424). The customer turns off gas sampling unit 2200 in response to the readout of solid state timer; or alternatively, gas sampling unit 2200 may automatically turn off when the end of the desired sampling interval is reached (per step 2426). The customer disconnects gas sampling unit 2200 from the gas supply and places the unit into the reusable shipping container (per step 2428). The customer places a pre-printed return shipping label on the container and ships the unit back to analysis facility (per step 2430).

The analysis facility receives gas sampling unit 2200 and logs the unit's arrival into its inventory management system (per step 2432). The dry sampler is opened by a technician and the contents of the sampling components is analyzed using methods known in the art (per step 2434, Figure 24C). The analysis facility generates a report containing results of measurements taken by gas sampling unit 2200 while installed at the customer site (per step 2436). The report is sent to the customer via hardcopy and/or in electronic format such as email (per step 2438). In addition, the analysis facility may send a copy of the results to a third party such as a certification or standards setting organization or government entity having some form of oversight authority for the customer site (per step 2440). An alternative embodiment of the analysis facility can maintain a web site containing the results of sampling data taken by gas sampling unit 2200. Secure access by way of passwords or other security means known in the art may be used to prevent unauthorized access to data on the web site.

The analysis facility reconditions gas sampling unit 2200 so that it can be reused by a customer for taking additional contamination measurements (per step 2442). The analysis facility returns the dry sampler to the customer (per step 2444) and the customer uses gas sampling unit 2200 to perform additional contamination measurements (per step 2446).

As previously discussed, wet impingers may be employed in embodiments of gas sampling unit 2200 when it is desirable to compare results obtained using dry traps to results obtained using wet media. When wet impingers are employed in gas sampling unit 2200, they may be connected in series. Wet impingers contain deionized water and are used for determining nitrogen containing acidic species in a gas sample. For example, nitric acid (HNO_3) may be measured as NO_3^- ion and nitrous acid (HNO_2) measured as NO_2^-. In particular, wet impingers are used to provide a result indicative of the difference between a measured value of ionic NO_x and an actual value associated with atmospheric ionic NO_x. Atmospheric NO_x represents the total of ionic and non-ionic NO_x present in the air within a cleanroom. In contrast, atmospheric ionic NO_x (NO_x^-) is the total of nitric acid (HNO_3) as measured as the NO_3^- ion and nitrous acid (HNO_2) measured as NO_2^-. Virtual NO_x^- is the fraction of ionic NO_x as measured by the series wet impingers 86 and 88, respectively. Virtual NO_x^- is a generated result caused by the interaction between atmospheric non-ionic NO_x and water. Virtual ionic NO_x is formed by way of impingers as follows:

$$NO_2(\text{gas=g}) \rightarrow NO_2\,(\text{water=w}) \tag{9}$$

$$NO(g) \rightarrow NO\,(w) \tag{10}$$

$$NO_2\,(w) + NO_2\,(w) \rightarrow \leftarrow N_2O_4(w) \tag{11}$$

$$N_2O_4(W) + H_2O \rightarrow HNO_2 + HNO_3(w) \quad (12)$$

$$NO_2\,(w) + NO(w) \rightarrow \leftarrow N_2O_3 \quad (13)$$

$$N_2O_3(w) + H_2O \rightarrow 2HNO_2(w) \quad (14)$$

In passing through a first wet impinger, a small fraction of atmospheric non-ionic NO_x will be converted to virtual ionic NO_x therein. The gas sample leaving the first wet impinger will contain almost the same amount and composition of atmosphericnon-ionic NO_x as the gas sample which entered it. A second wet impinger will contain substantially the same amount of virtual ionic NO_x as was measured in first wet impinger. Actual amounts of ionic NO_x will be effectively (i.e. substantially 99%) retained by the first wet impinger. By subtracting the two results, the difference will represent the actual amount of ionic NO_x present in the atmosphere.

Tenax traps are used to retain non-acids and non-bases which typically consist of condensables, organic compounds, and refractory compounds. Tenax traps may be custom fabricated for use in gas sampling unit 2200 or they may be purchased as an off-the-shelf item. By way of example, an embodiment of gas sampling unit 2200 employs Perkin Elmer Supelco Tenax traps.

Embodiments of gas sampling unit 2200 may further include a controller for operating components such as a solid state timer a, vacuum pump, a pressure regulator, computer controllable entry and exhaust manifolds, computer controllable pre-purge bypass valves, data displays, network interfaces, and the like. Figure 25 illustrates an embodiment of a controller 2500 in the form of a general-purpose computer that executes machine-readable instructions, or function-executable code, for performing control of gas sampling unit 2200. The exemplary computer 2500 includes a processor 2502, main memory 2504, read only memory (ROM) 2506, storage device 2508, bus 2510, display 2512, keyboard 2514, cursor control 2516, and communication interface 2518.

The processor 2502 may be any type of conventional processing device that interprets and executes instructions. Main memory 2504 may be a random access memory (RAM) or a similar dynamic storage device. Main memory 2504 stores information and instructions to be executed by processor 2502. Main memory 2504 may also be used for storing temporary variables or other intermediate information during execution of instructions by processor 2502. ROM 2506 stores static information and instructions for processor 2502. It will be appreciated that ROM 2506 may be replaced with some other type of static storage device. The data storage device 2508 may include any type of magnetic or optical media and its corresponding interfaces and operational hardware. Data storage device 2508 stores information and instructions for use by processor 2502. Bus 2510 includes a set of hardware lines (conductors, optical fibers, or the like) that allow for data transfer among the components of computer 2500.

The display device 2512 may be a cathode ray tube (CRT), liquid crystal display (LCD) or the like, for displaying information to a user. The keyboard 2514 and cursor control 2516 allow the user to interact with the computer 2500. In alternative embodiments, the keyboard 2514 may be replaced with a touch pad having function specific keys. The cursor control 2516 may be, for example, a mouse. In an alternative configuration, the keyboard 2514 and cursor control 2516 can be replaced with a microphone and voice recognition means to enable the user to interact with the computer 2500.

Communication interface 2518 enables the computer 2500 to communicate with other devices/systems via any communications medium. For example, communication interface 2518 may be a modem, an Ethernet interface to a LAN (wired or wireless), or a printer interface. Alternatively, communication interface 2518 can be any other interface that enables communication between the computer 2500 and other devices or systems.

By way of example, a computer 2500 consistent with the present invention provides a gas sampling unit 2200 with the ability to communicate over a network while operating in a cleanroom. Alternatively, a network may convey signals to gas sampling unit 2500 for remotely turning the unit on at a determined time and for remotely turning the unit off when a determined sampling interval has been concluded. In addition, computer 2500 may be used to calibrate components within dry sampler 2200. The computer 2500 performs operations necessary to complete desired actions in response to processor 2502 executing sequences of instructions contained in, for example, memory 2504. Such instructions may be read into memory 2504 from another computer-readable medium, such as a data storage device 2508, or from another device via communication interface 2518. Execution of the sequences of instructions contained in memory 2504 causes processor 2502 to perform a method for controlling gas sampling unit 2200. Alternatively, hard-wired circuitry may be used in place of or in combination with software instructions to implement the present invention. Thus, the present invention is not limited to any specific combination of hardware circuitry and software.

FIG. 26 illustrates a schematic representation of a system 2600 for monitoring contaminants in a reactive gas using, among other things, a surface acoustic wave (SAW) detector. System 2600 includes an inlet 2604, a chamber 2606 containing a media 2612, an outlet 2608, an inlet sample port 2614, a mid-stack sample port 2616, an outlet sample port 2618, a sample manifold 2620, a SAW detector 2622, a detector manifold 2626, a detector control line 2624, a dry sampler 2630, a dry sampler input line 2628, a dry sampler output line 2632, an analyzer 2636, an analyzer input line 2634 and an analyzer output line 2638.

An input gas sample 2602 passes through inlet 2604 and into chamber 2606. Contaminants present in gas sample 2602 are removed using media 2612 to produce an outlet gas sample 2610. A sample manifold 2620 may route a portion of a gas to SAW detector 2622 using inlet sample port 2614, mid-stack sample port 2616 or outlet sample port 2618. SAW detector 2622 may accumulate contaminants on a surface of the detector. As contaminants build up, an output signal associated with SAW detector 2622 will change. When contaminant levels on the surface of SAW detector 2622 reach or exceed a determined threshold, detector manifold 2626 may be activated, or controlled, by detector control line 2624.

When activated, detector manifold 2626 may allow a gas sample to pass through analyzer line 2634 before entering analyzer 2636. Analyzer 2636 may be a gas chromatograph or other analysis tool capable of determining a contaminant present in the gas sample. Analyzer 2636 may have an output line 2638 for exhausting the gas sample.

Detector manifold 2626 may route the gas sample through dry sampler input line 2628 to dry sampler 2630. Dry sampler 2630 may include any combination of dry traps, Tenax traps, wet impingers, and/or SAW detectors 2622 for collecting and measuring contaminants in the gas sample. Dry sampler 2630 may include an outlet 2632 for exhausting a gas sampler after passing through dry sampler 2630.

The detector can be used to initiate sampler system operation, or alternatively can be used to terminate sampler operation and indicate to the user that the sampler contents are ready to be analyzed.

In view of the wide variety of embodiments to which the principles of the present invention can be applied, it should be understood that the illustrated embodiments are exemplary only, and should not be taken as limiting the scope of the present invention. The claims should not be read as limited to the described order or elements unless stated to that effect. Therefore, all embodiments that come within the scope and spirit of the following claims and equivalents thereto are claimed as the invention.

CLAIMS

What is claimed:

1. A gas filter for a reactive gas used in a semiconductor processing system comprising:

    a container comprising:

        a tube portion having an inlet end, an outlet end, and an internal chamber;

        an inlet port having an inlet particle filter;

        an outlet port;

        a filter media substantially filling said internal chamber; and

        a sampling port for facilitating measurement of a contaminant in said reactive gas.

2. The gas filter of claim 1, wherein said sampling port makes at least a portion of said reactive gas available to a sensor.

3. The filter of claim 2 wherein said contaminant adheres to a surface of said sensor.

4. The filter of claim 3 wherein said surface comprises a coating for facilitating adherence of said contaminant.

5. The filter of claim 4 wherein said sensor produces an output signal representative of said contaminant and initiating a sample measurement or terminating a sample measurement.

6. The filter of claim 5 wherein said output signal is a voltage that changes amplitude in response to the presence of said contaminant.

7. The filter of claim 5 wherein said output signal is a voltage that changes amplitude in response to the presence of said contaminant.

8. The filter of claim 5 further comprising a detector for identifying said contaminant, said detector communicatively coupled to said sensor.

9. The filter of claim 6 wherein said detector comprises a gas chromatograph for identifying said contaminant.

10. The filter of claim 1 wherein said sampling port is communicatively coupled to a sampling device in a manner causing a contaminant in said reactive gas to be made available to said sampling device.

11. The filter of claim 10 wherein said sampling device comprises a dry trap.

12. The filter of claim 10 wherein said sampling device comprises a Tenax trap.

13. The filter of claim 10 wherein said sampling device comprises a wet impinger.

14. The filter of claim 13 wherein said wet impinger comprises:

a first wet impinger having a first input end for receiving said reactive gas from said sampling port and a first output end; and

a second wet impinger having a second input end coupled to said first output end for receiving at least a portion of said received reactive gas from said first wet impinger and further having a second output end.

15. The filter of claim 14 wherein said first and second wet impingers together allow determination of a virtual NOx level associated with said reactive gas.

16. The filter of claim 10 wherein said sampling device is portable.

17. The filter of claim 16 wherein said sampling device is received from an analysis facility prior to being coupled to said sampling port, said sampling device further being returned to said analysis facility for analysis of samples received by said sampling device while coupled to said sampling port.

18. The filter of claim 16 wherein said sampling device is handheld.

19. The filter of claim 18 wherein said sampling device provides a result to a user after making a measurement.

20. The filter of claim 1 wherein said sampling port is located proximate to said input port.

21. The filter of claim 1 wherein said sampling port is located proximate to said output port.

22. The filter of claim 1 wherein said sampling port is located between said input port and said output port.

23. The filter of claim 1 wherein said output port has an outlet particle filter extending into said internal chamber.

24. The filter of claim 1 wherein said filter provides an output gas stream having a concentration of ammonia of no greater than about 1 ppbv and a concentration of sulfur dioxide no greater than about 1 ppbv for an input gas stream having a concentration of ammonia no greater than about 10 ppbv and a concentration of sulfur dioxide no greater than about 5 ppbv, said gas filter having a pressure drop of no greater than about 35 psi for an input gas stream pressure in the range from about 70 psi to about 100 psi and an inlet gas stream flow rate in the range from about 20 slpm to about 50 slpm.

25. The gas filter of claim 1, said inlet further having a fill port.

26. The gas filter of claim 1, wherein said substantially cylindrical tube portion has a central axis and one of said inlet port and said outlet port is offset from said central axis and the other of said inlet port and said outlet port is substantially on said central axis.

27. The gas filter of claim 1, wherein said substantially cylindrical tube portion has a central axis and said inlet port and said outlet port are offset from said central axis.

28. The gas filter of claim 1, wherein at least one of said inlet particle filter and said outlet particle filter comprise a porous nickel particle filter capable of filtering particles having a diameter of about 0.003 microns or greater.

29. The gas filter of claim 1, wherein said reactive gas comprises clean dry air.

30. The gas filter of claim 1, wherein said volume of filter media is no greater than about 3.0 liters.

31. The gas filter of claim 1, wherein said filter media comprises granulated activated charcoal (GAC).

32. The gas filter of claim 1, wherein said filter media comprises phosphoric acid treated granulated activated charcoal.

33. The gas filter of claim 1, wherein said filter media comprises potassium carbonate treated granulated activated charcoal.

34. The gas filter of claim 1, wherein said filter media comprises phosphoric acid treated granulated activated charcoal.

35. The gas filter of claim 1, wherein said filter media comprises two or more bedded filter materials.

36. The gas filter of claim 34, wherein said filter media comprises a bed substantially of a GAC filter material and a bed comprising a phosphoric acid treated granulated activated charcoal filter material.

37. The gas filter of claim 35, wherein said filter media further comprises a potassium carbonate treated GAC filter material.

38. The gas filter of claim 1, wherein said gas filter supplies an output gas stream having a concentration of hexamethyldisiloxane (HMDSO) of no greater than

about 10 ppbv for an input gas stream having a concentration of condensable organics no greater than about100 ppbv.

39. The gas filter of claim 1, wherein said filter media has a volume of no greater than about 0.5 liters and output gas stream has a concentration of ammonia of no greater than about 1 ppbv and a concentration of sulfur dioxide no greater than about 1 ppbv for an input gas stream having a concentration of ammonia no greater than about 10 ppbv and a concentration of sulfur dioxide no greater than about 5 ppbv, said gas filter having a pressure drop of no greater than about 35 psi for an input gas stream pressure in the range from about 70 psi to about 100 psi and an inlet gas stream flow rate in the range from about 20 slpm to about 50 slpm.

40. A gas filter for a reactive gas comprising:

a container comprising:

a substantially cylindrical tube portion having an inlet end, an outlet end, and an internal chamber;

an inlet port having an inlet particle filter that extends into the internal chamber;

an outlet port having an outlet particle filter that extends into the internal chamber; and

a filter media that fills the internal chamber, the gas filter supplying an output gas stream having a concentration of ammonia of no greater than about 1 ppbv and a concentration of sulfur dioxide no greater than about 1 ppbv for an input gas stream having a concentration of ammonia no greater than about 10 ppbv and a concentration of sulfur dioxide no greater than about 5 ppbv, the gas filter having a pressure drop of no greater than about 35 psi for an input gas stream pressure in the range from about 70 psi to about 100 psi and an inlet gas stream flow rate in the range from about 20 slpm to about 50 slpm.

41. The gas filter of claim 40, the inlet end further having a fill port.

42. The gas filter of claim 40, wherein the substantially cylindrical tube portion has a central axis and one of the inlet port and outlet port is offset from the central axis and the other of the inlet port and outlet port is substantially on the central axis.

43. The gas filter of claim 40, wherein the substantially cylindrical tube portion has a central axis and the inlet port and outlet port are offset from the central axis.

44. The gas filter of claim 40, wherein at least one of the inlet particle filter and outlet particle filter comprise a porous nickel particle filter capable of filtering particles having a diameter of about 0.003 microns or greater.

45. The gas filter of claim 40, wherein the reactive gas comprises clean dry air.

46. The gas filter of claim 40, wherein the volume of filter media is no greater than about 3.0 liters.

47. The gas filter of claim 40, wherein the filter media comprises granulated activated charcoal (GAC).

48. The gas filter of claim 40, wherein the filter media comprises phosphoric acid treated granulated activated charcoal.

49. The gas filter of claim 40, wherein the filter media comprises potassium carbonate treated granulated activated charcoal.

50. The gas filter of claim 40, wherein the filter media comprises phosphoric acid treated granulated activated charcoal.

51. The gas filter of claim 40, wherein the filter media comprises two or more bedded filter materials.

52. The gas filter of claim 50, wherein the filter media comprises a bed substantially of a GAC filter material and a bed comprising a phosphoric acid treated granulated activated charcoal filter material.

53. The gas filter of claim 51, wherein the filter media further comprises a potassium carbonate treated GAC filter material.

54. The gas filter of claim 40, wherein the gas filter supplies an output gas stream having a concentration of hexamethyldisiloxane (HMDSO) of no greater than about 10 ppbv for an input gas stream having a concentration of condensable orgnaics no greater than about 100 ppbv.

55. A gas filter for a reactive gas comprising:

a container comprising:

a substantially cylindrical tube portion having an inlet end, an outlet end, and an internal chamber;

an inlet port having an inlet particle filter that extends into the internal chamber;

an outlet port having an outlet particle filter that extends into the internal chamber; and

a filter media in the internal chamber, the filter media having a volume of no greater than about 0.5 liters, the gas filter supplying an output gas stream having a concentration of ammonia of no greater than about 1 ppbv and a concentration of sulfur dioxide no greater than about 1 ppbv for an input gas stream having a concentration of ammonia no greater than about 10 ppbv and a concentration of sulfur dioxide no greater than about 5 ppbv, the gas filter having a pressure drop of no greater than about 35 psi for an input gas stream pressure in the range from about70 psi to about 100 psi and an inlet gas stream flow rate in the range from about 20 slpm to about 50 slpm.

56. The gas filter of claim 55, the inlet end further having a fill port.

57. The gas filter of claim 55, wherein the substantially cylindrical tube portion has a central axis and one of the inlet port and outlet port is offset from the central axis and the other of the inlet port and outlet port is substantially on the central axis.

58. The gas filter of claim 55, wherein the substantially cylindrical tube portion has a central axis and the inlet port and outlet port are offset from the central axis.

59. The gas filter of claim 55, wherein at least one of the inlet particle filter and outlet particle filter comprise a porous nickel particle filter capable of filtering particles having a diameter of about 0.003 microns or greater.

60. The gas filter of claim 55, wherein the reactive gas comprises clean dry air.

61. The gas filter of claim 55, wherein the filter media comprises granulated activated charcoal (GAC).

62. The gas filter of claim 55, wherein the filter media comprises phosphoric acid treated granulated activated charcoal.

63. The gas filter of claim 55, wherein the filter media comprises potassium carbonate treated granulated activated charcoal.

64. The gas filter of claim 55, wherein the filter media comprises phosphoric acid treated granulated activated charcoal.

65. The gas filter of claim 55, wherein the filter media comprises two or more bedded filter materials.

66. The gas filter of claim 64, wherein the filter media comprises a bed substantially of a GAC filter material and a bed comprising a phosphoric acid treated granulated activated charcoal filter material.

67. The gas filter of claim 65, wherein the filter media further comprises a potassium carbonate treated GAC filter material.

68. The gas filter of claim 55, wherein the gas filter supplies an output gas stream having a concentration of hexamethyldisiloxane (HMDSO) of no greater than about 10 ppbv for an input gas stream having a concentration of condensable organics no greater than about 100 ppbv.

69. A method of using the gas filter device of claim 1.

70. A method of using the gas filter of claim 40.

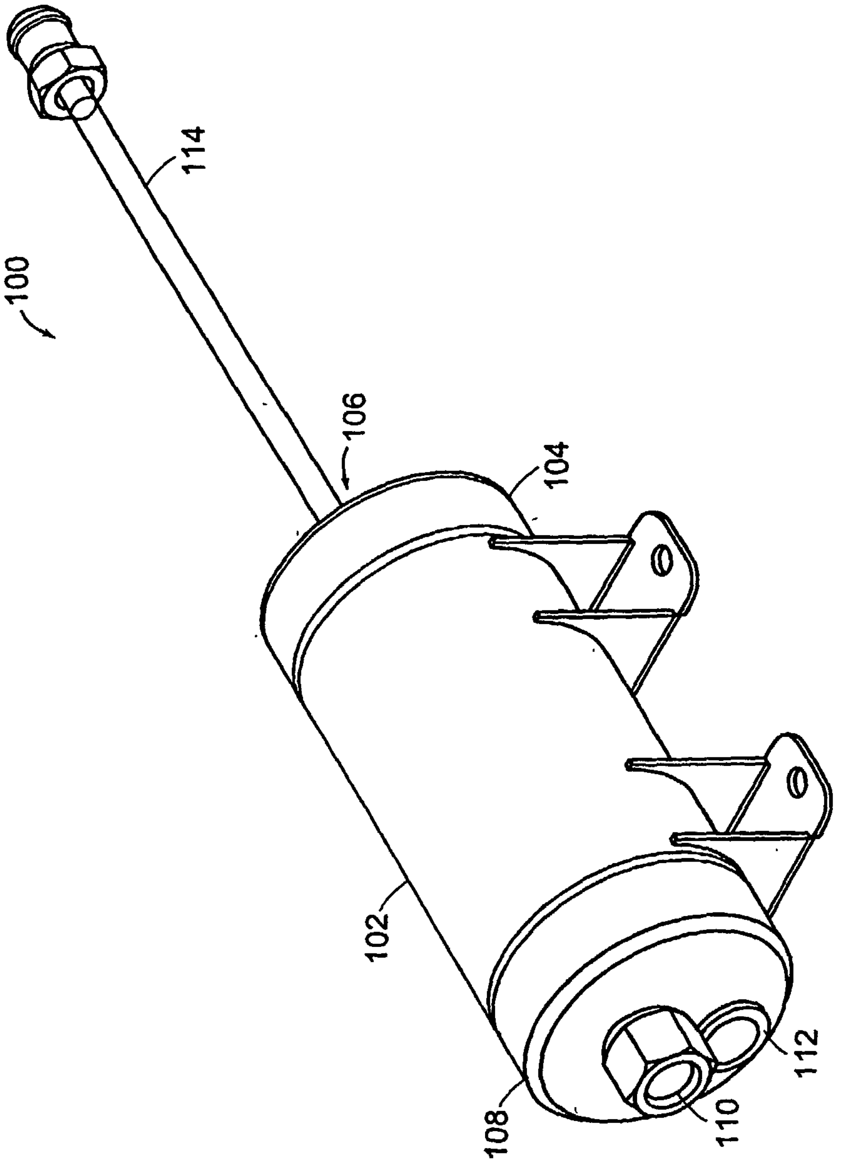


FIG. 1

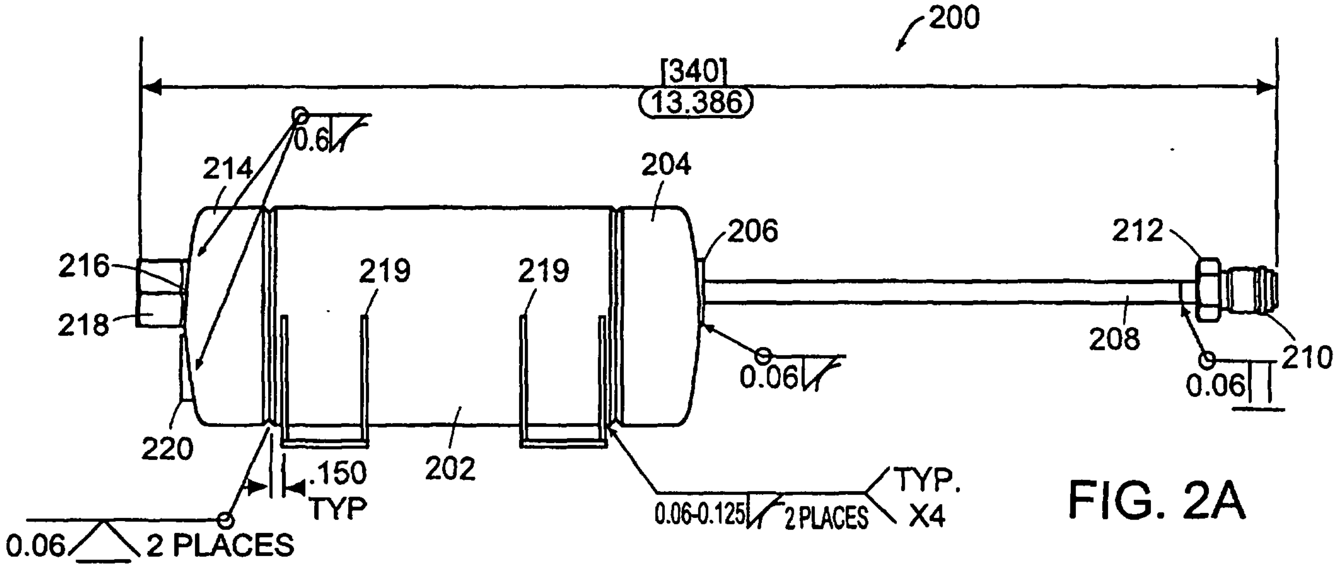


FIG. 2A

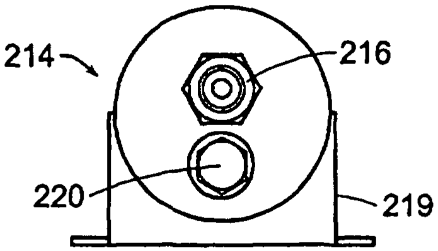


FIG. 2B

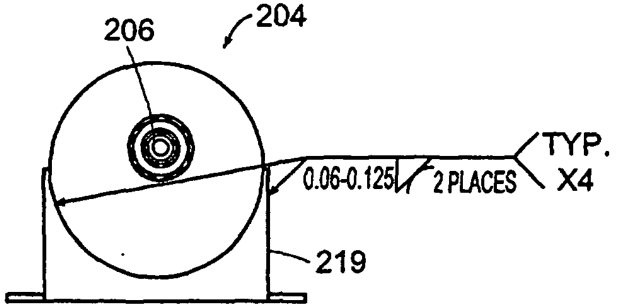


FIG. 2C

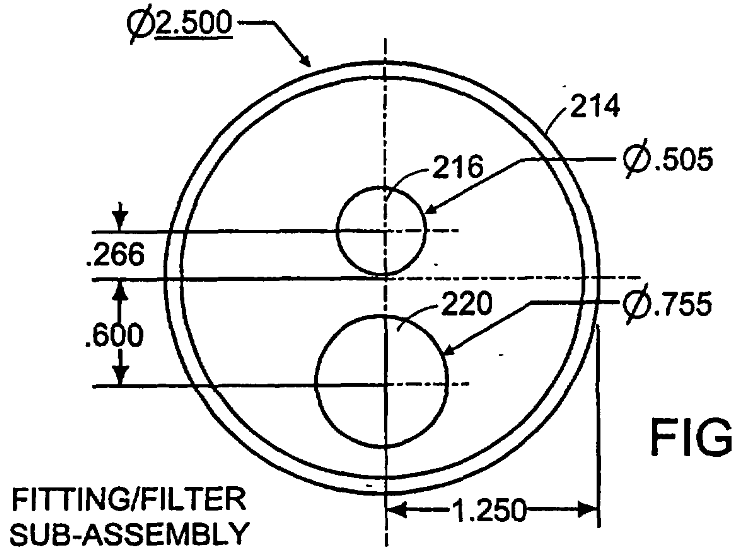


FIG. 2D

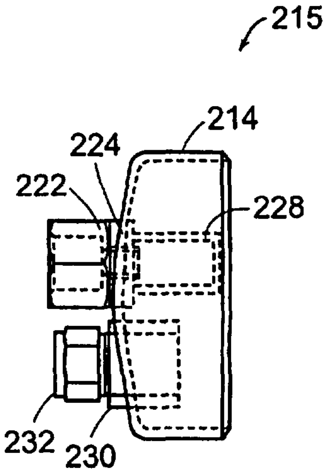


FIG. 2F

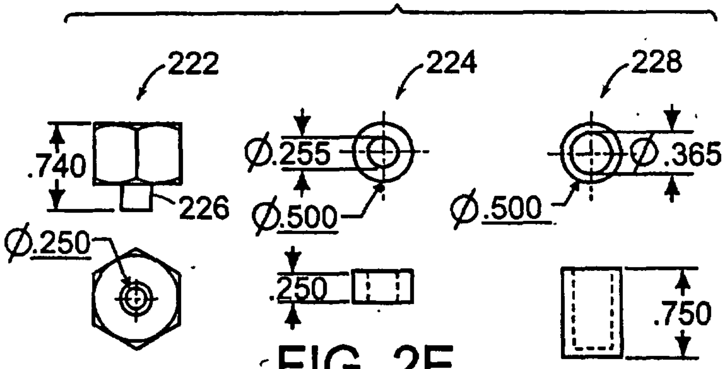


FIG. 2E

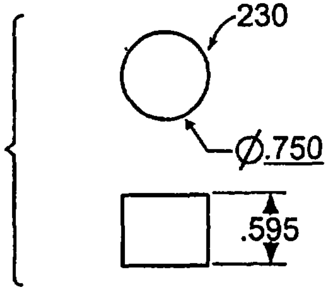


FIG. 2G

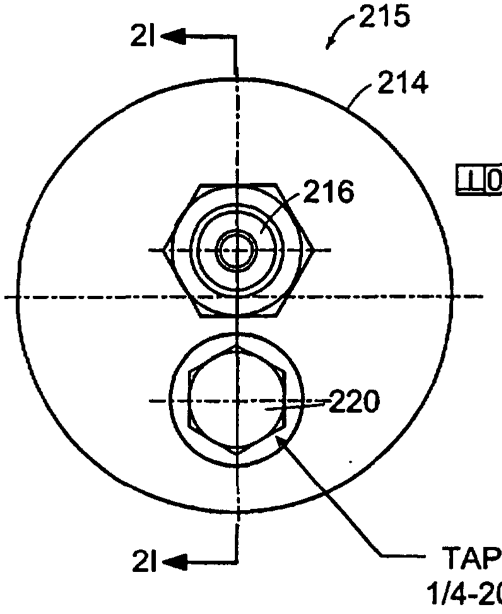


FIG. 2H

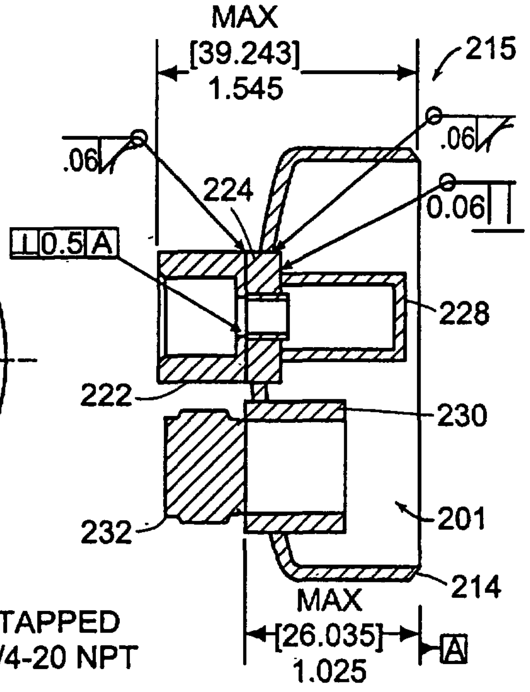


FIG. 2I

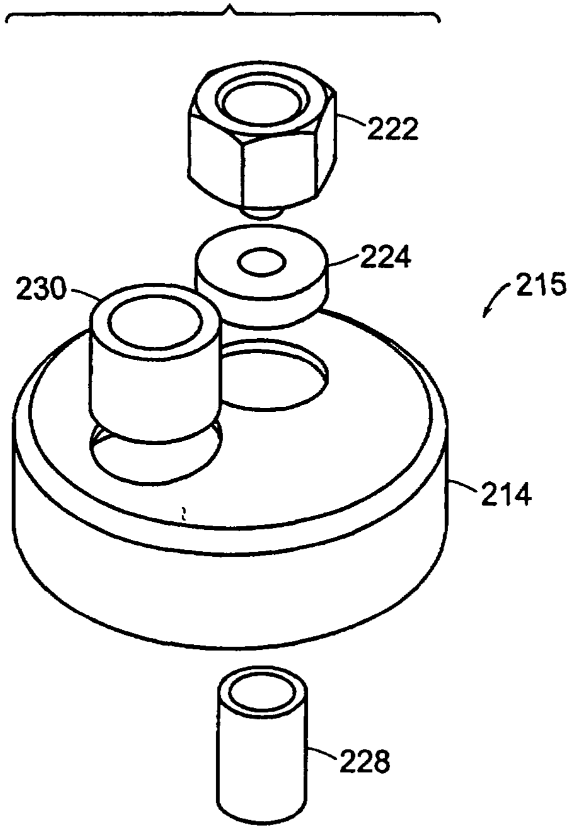


FIG. 2J

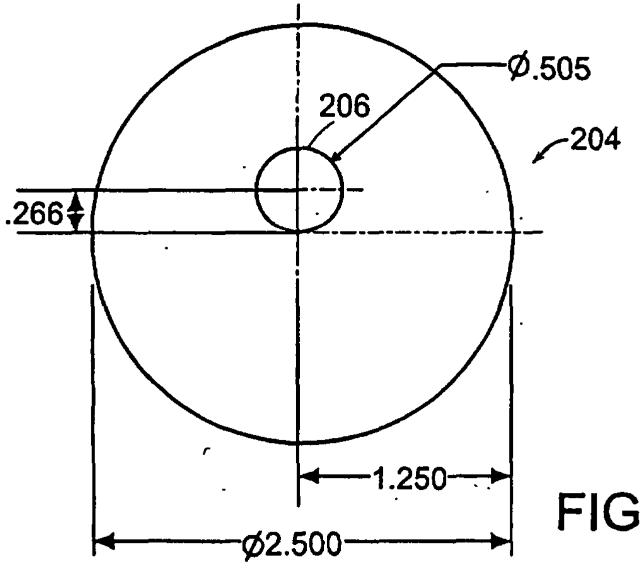


FIG. 2K

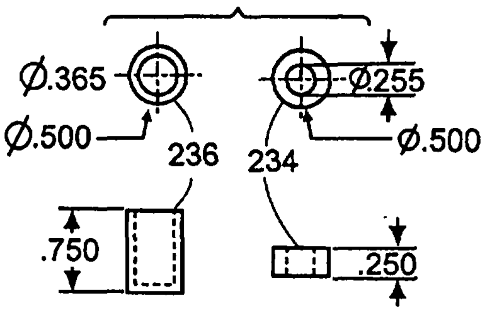


FIG. 2M

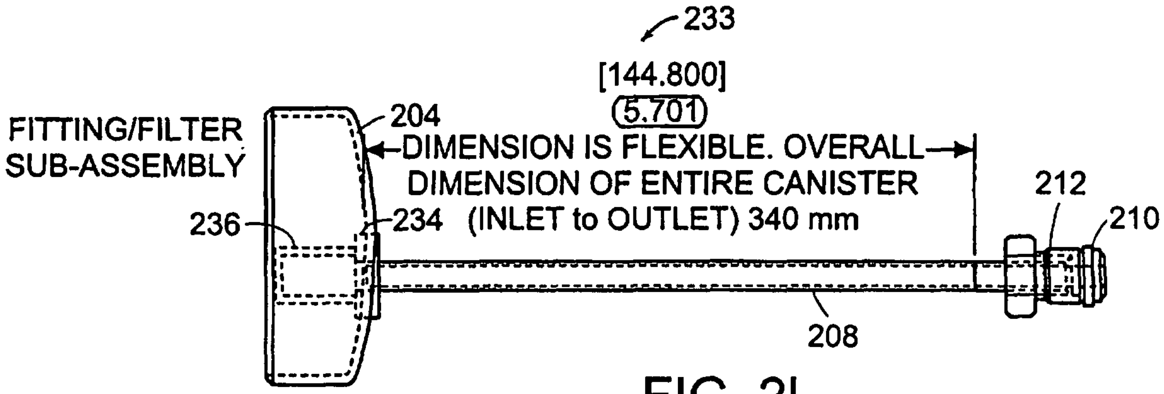


FIG. 2L

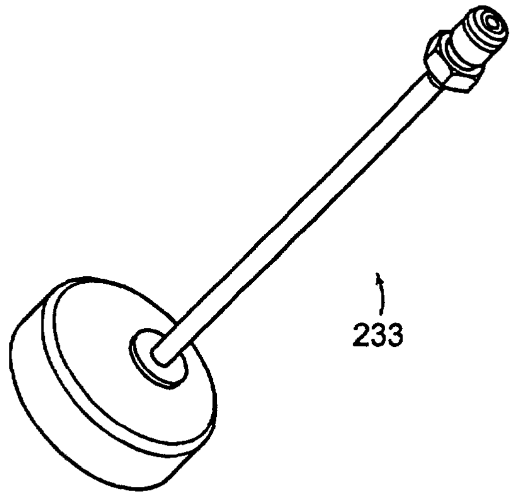


FIG. 2P

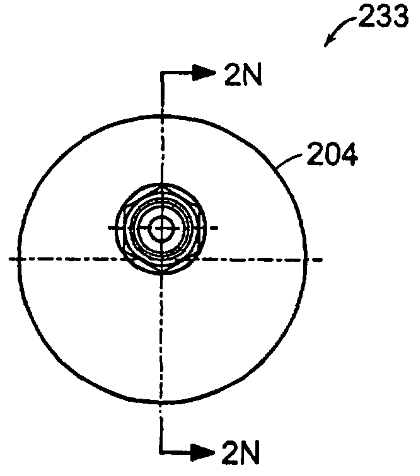


FIG. 2O

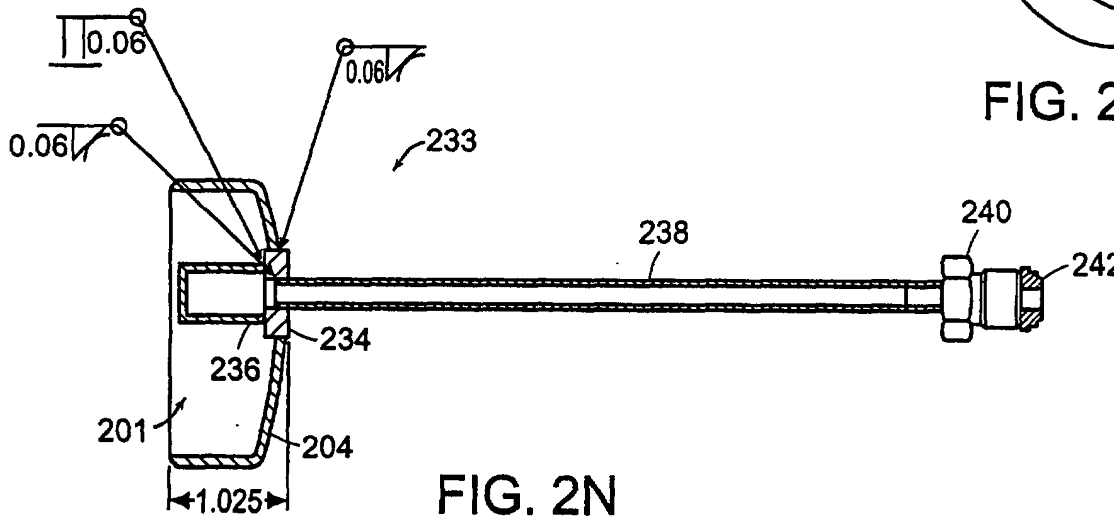


FIG. 2N

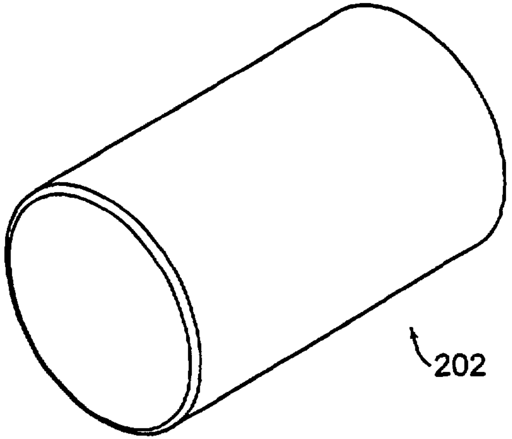


FIG. 2Q

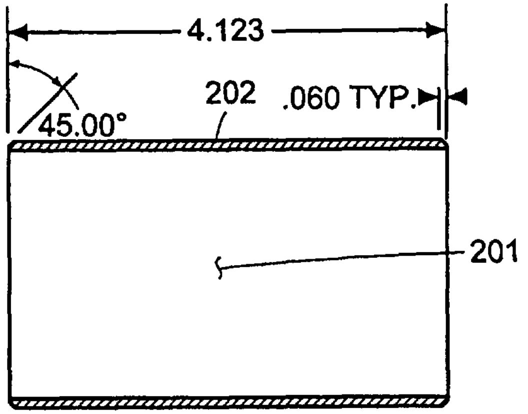


FIG. 2S

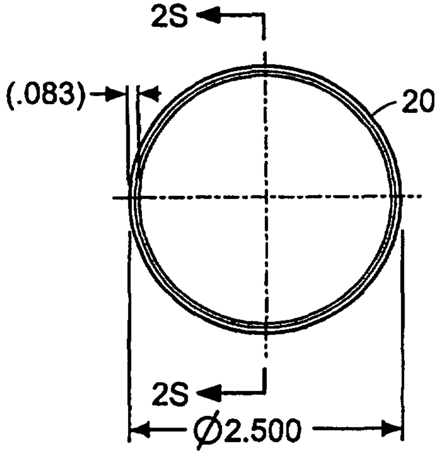


FIG. 2R

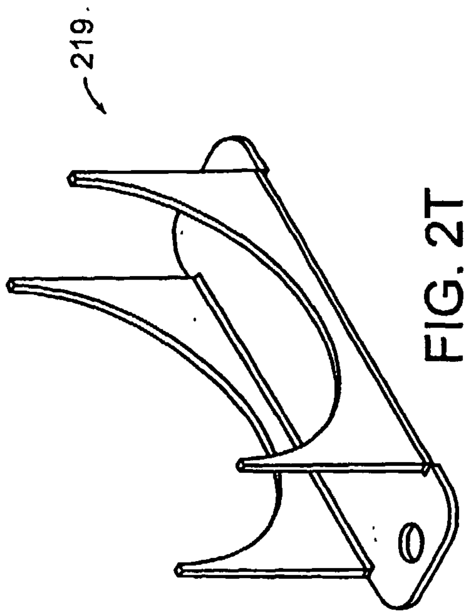


FIG. 2T

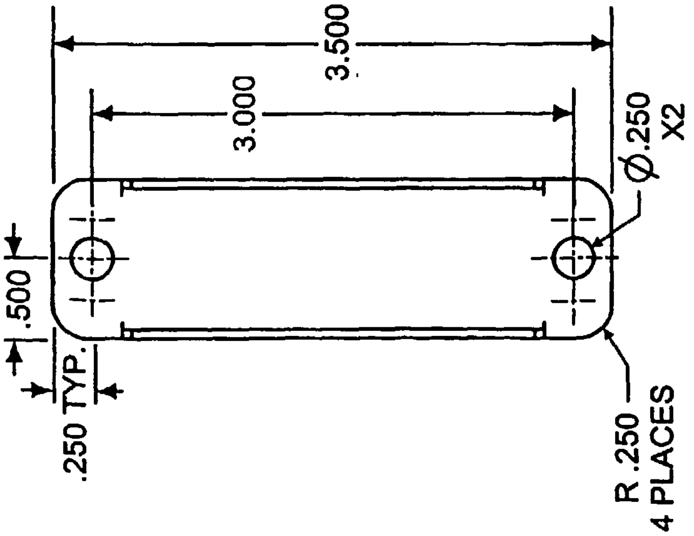


FIG. 2U

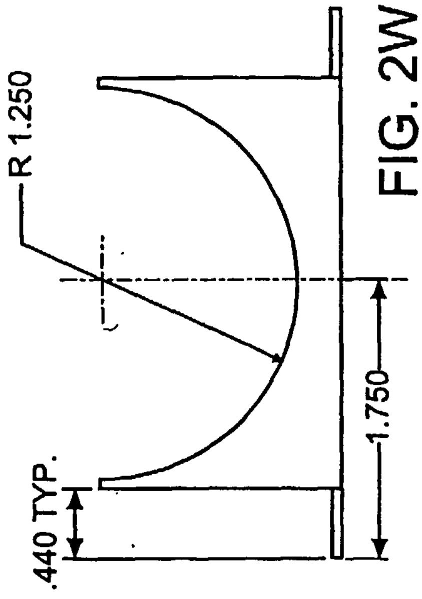


FIG. 2W

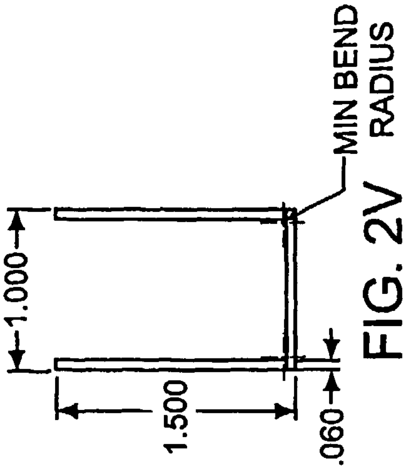


FIG. 2V

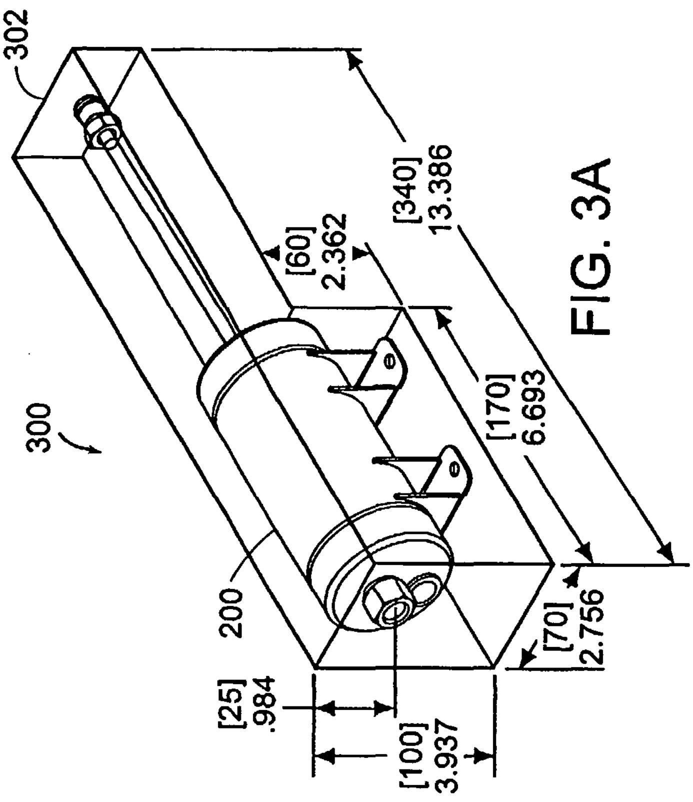


FIG. 3A

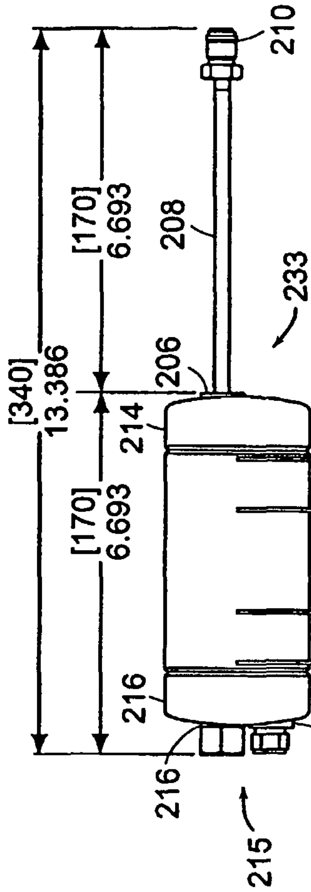


FIG. 3D

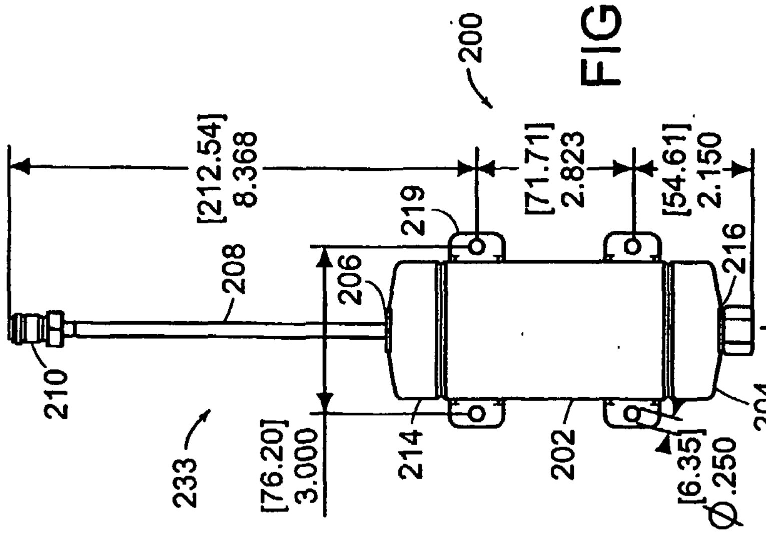


FIG. 3B

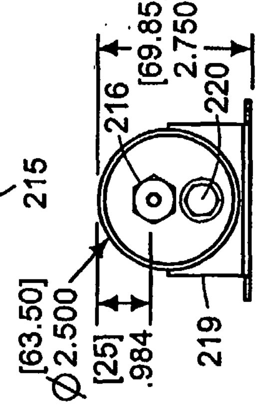


FIG. 3C

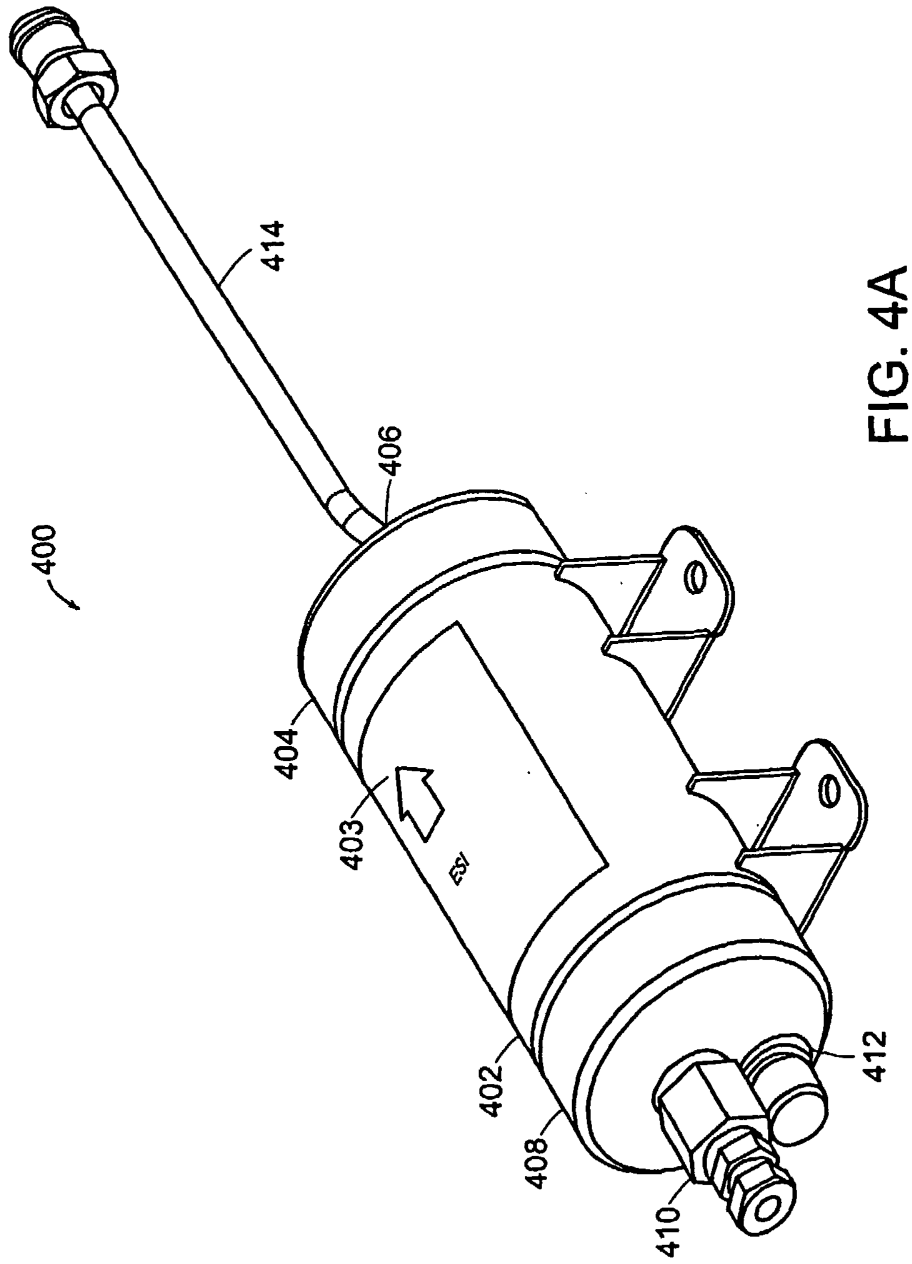


FIG. 4A

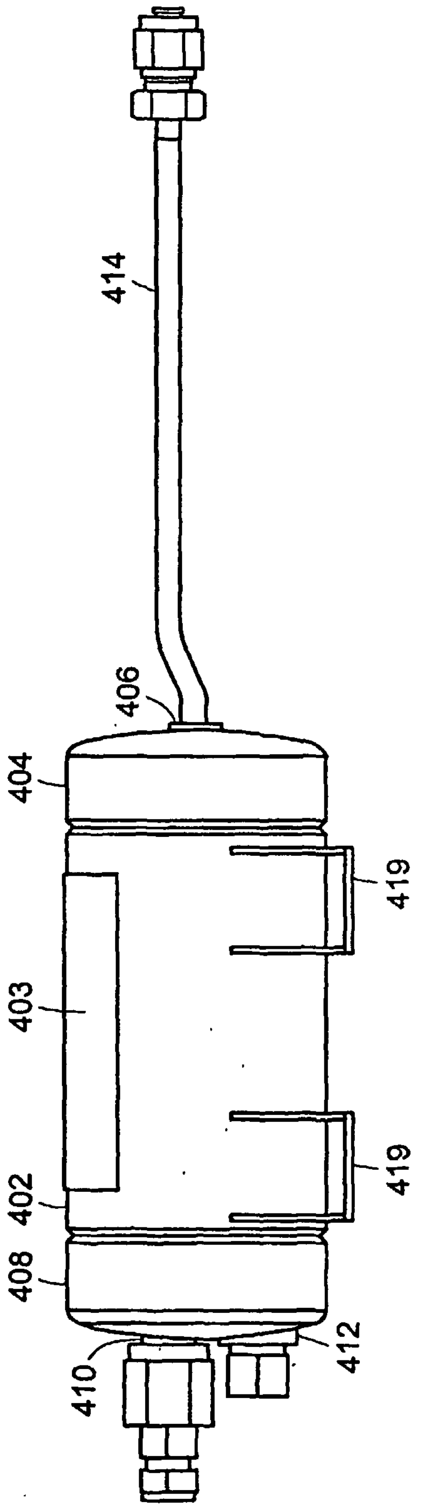


FIG. 4B

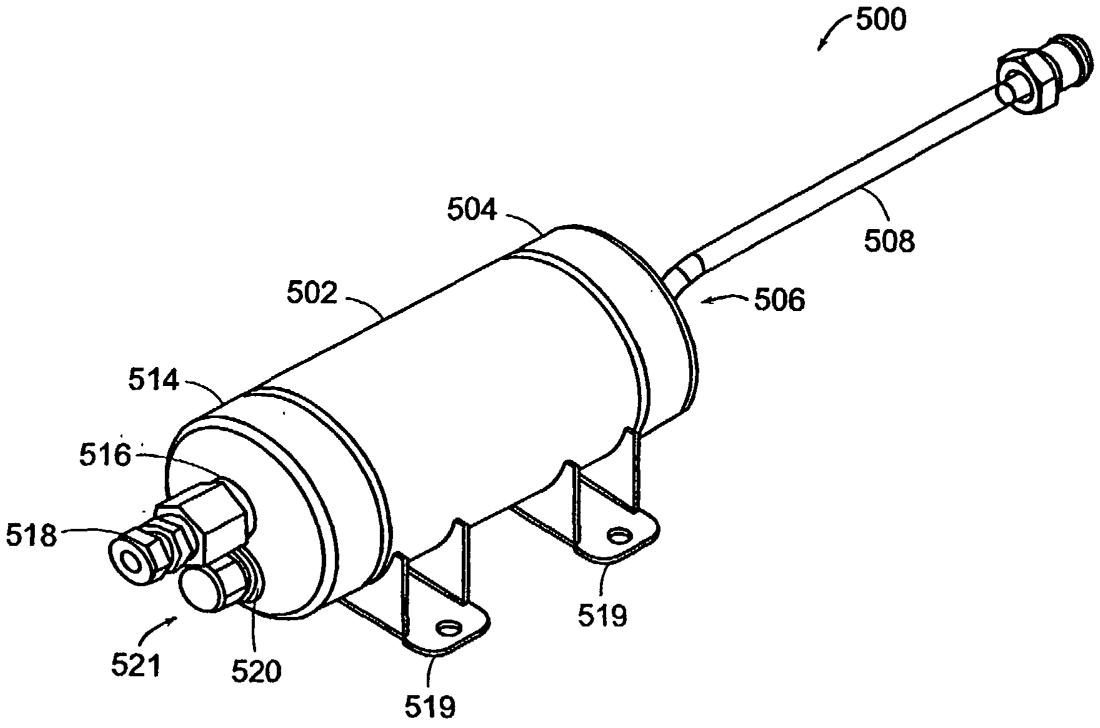


FIG. 5A

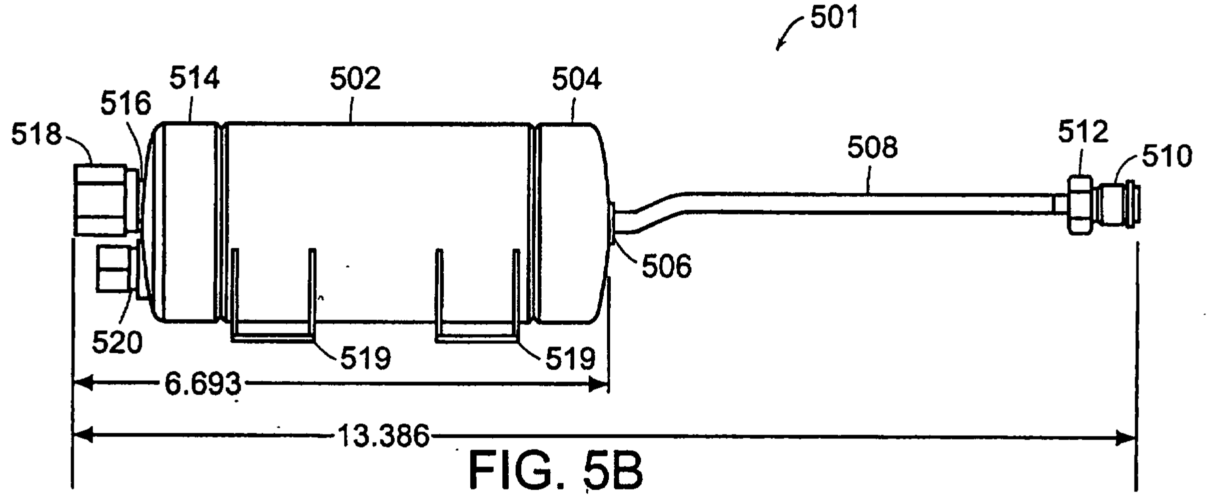
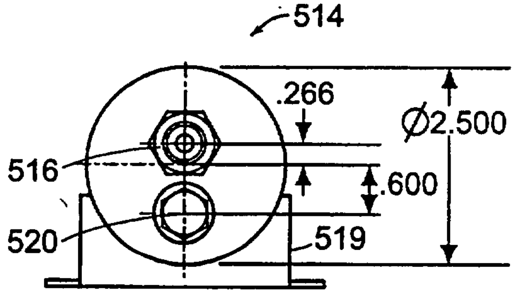
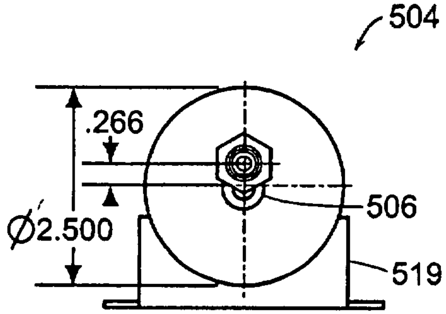


FIG. 5B



INLET VIEW

FIG. 5C



OUTLET VIEW

FIG. 5D

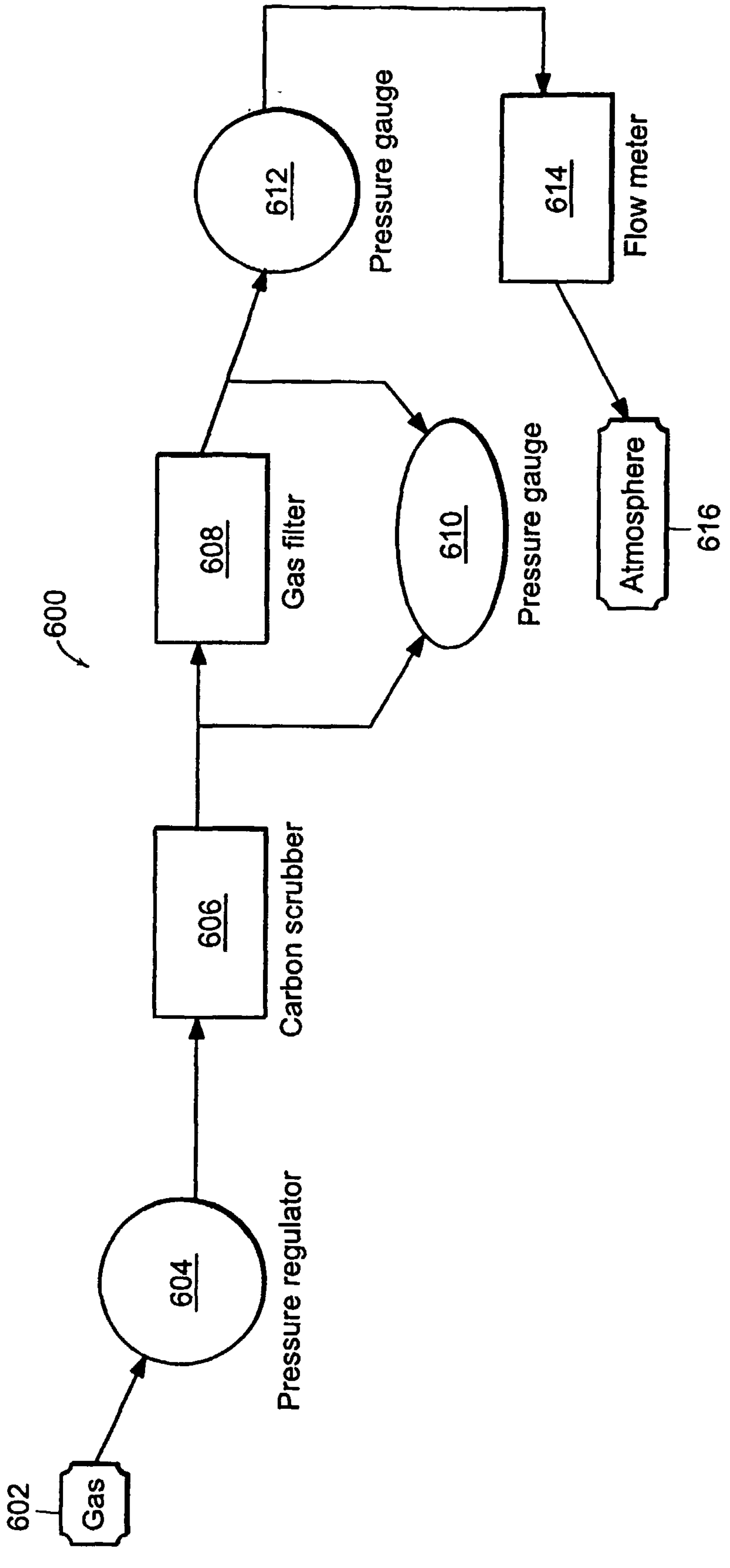

600
602
Gas
604
Pressure regulator
606
Carbon scrubber
608
Gas filter
610
Pressure gauge
612
Pressure gauge
614
Flow meter
Atmosphere
616

FIG. 6

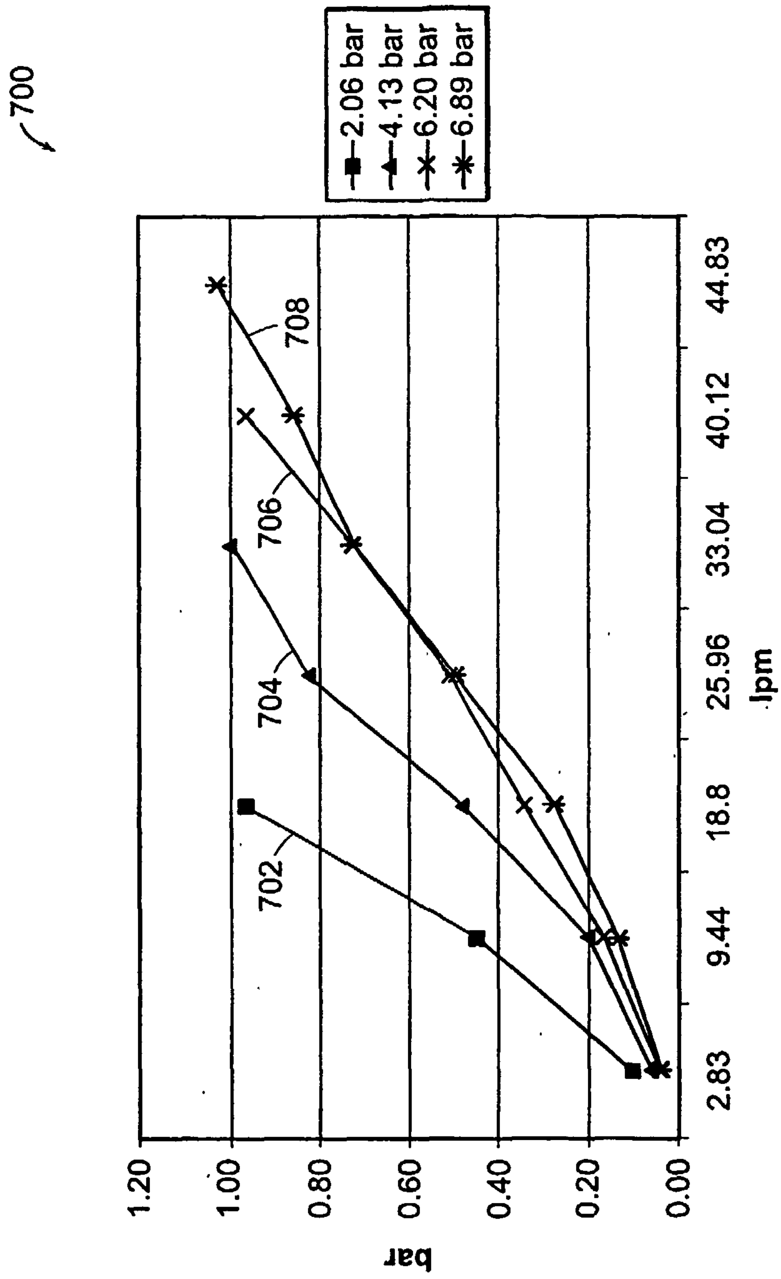

700
—■—2.06 bar
—▲—4.13 bar
—✕—6.20 bar
—✱—6.89 bar
bar
1.20
1.00
0.80
0.60
0.40
0.20
0.00
lpm
2.83
9.44
18.8
25.96
33.04
40.12
44.83
702
704
706
708

FIG. 7A

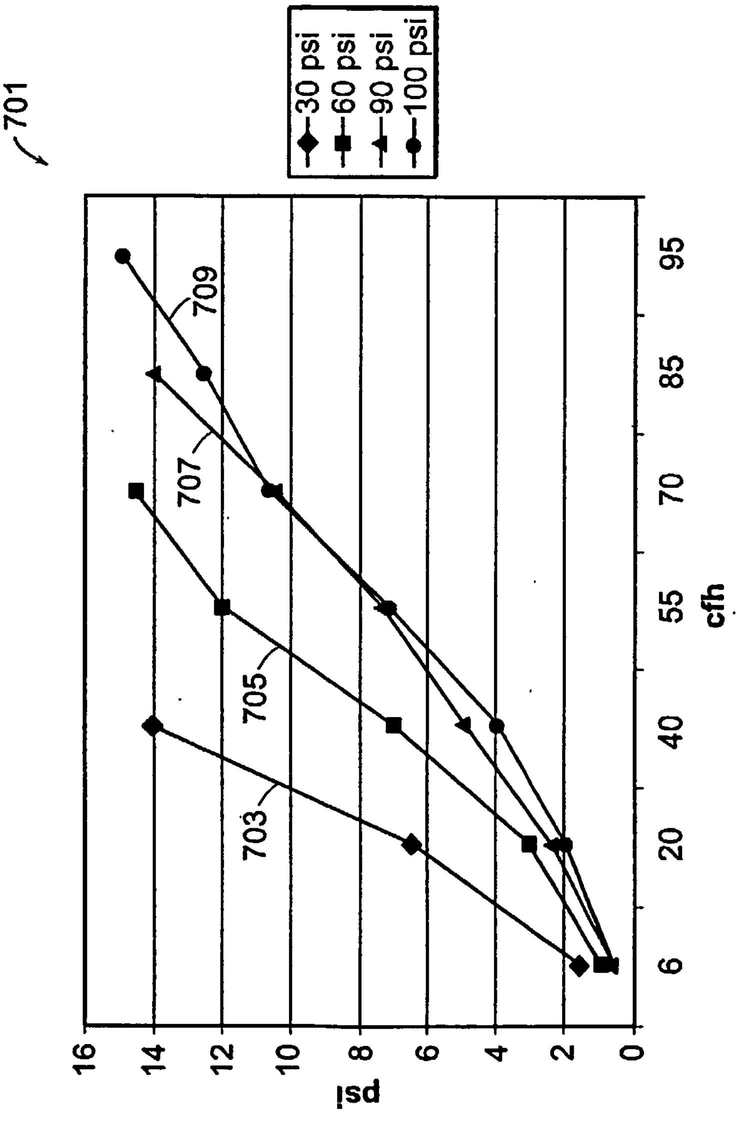

701
psi
0
2
4
6
8
10
12
14
16
cfh
6
20
40
55
70
85
95
703
705
707
709
30 psi
60 psi
90 psi
100 psi

FIG. 7B

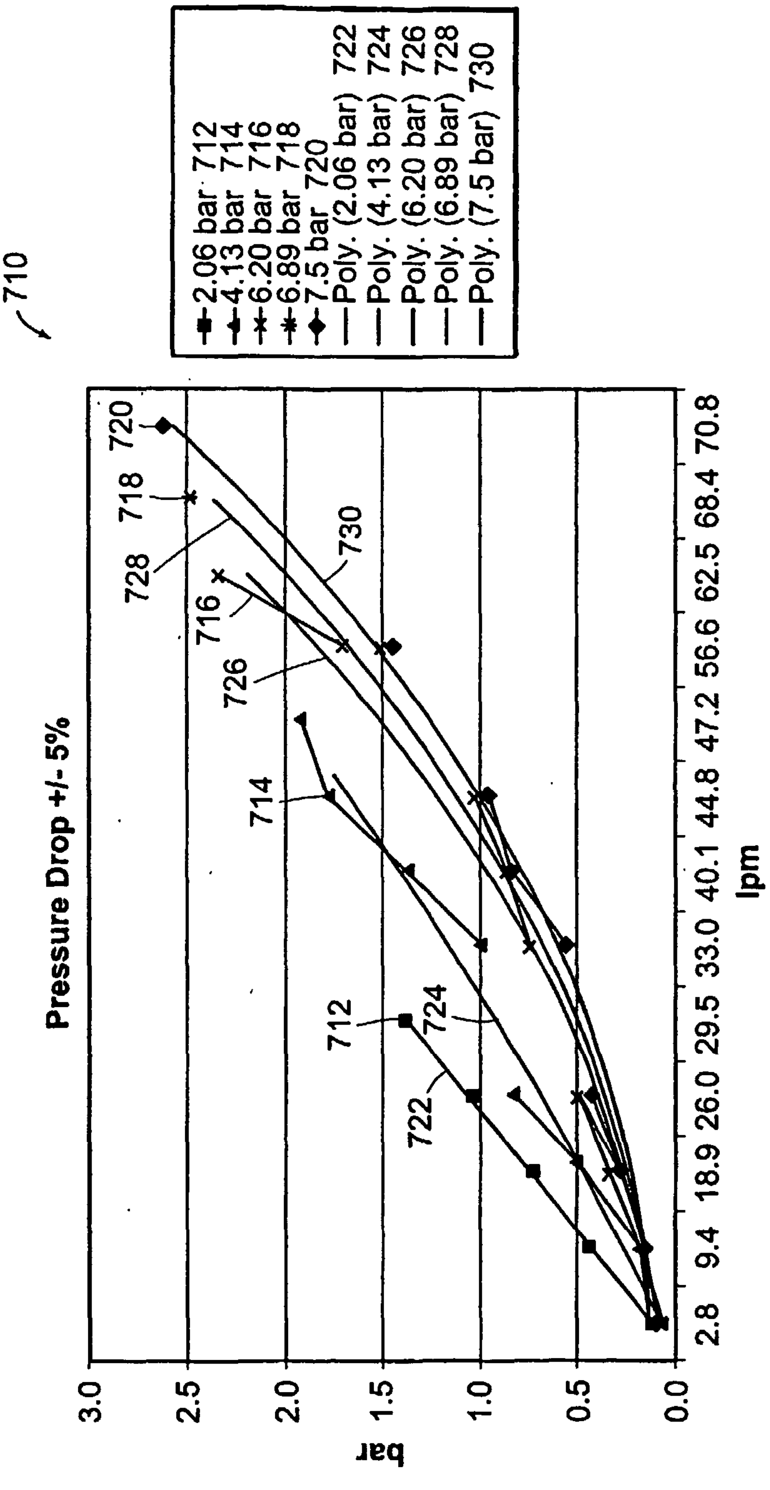

710
Pressure Drop +/- 5%
2.06 bar 712
4.13 bar 714
6.20 bar 716
6.89 bar 718
7.5 bar 720
Poly. (2.06 bar) 722
Poly. (4.13 bar) 724
Poly. (6.20 bar) 726
Poly. (6.89 bar) 728
Poly. (7.5 bar) 730
bar
3.0
2.5
2.0
1.5
1.0
0.5
0.0
lpm
2.8
9.4
18.9
26.0
29.5
33.0
40.1
44.8
47.2
56.6
62.5
68.4
70.8
712
722
724
714
726
716
728
718
730
720

FIG. 7C

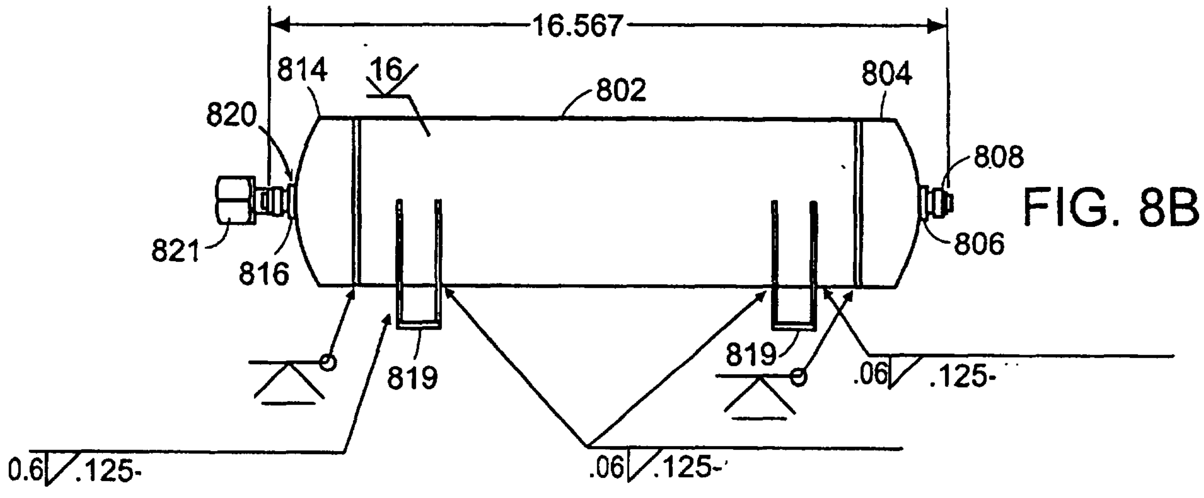


FIG. 8B

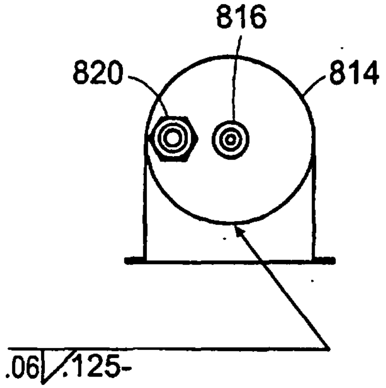


FIG. 8D

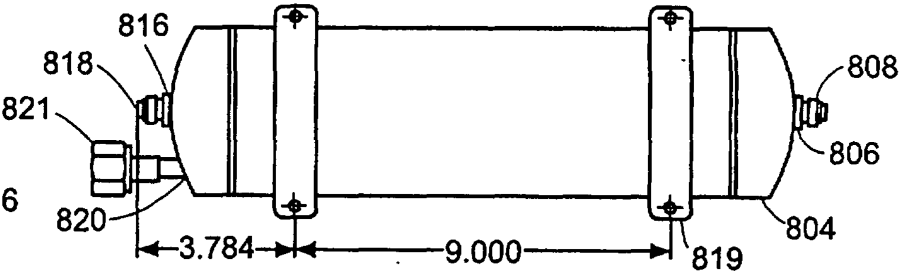


FIG. 8C

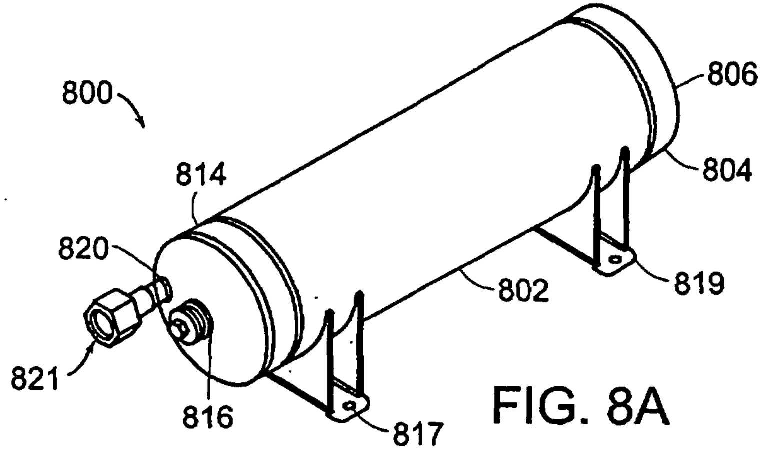


FIG. 8A

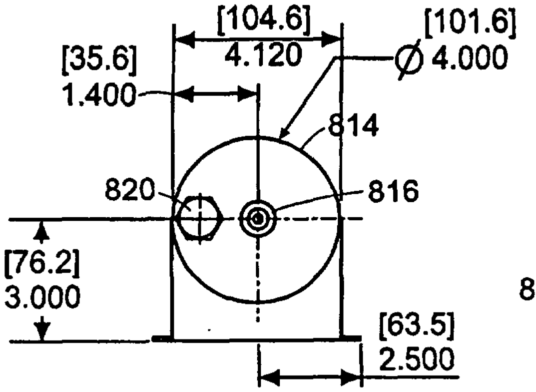


FIG. 8G

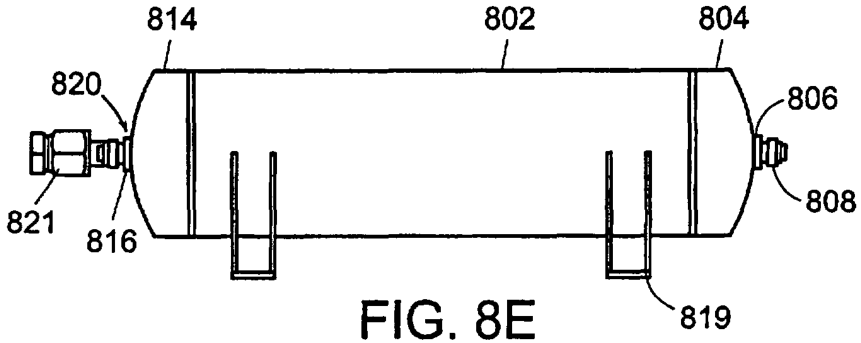


FIG. 8E

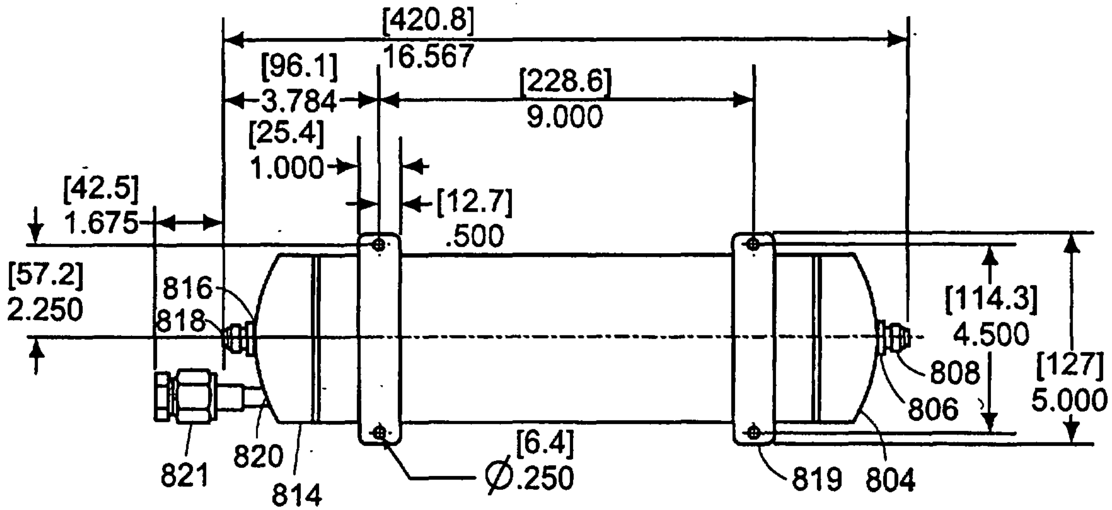


FIG. 8F

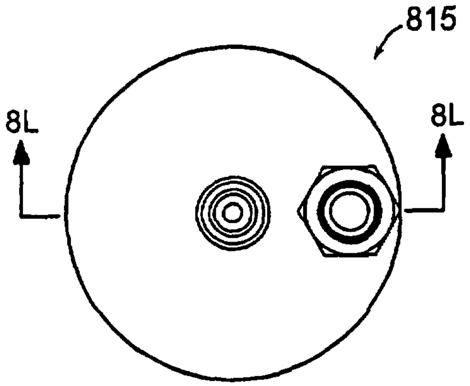


FIG. 8K

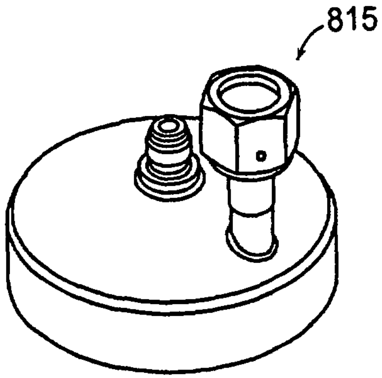


FIG. 8H

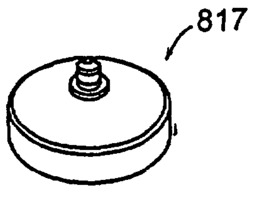


FIG. 8I

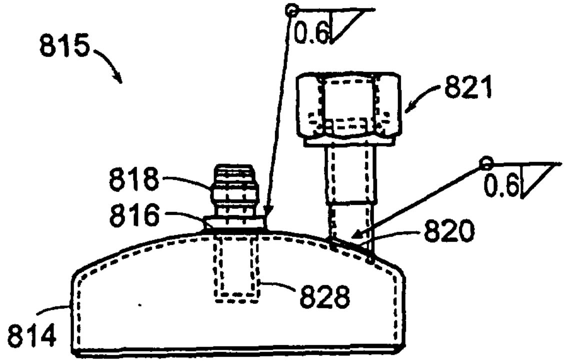


FIG. 8J

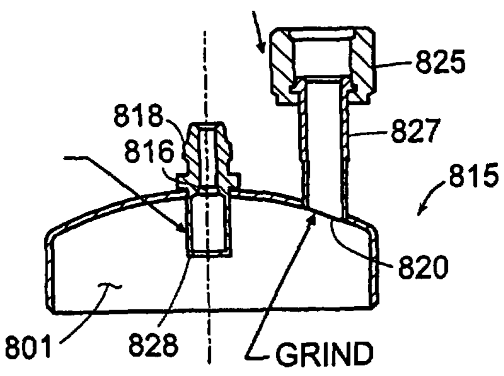


FIG. 8L

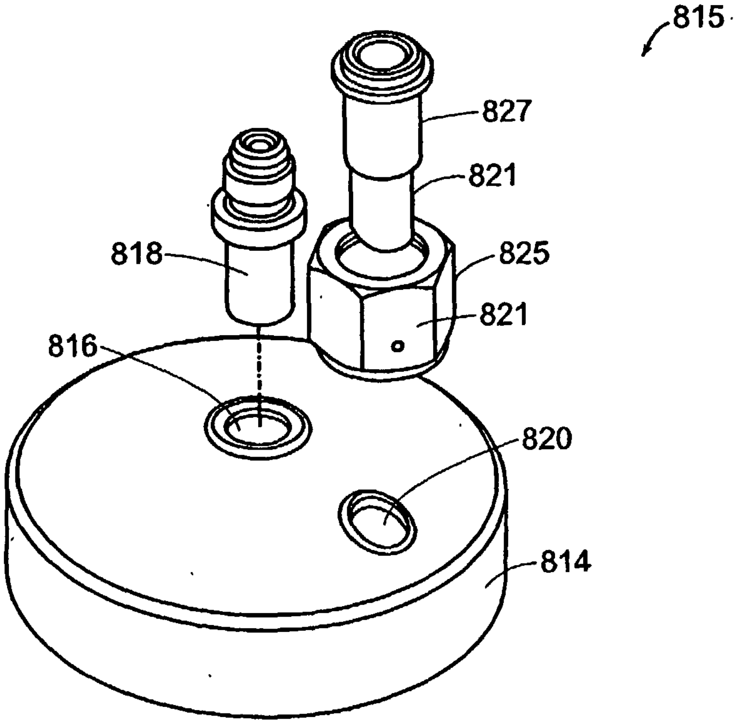


FIG. 8M

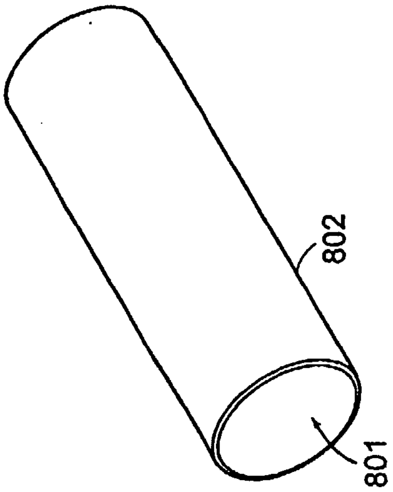


FIG. 8N

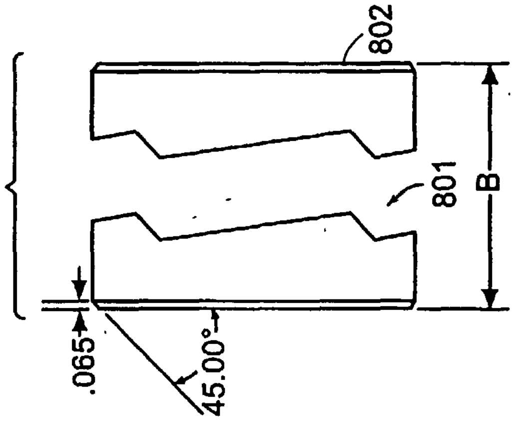


FIG. 8O

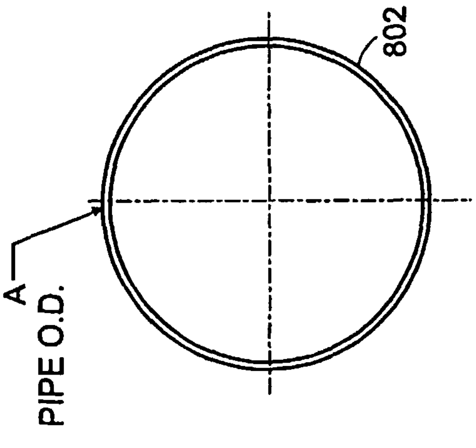


FIG. 8P

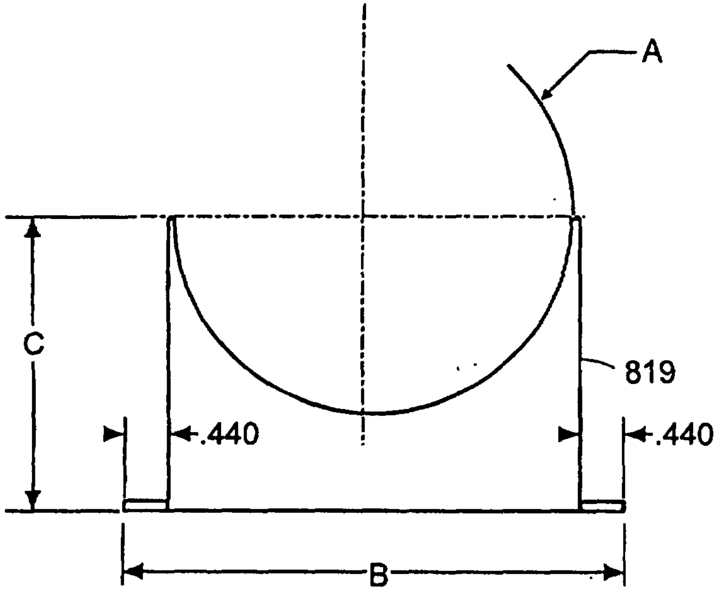


FIG. 8R

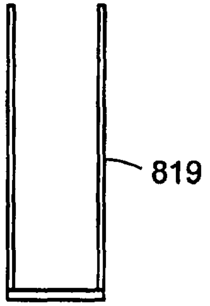


FIG. 8T

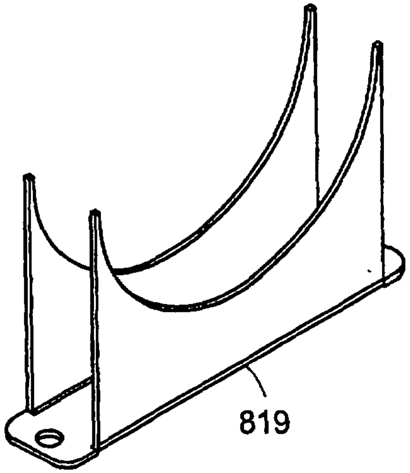


FIG. 8Q

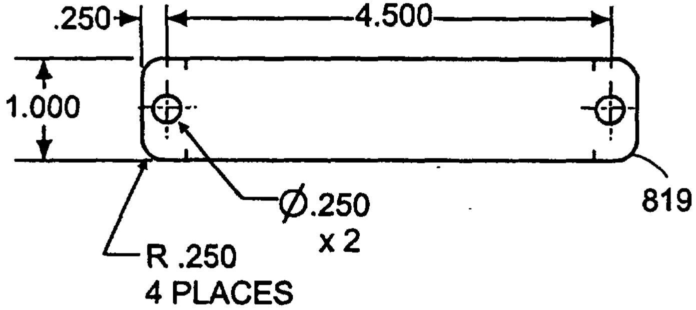


FIG. 8S

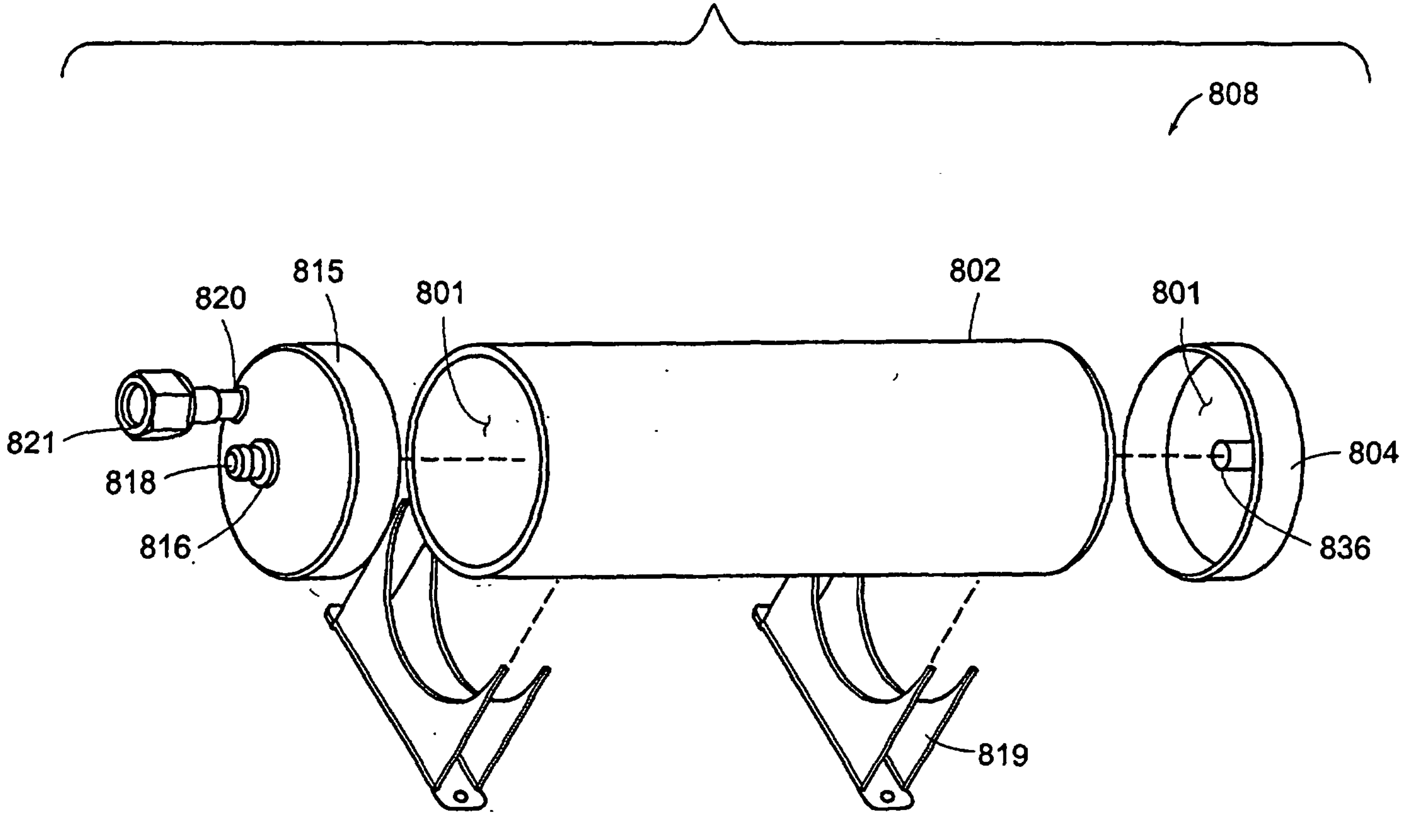


FIG. 8U

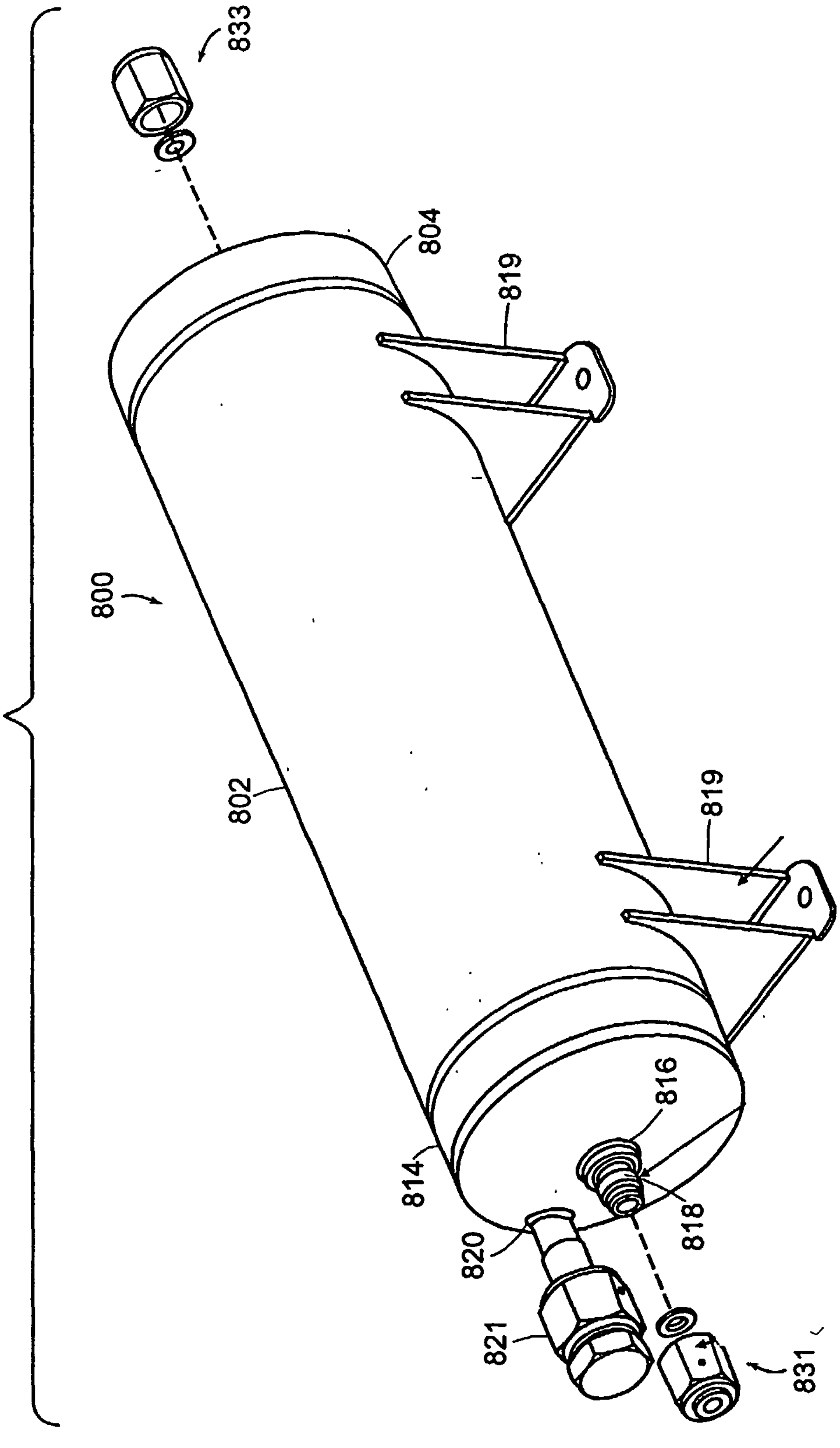


FIG. 8V

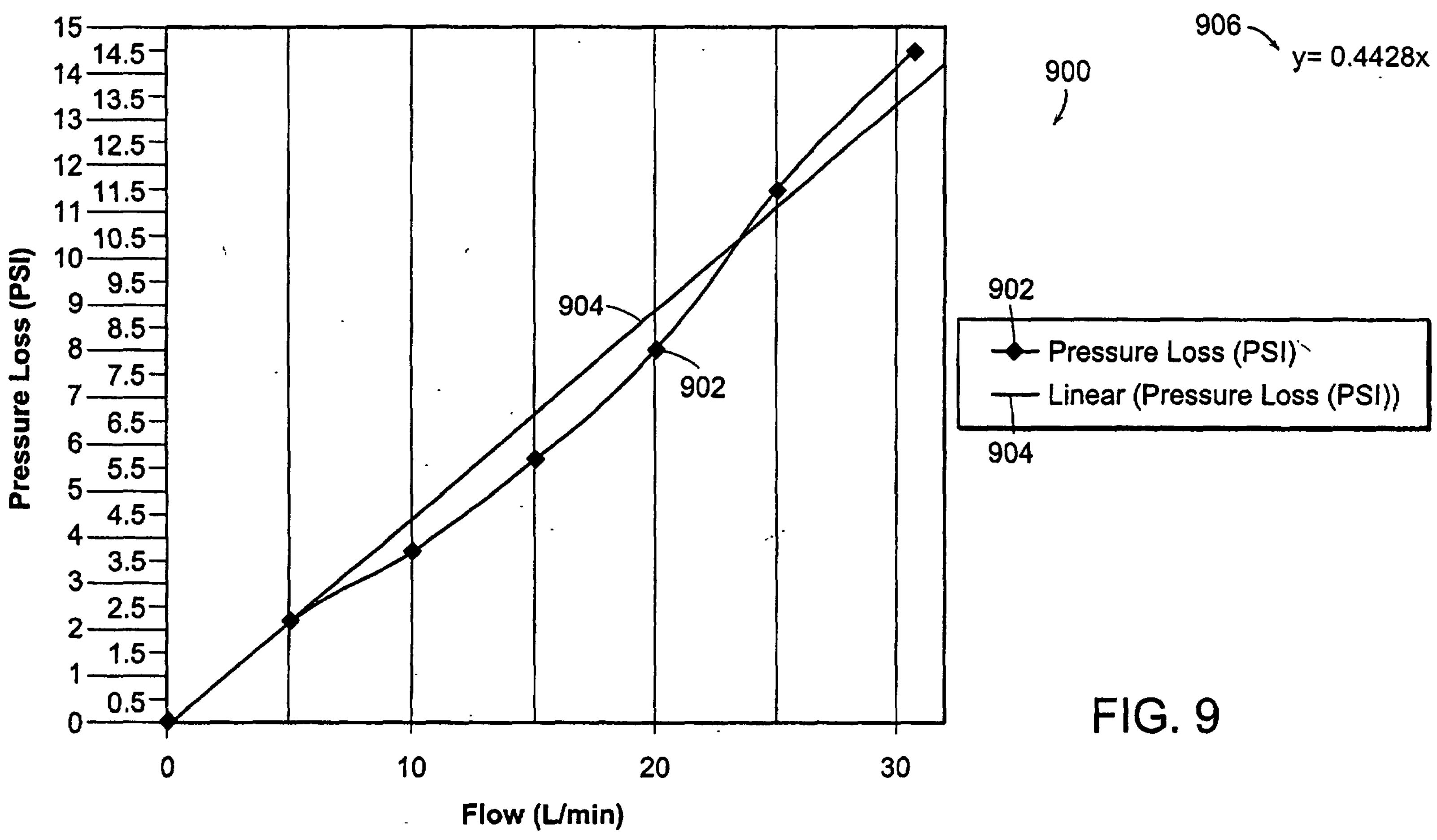

Pressure Loss (PSI) of CDA Canister w/ partical filters 2.5x12"

FIG. 9

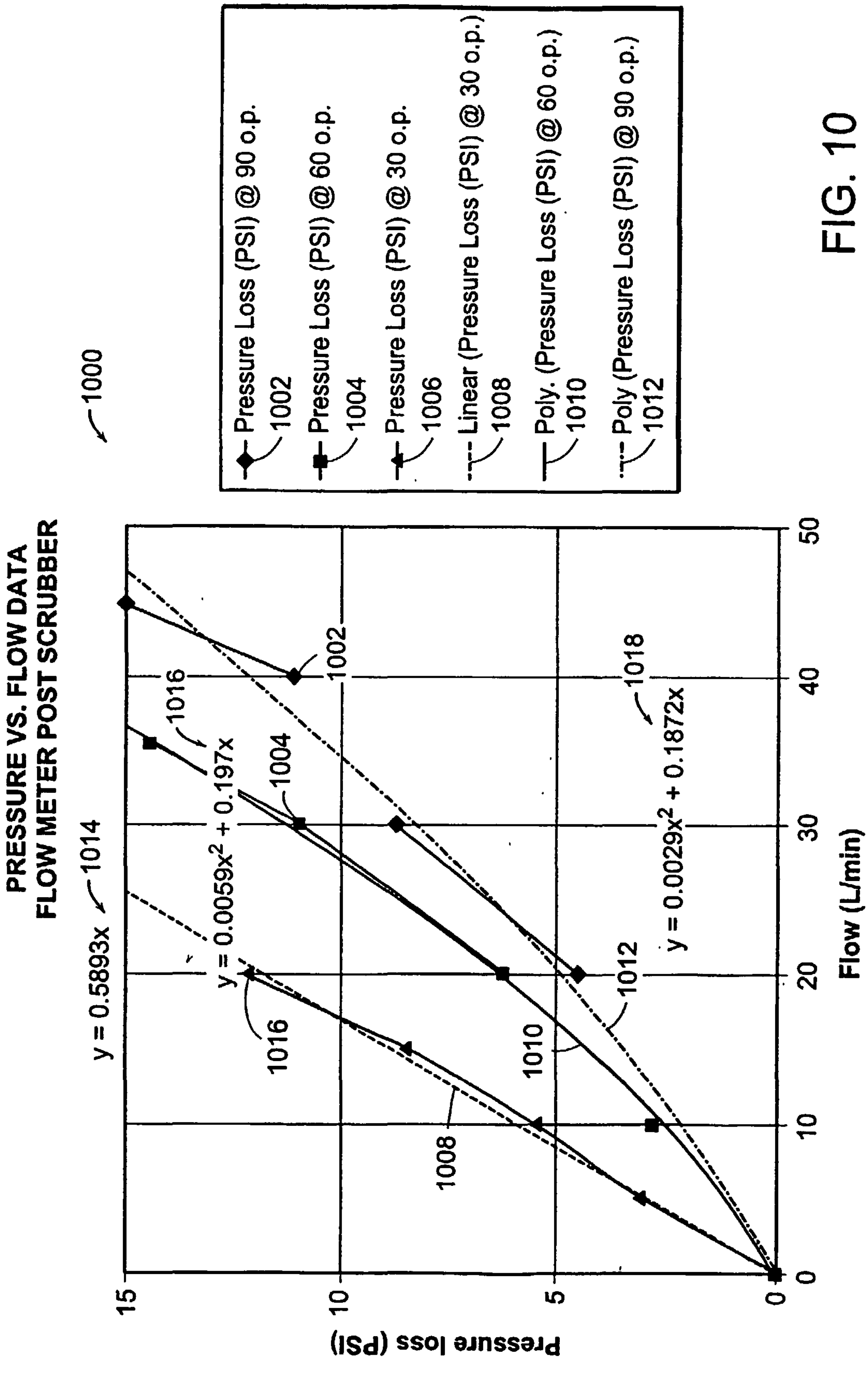

PRESSURE VS. FLOW DATA
FLOW METER POST SCRUBBER
1000
Pressure Loss (PSI) @ 90 o.p.
1002
Pressure Loss (PSI) @ 60 o.p.
1004
Pressure Loss (PSI) @ 30 o.p.
1006
Linear (Pressure Loss (PSI) @ 30 o.p.)
1008
Poly. (Pressure Loss (PSI) @ 60 o.p.)
1010
Poly (Pressure Loss (PSI) @ 90 o.p.)
1012
y = 0.5893x
1014
y = 0.0059x² + 0.197x
1016
1016
y = 0.0029x² + 0.1872x
1018
1002
1004
1008
1010
1012
Pressure loss (PSI)
15
10
5
0
0
10
20
30
40
50
Flow (L/min)

FIG. 10

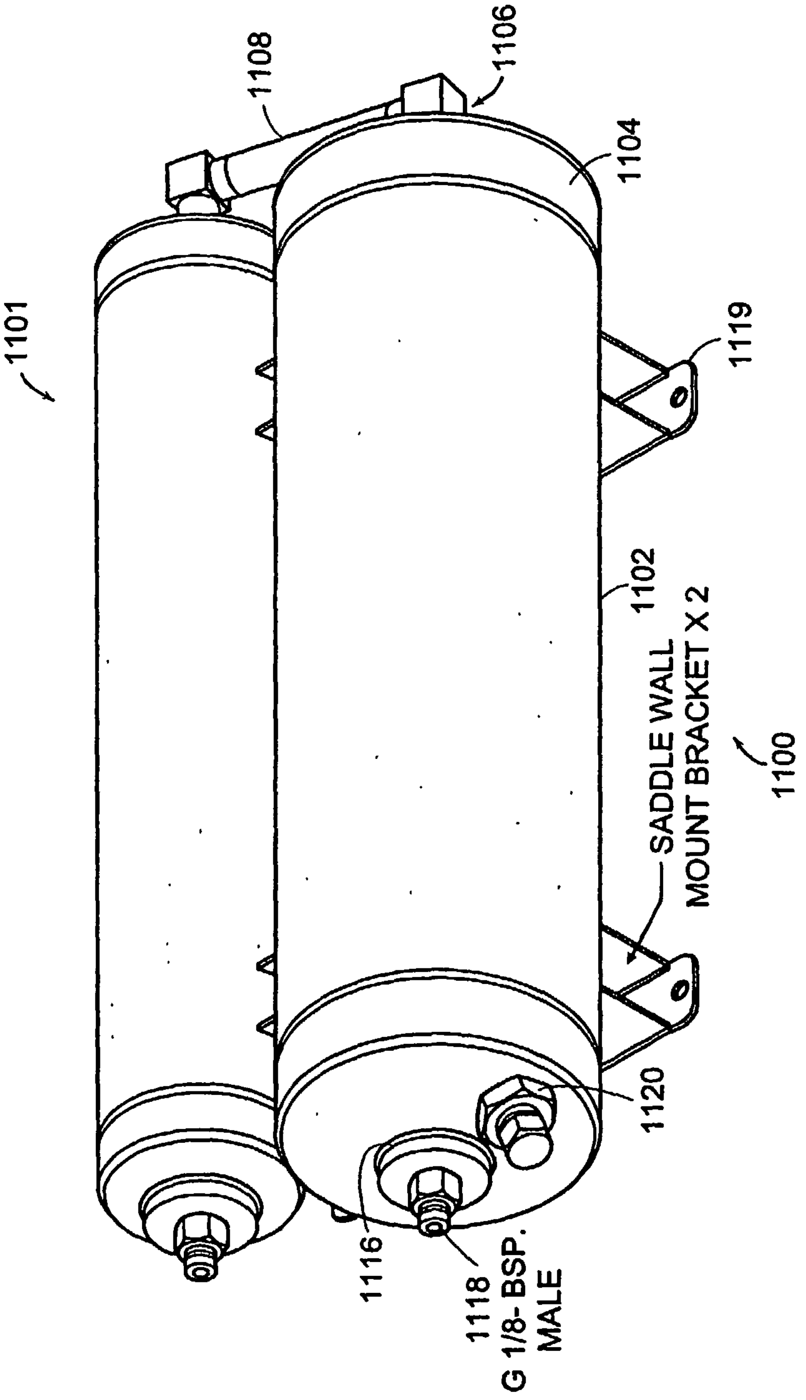

1101
1108
1106
1104
1119
1102
SADDLE WALL MOUNT BRACKET X 2
1100
1120
1116
1118
G 1/8- BSP. MALE

FIG. 11A

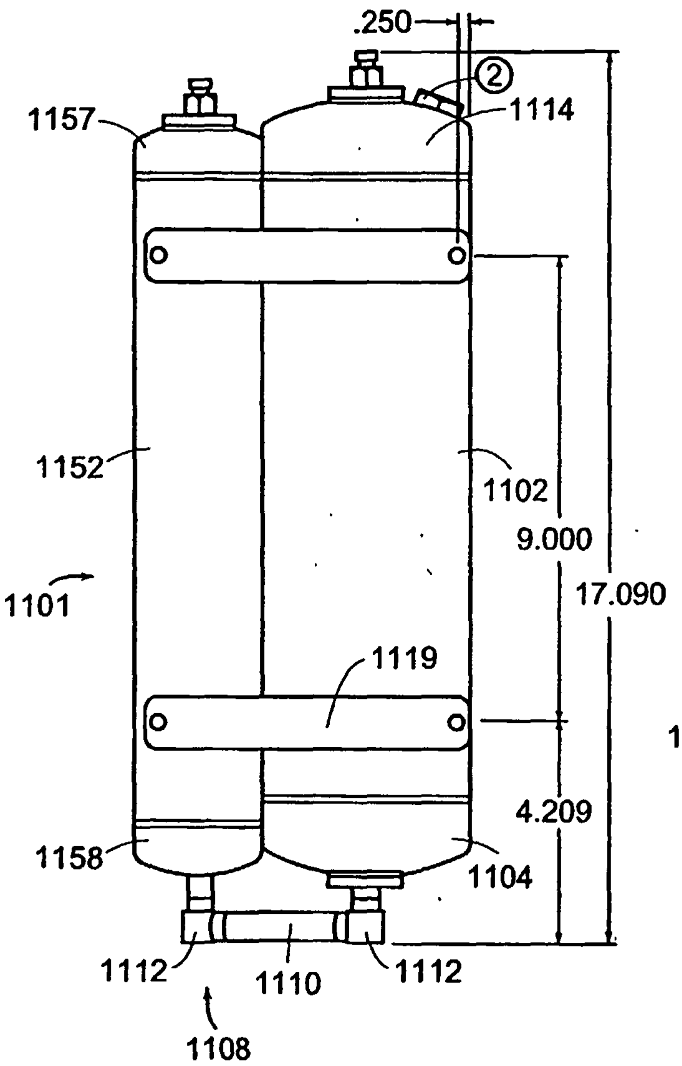


FIG. 11B

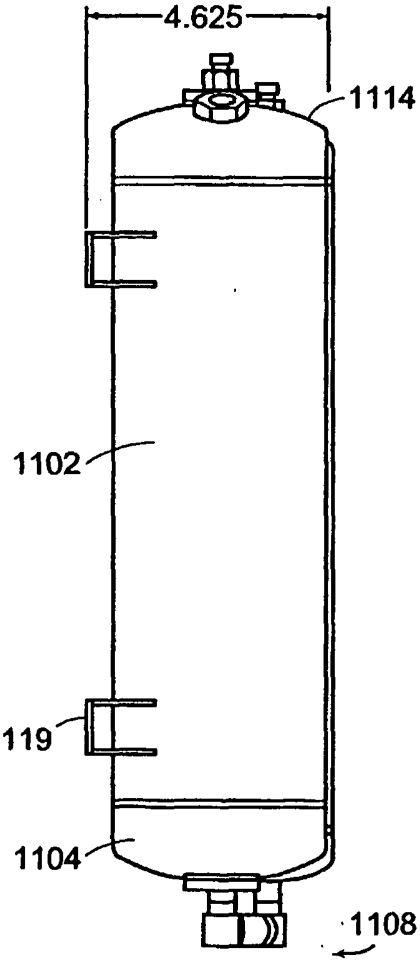


FIG. 11C

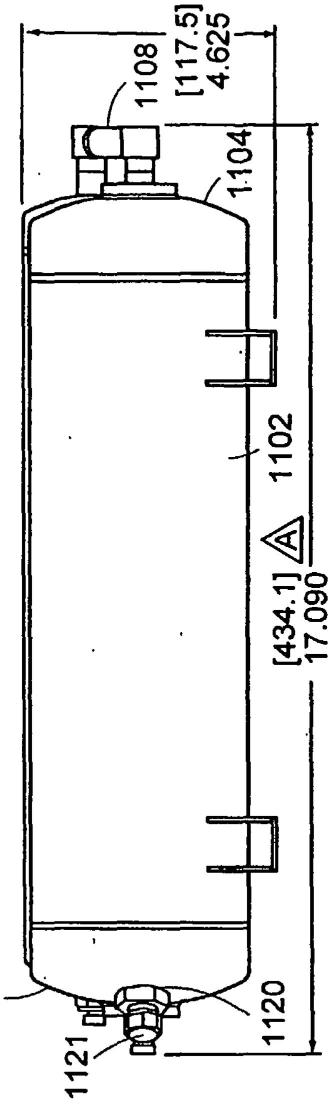


FIG. 11E

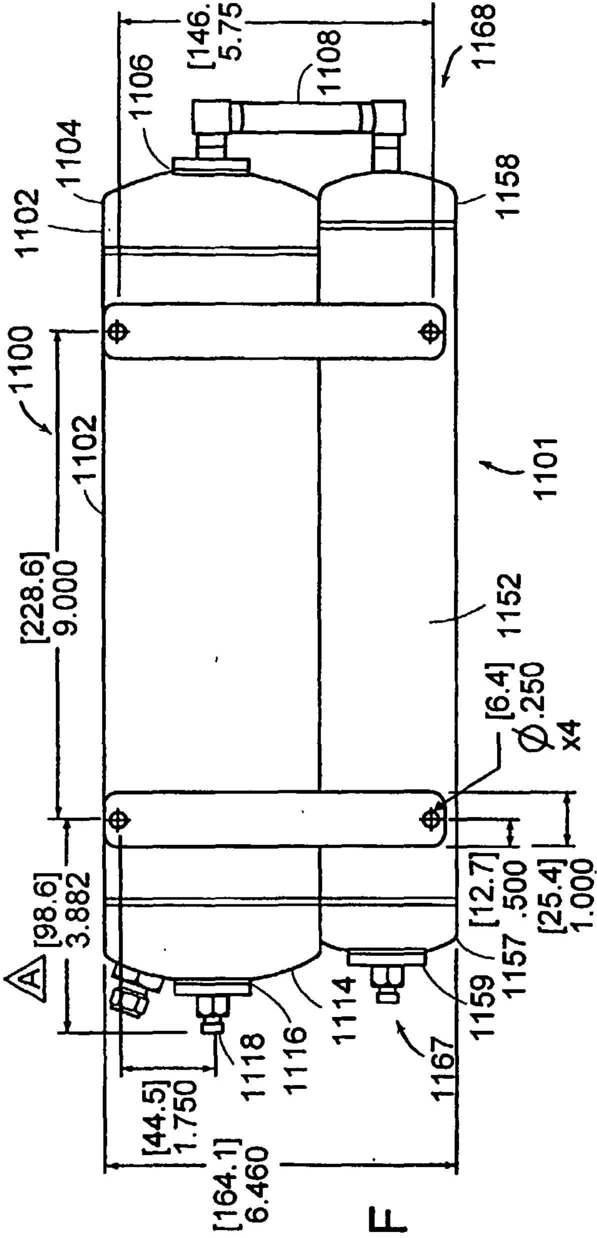


FIG. 11F

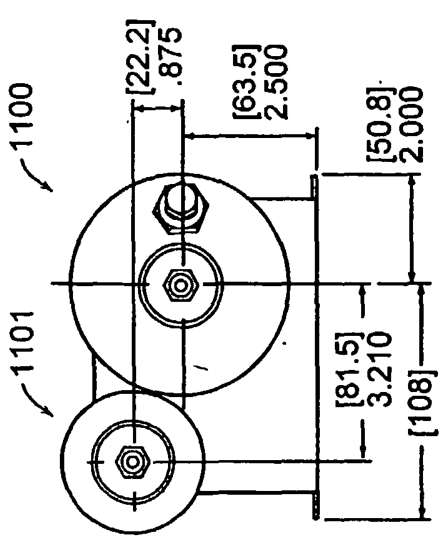


FIG. 11D

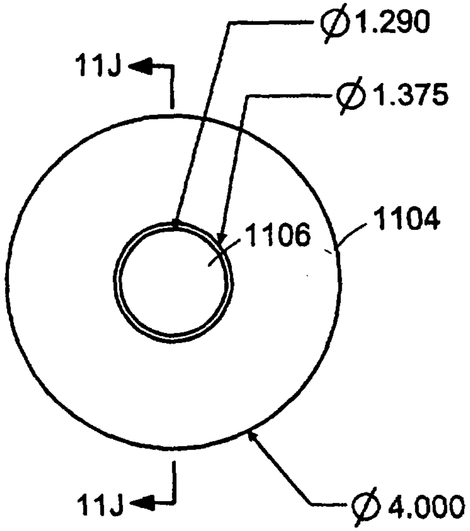


FIG. 11H

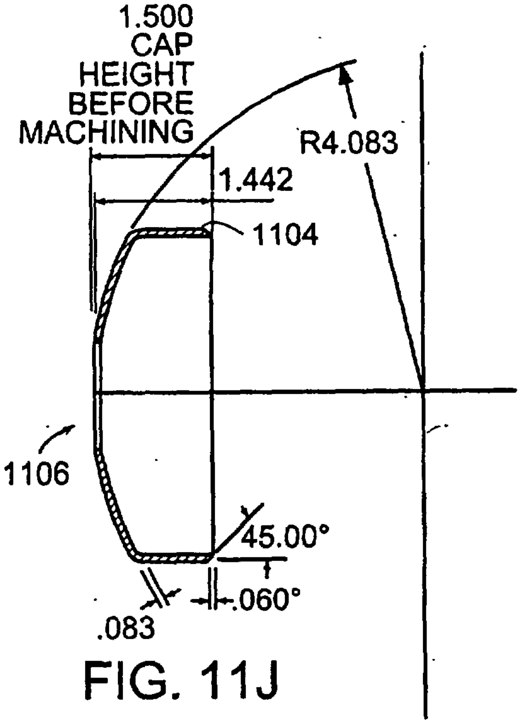


FIG. 11J

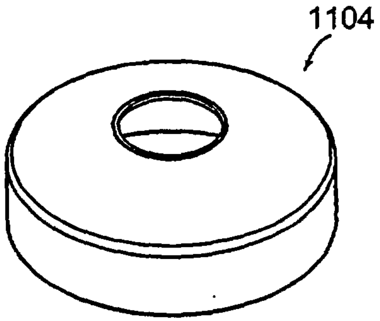


FIG. 11G

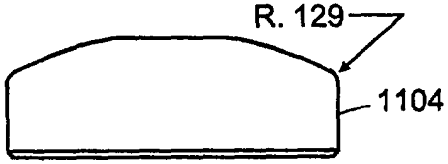


FIG. 11I

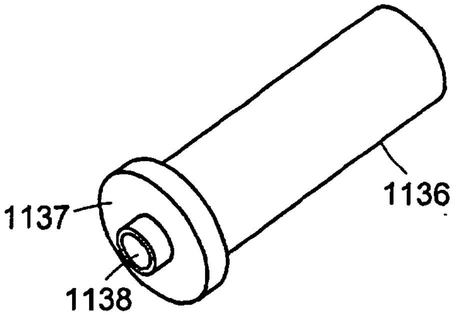


FIG. 11K

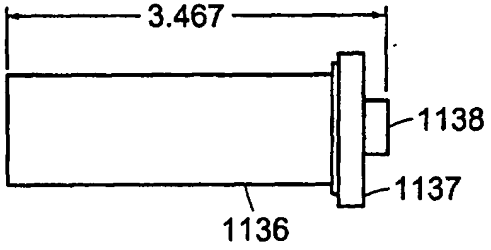


FIG. 11L

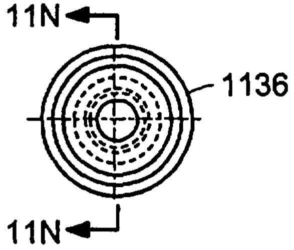


FIG. 11M

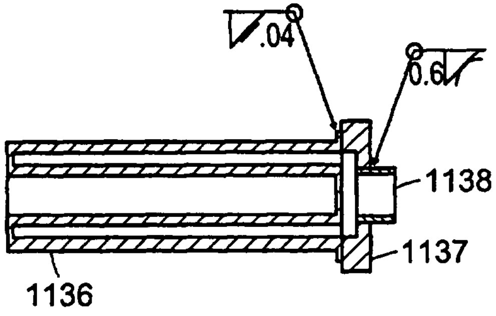


FIG. 11N

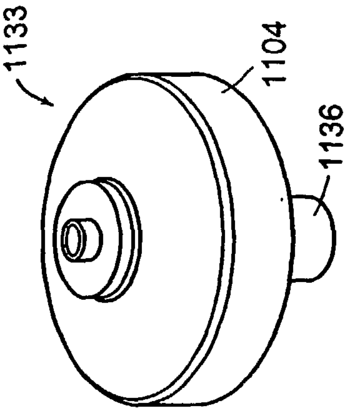


FIG. 11O

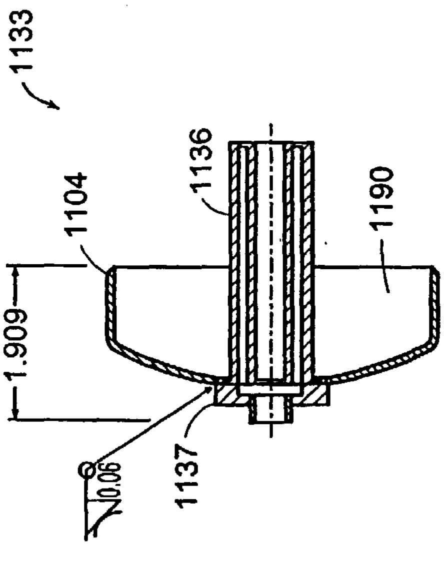


FIG. 11R

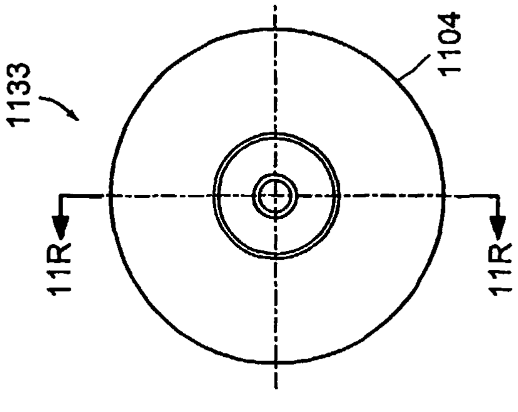


FIG. 11Q

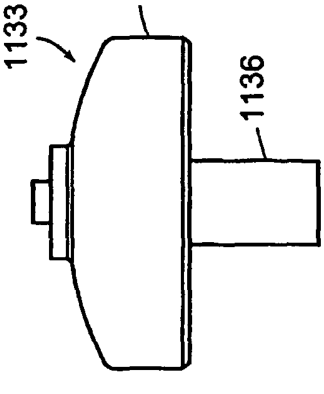


FIG. 11P

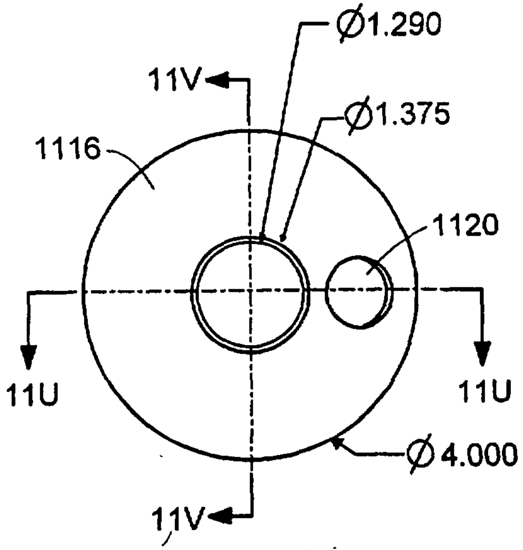


FIG. 11T

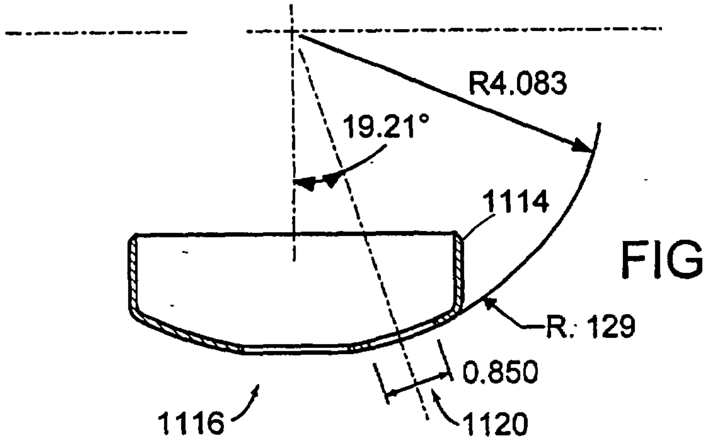


FIG. 11U

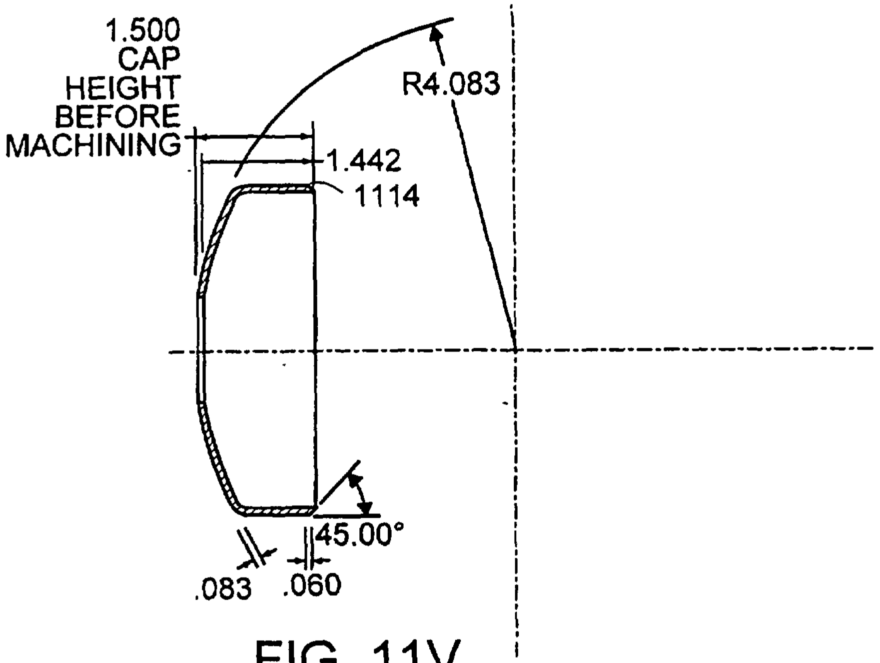


FIG. 11V

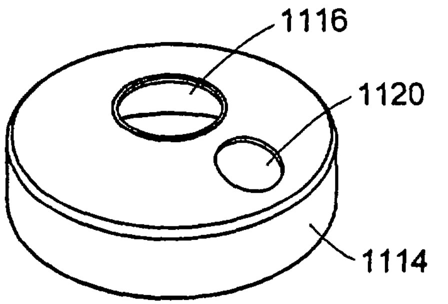


FIG. 11S

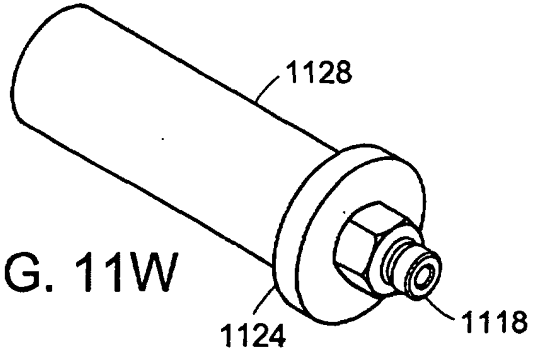


FIG. 11W

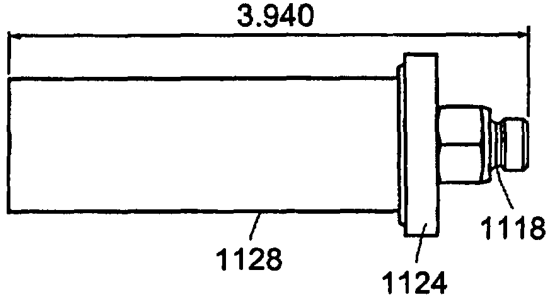


FIG. 11X

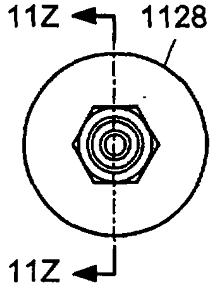


FIG. 11Y

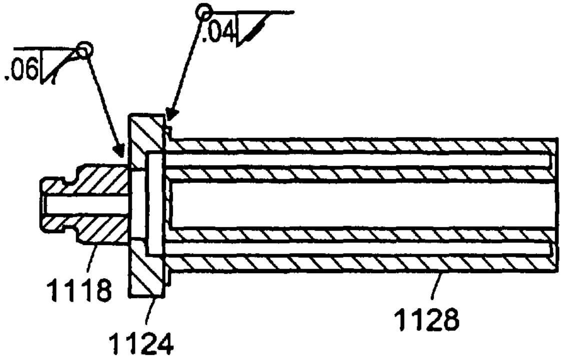


FIG. 11Z

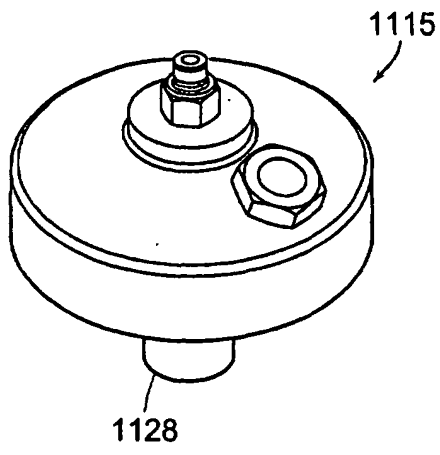


FIG. 11AA

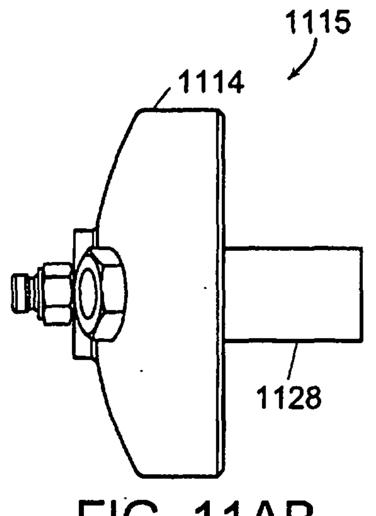


FIG. 11AB

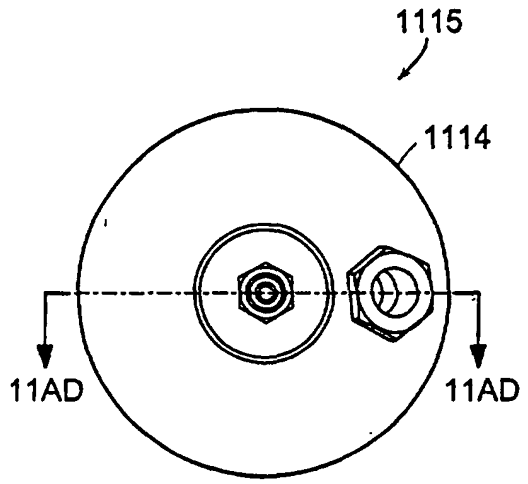


FIG. 11AC

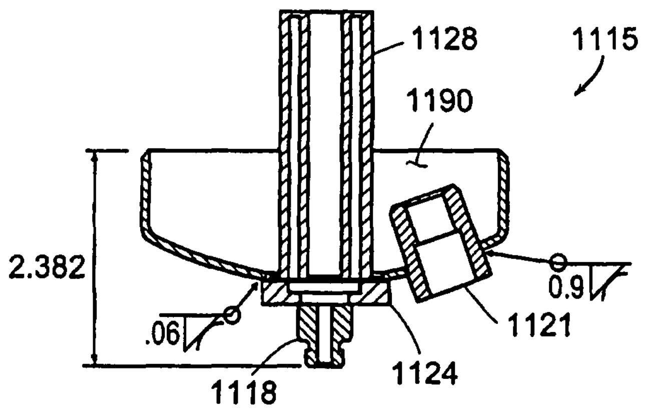


FIG. 11AD

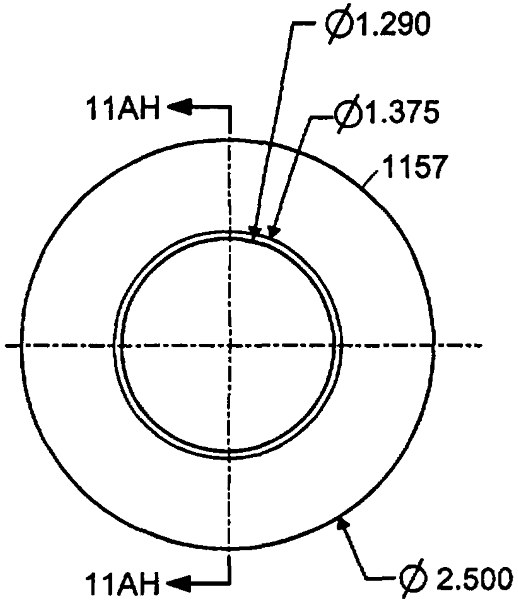


FIG. 11AG

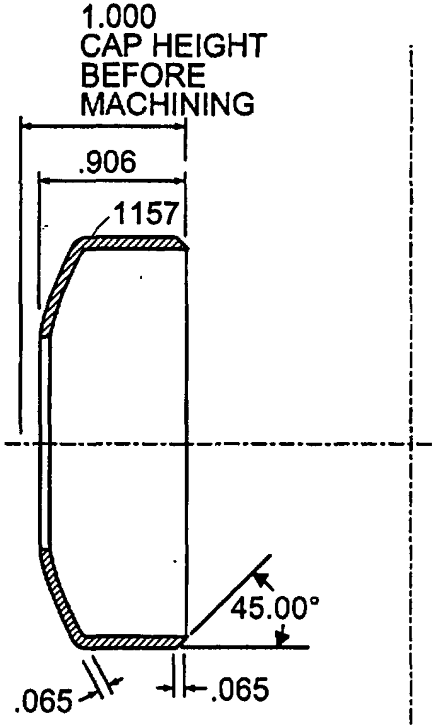


FIG. 11AH

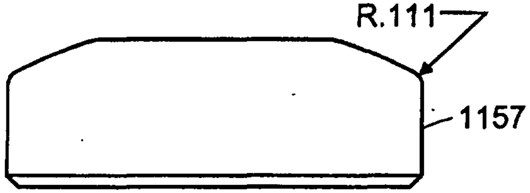


FIG. 11AF

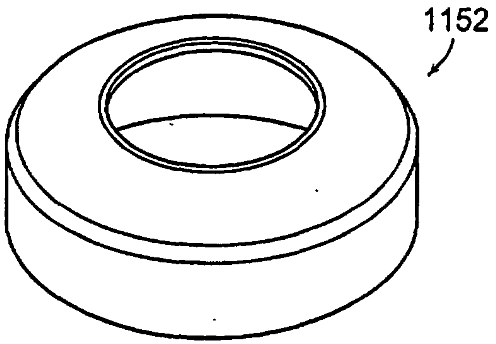


FIG. 11AE

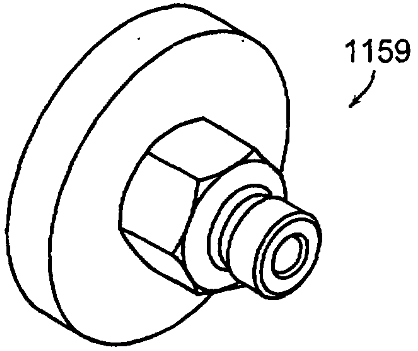


FIG. 11AI

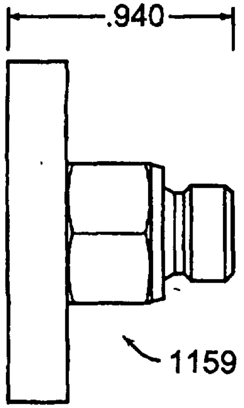


FIG. 11AJ

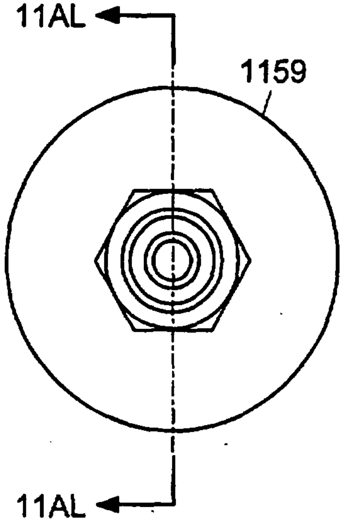


FIG. 11AK

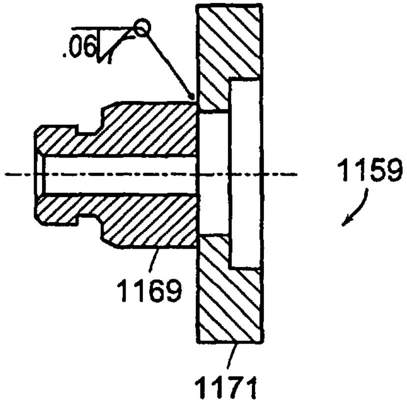


FIG. 11AL

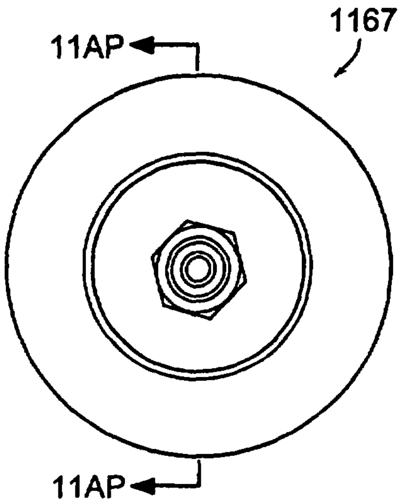


FIG. 11AO

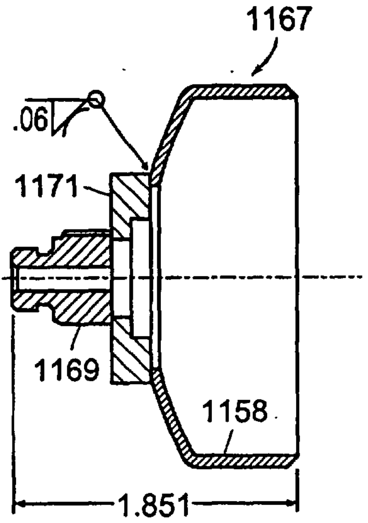


FIG. 11AP

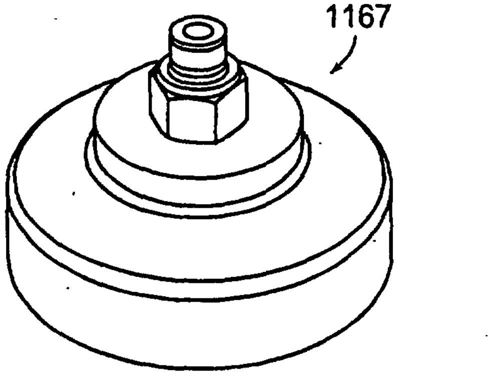


FIG. 11AM

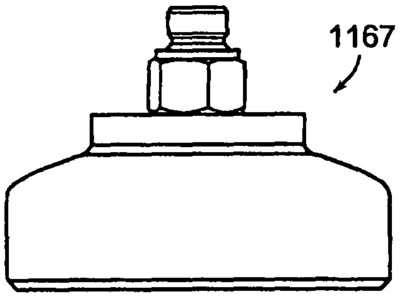


FIG. 11AN

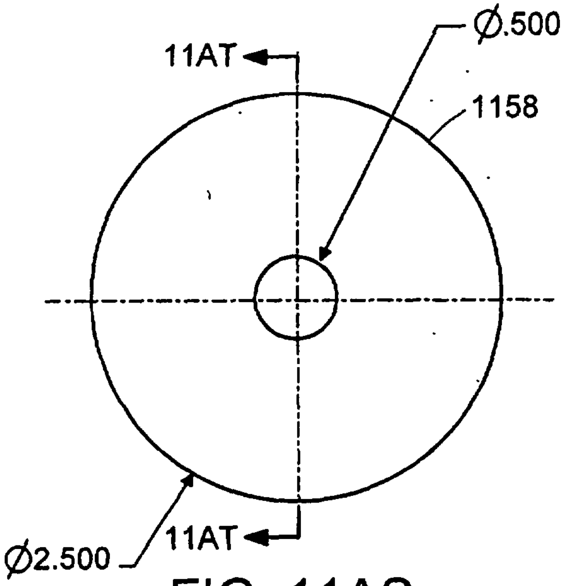


FIG. 11AS

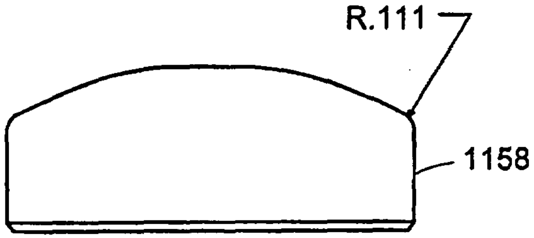


FIG. 11AR

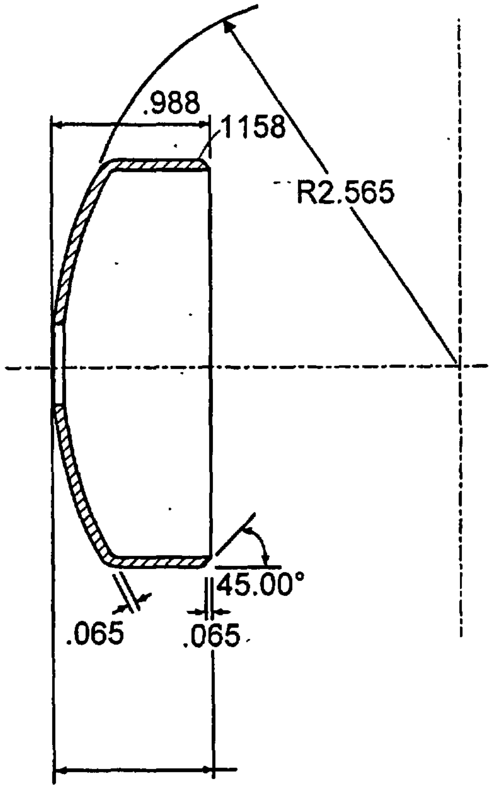


FIG. 11AT

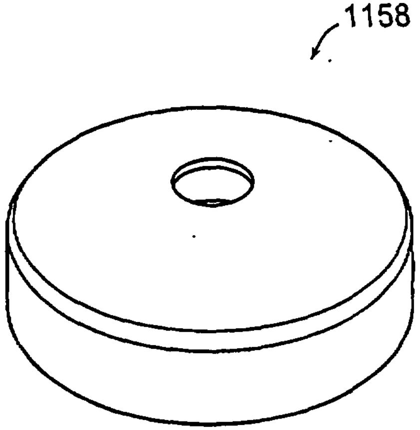


FIG. 11AQ

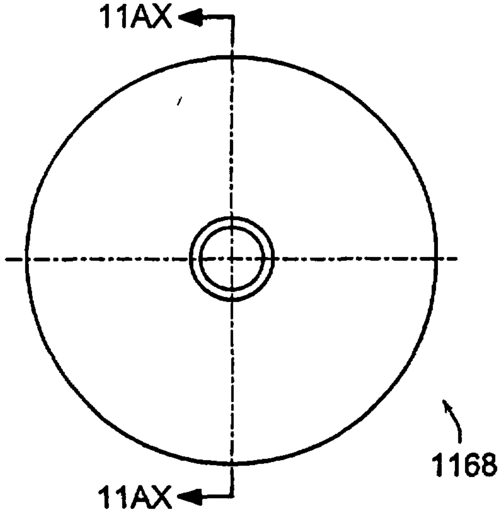


FIG. 11AW

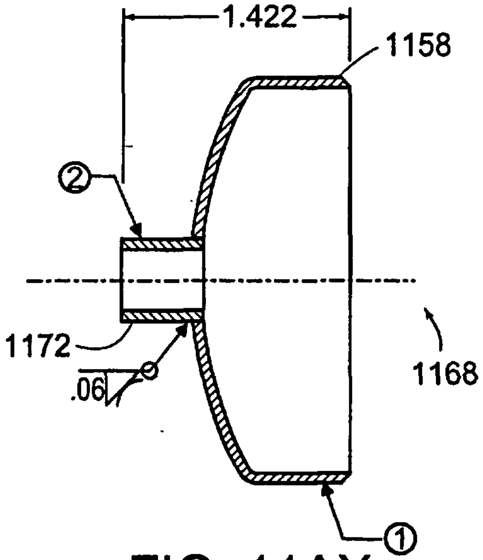


FIG. 11AX

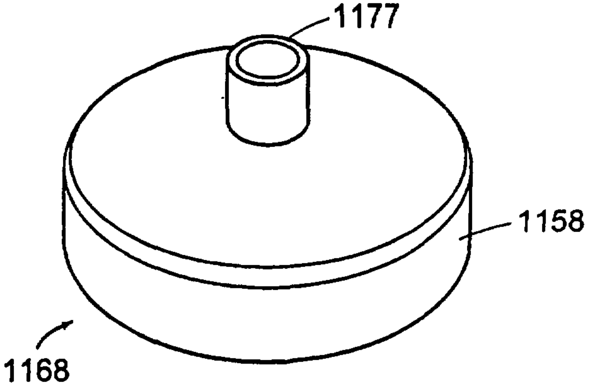


FIG. 11AU

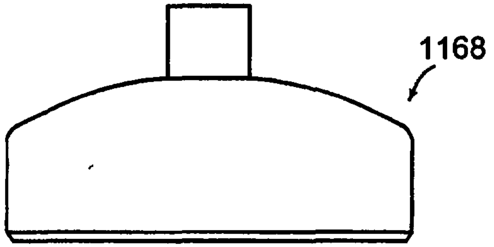


FIG. 11AV

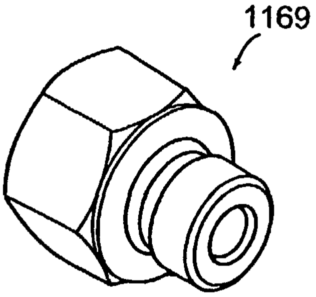


FIG. 11AY

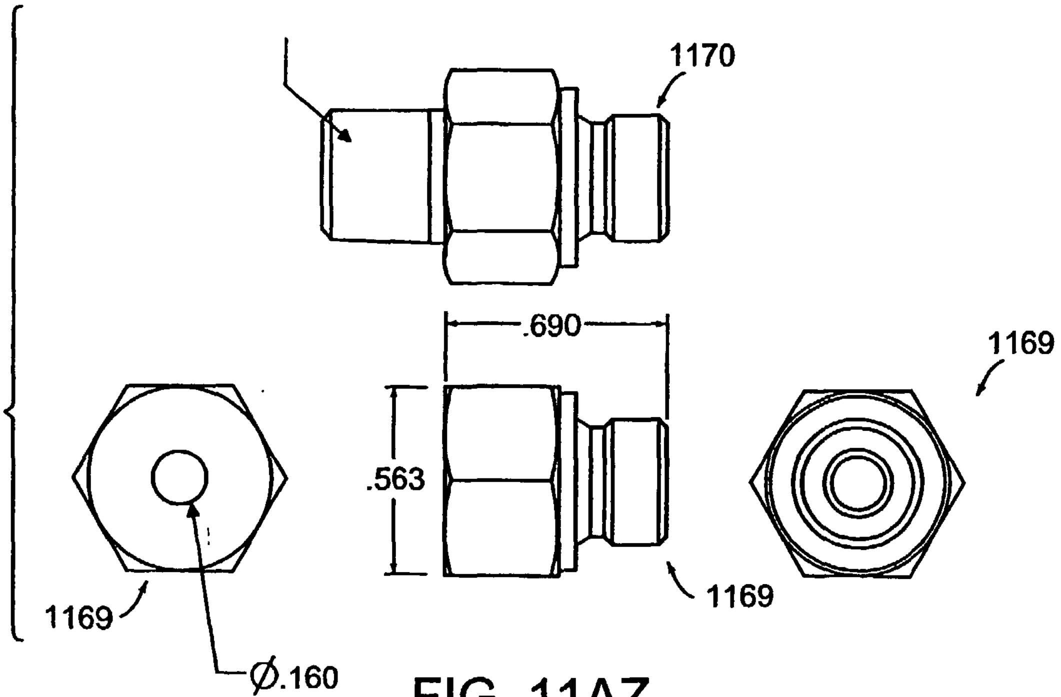


FIG. 11AZ

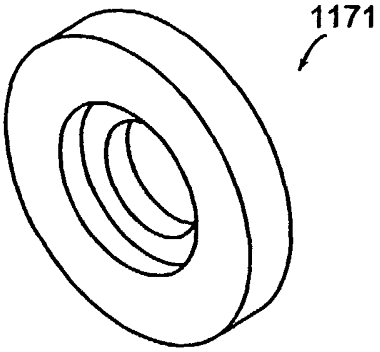


FIG. 11BA

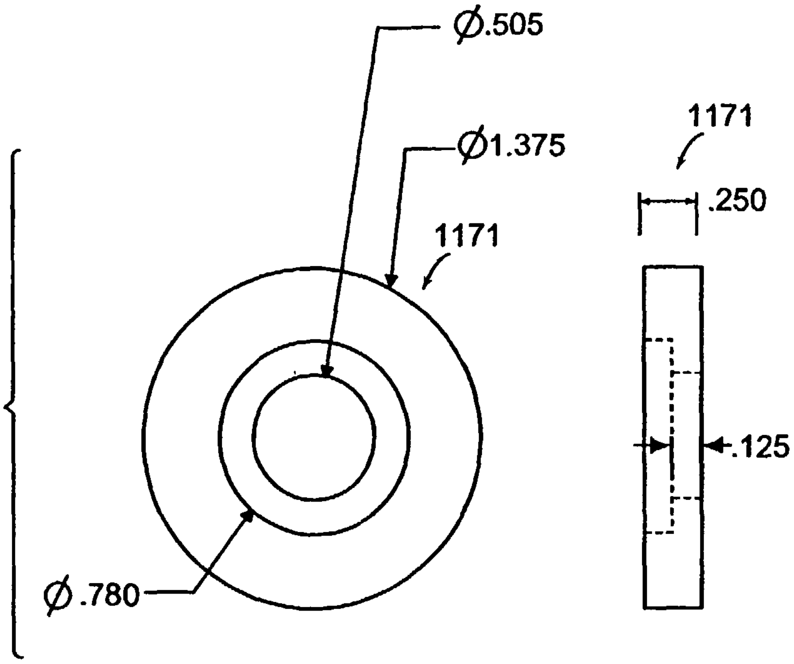


FIG. 11BB

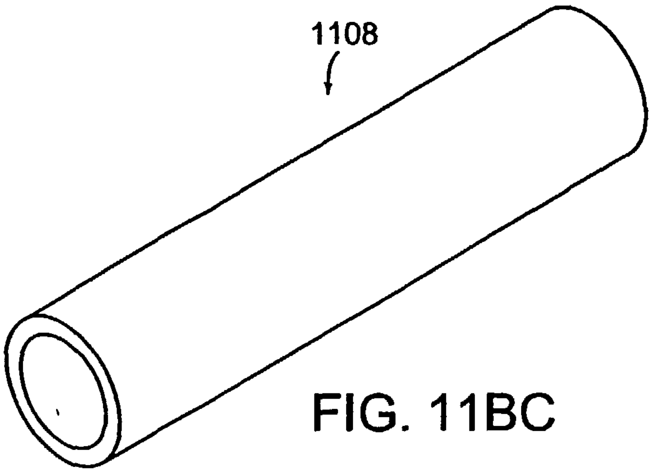


FIG. 11BC

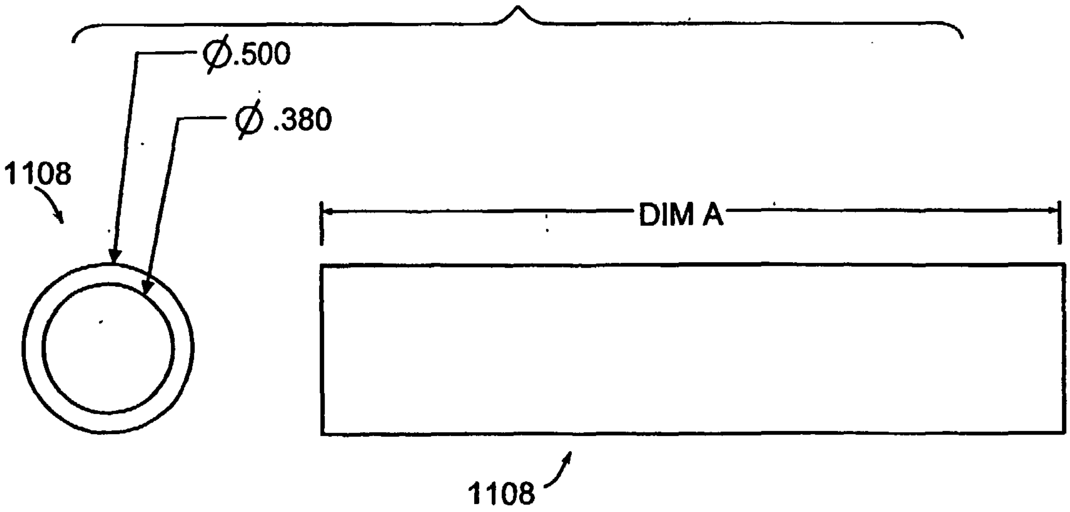


FIG. 11BD

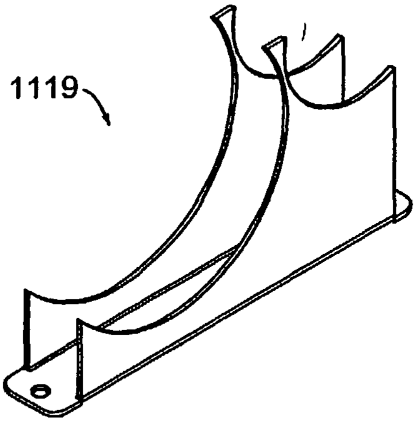


FIG. 11BE

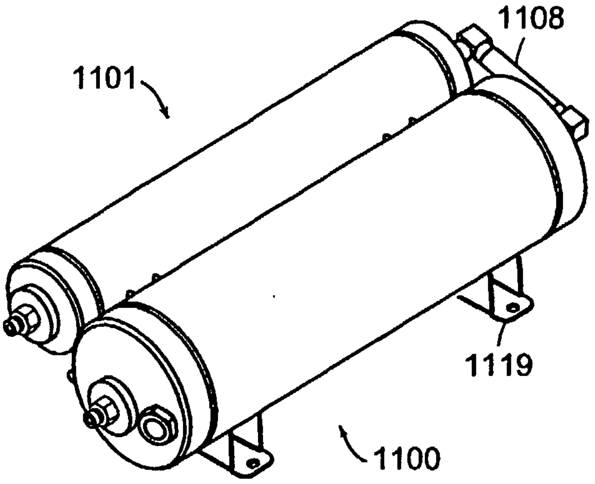


FIG. 11BG

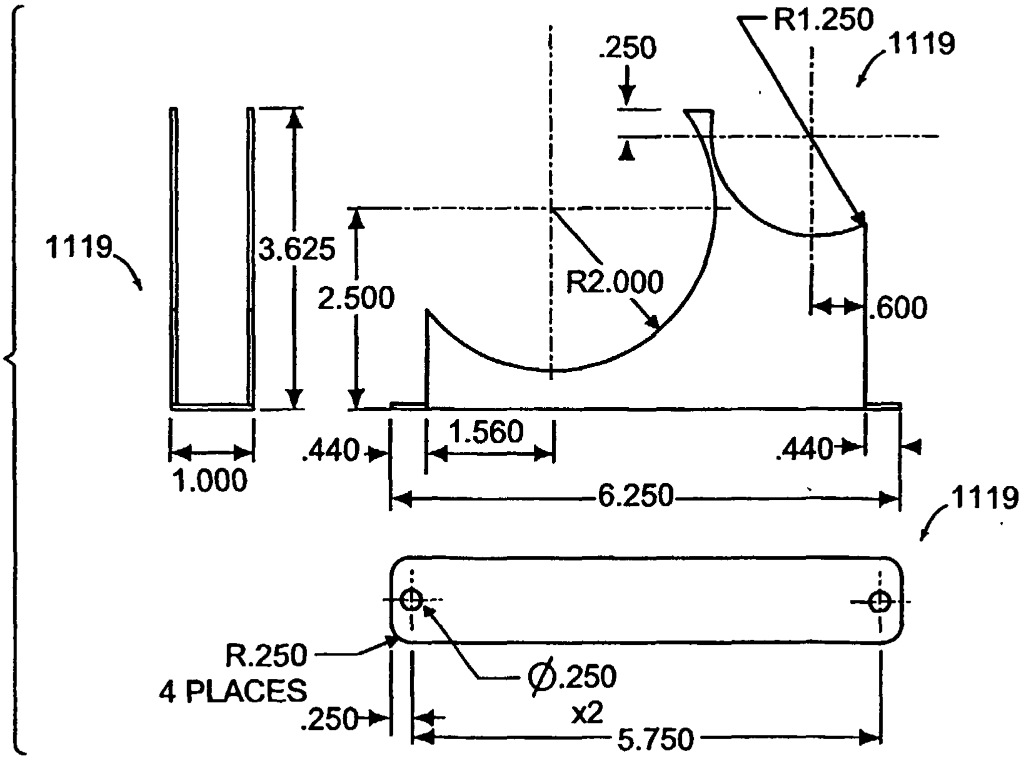


FIG. 11BF

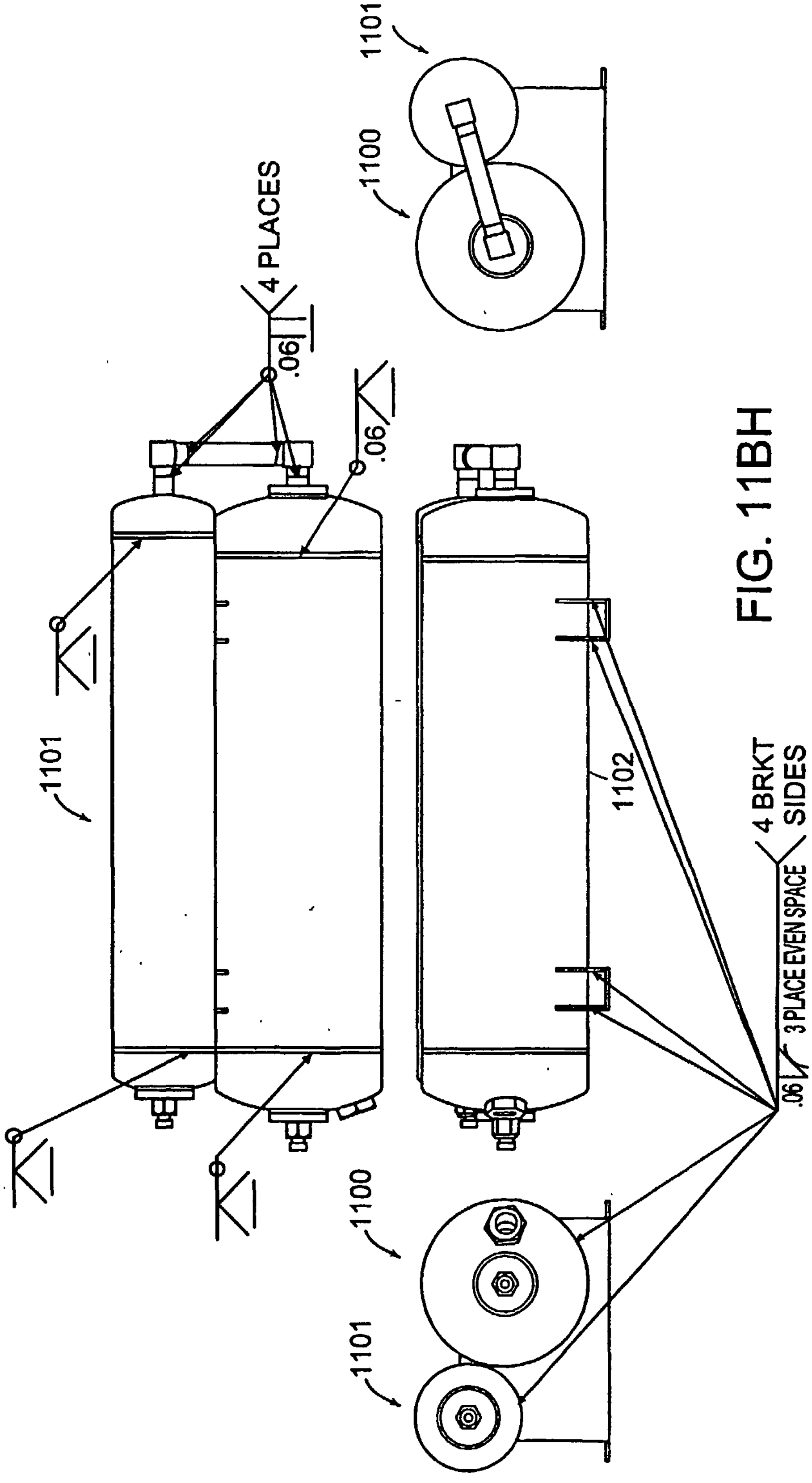

1101
1100
4 PLACES
.06
.06
1101
1102
4 BRKT
SIDES
3 PLACE EVEN SPACE
.06
1100
1101

FIG. 11BH

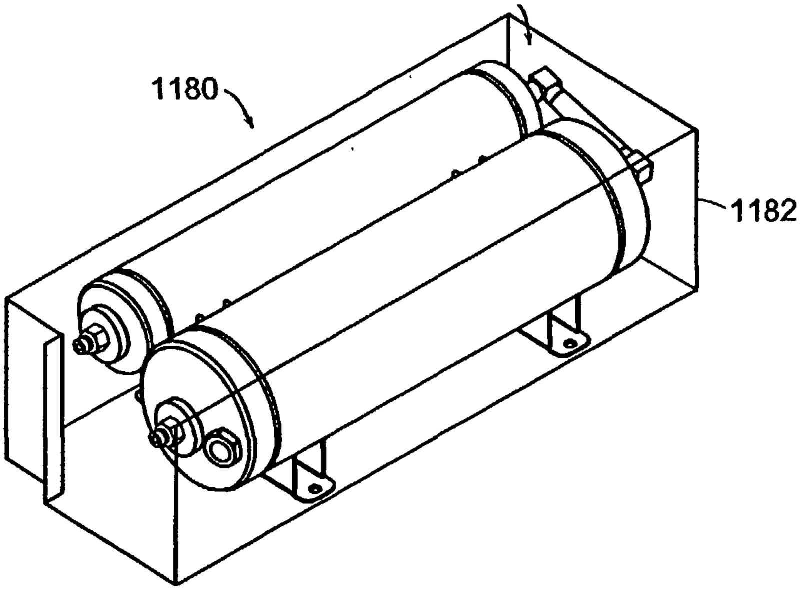


FIG. 11BI

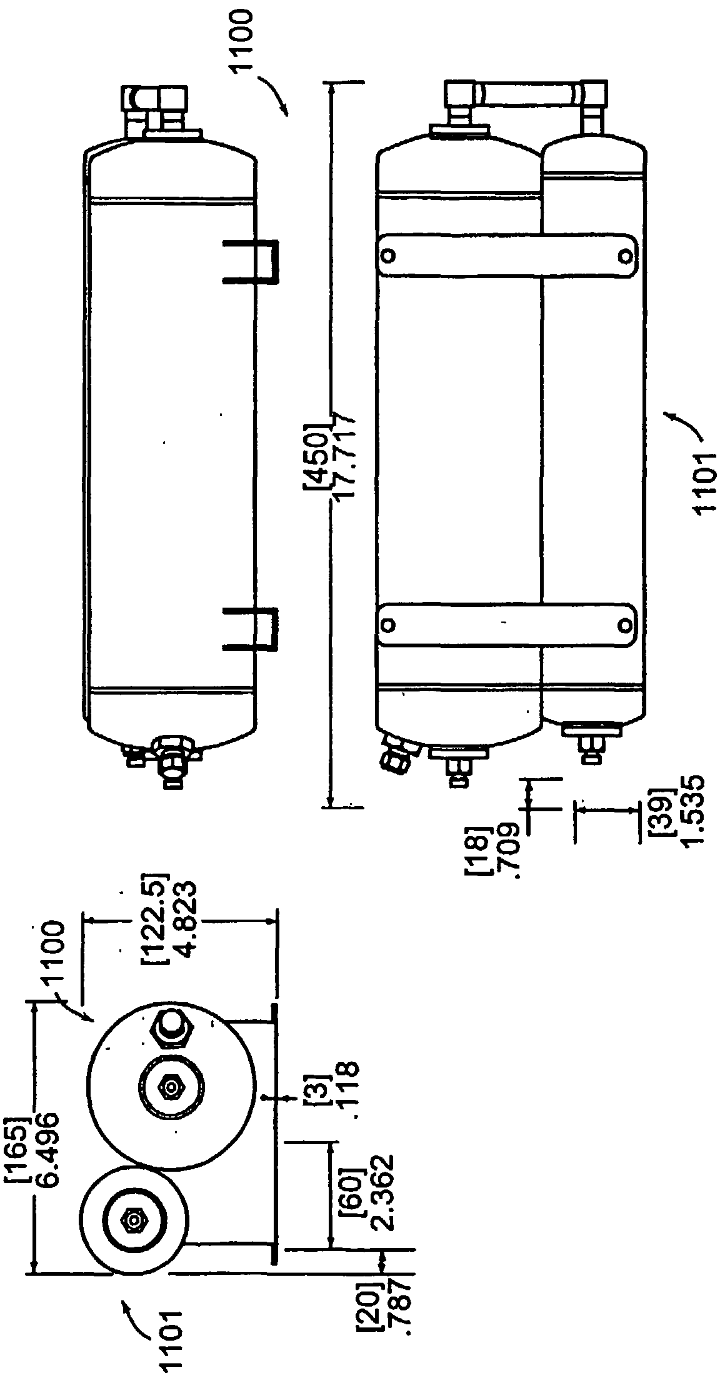

1100
[450]
17.717
1101
[18]
.709
[39]
1.535
[122.5]
4.823
1100
[165]
6.496
[3]
.118
[60]
2.362
[20]
.787
1101

FIG. 11BJ

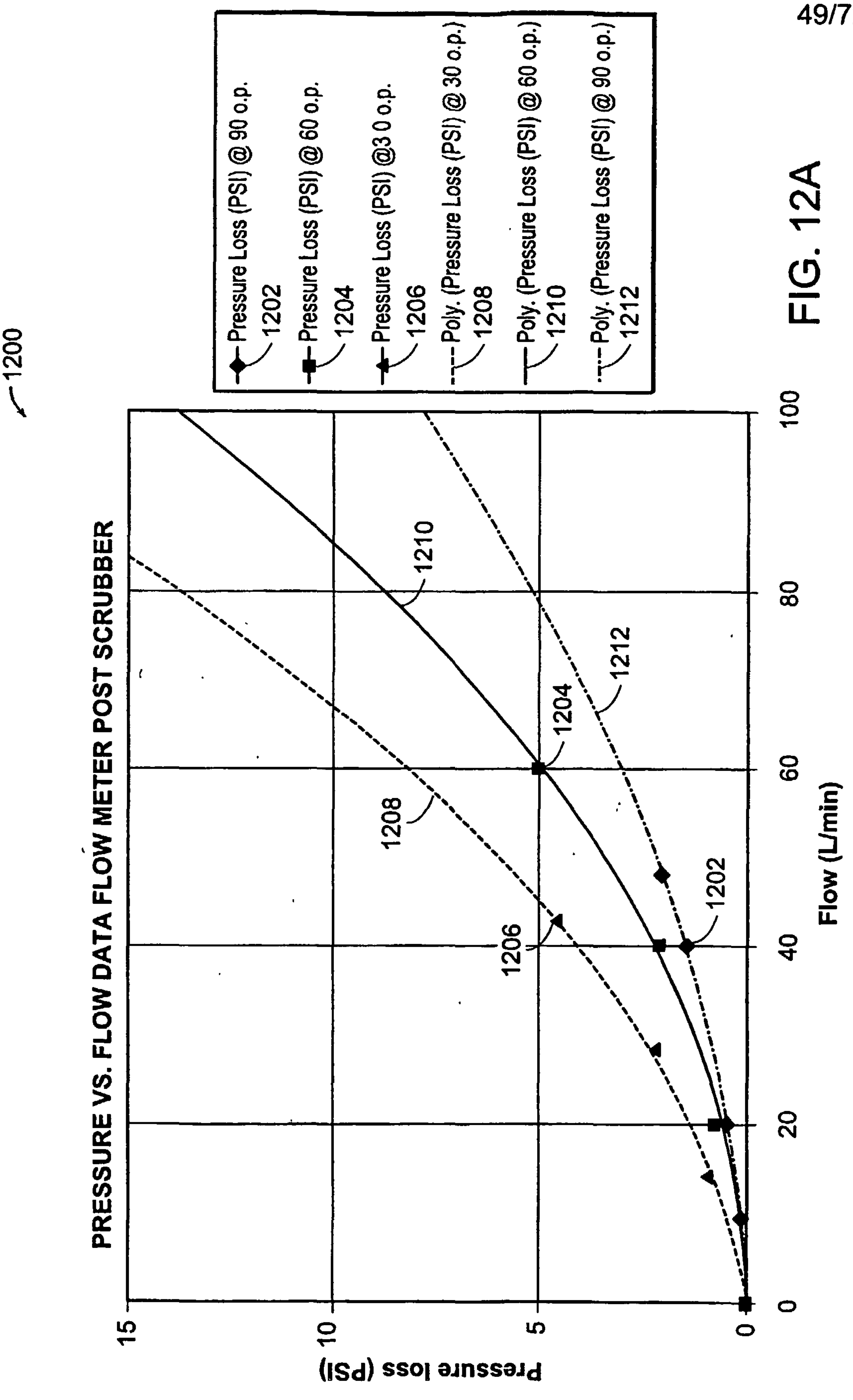

1200
PRESSURE VS. FLOW DATA FLOW METER POST SCRUBBER
Pressure loss (PSI)
15
10
5
0
Flow (L/min)
0
20
40
60
80
100
1202
1204
1206
1208
1210
1212
Pressure Loss (PSI) @ 90 o.p.
1202
Pressure Loss (PSI) @ 60 o.p.
1204
Pressure Loss (PSI) @3 0 o.p.
1206
Poly. (Pressure Loss (PSI) @ 30 o.p.)
1208
Poly. (Pressure Loss (PSI) @ 60 o.p.)
1210
Poly. (Pressure Loss (PSI) @ 90 o.p.)
1212

FIG. 12A

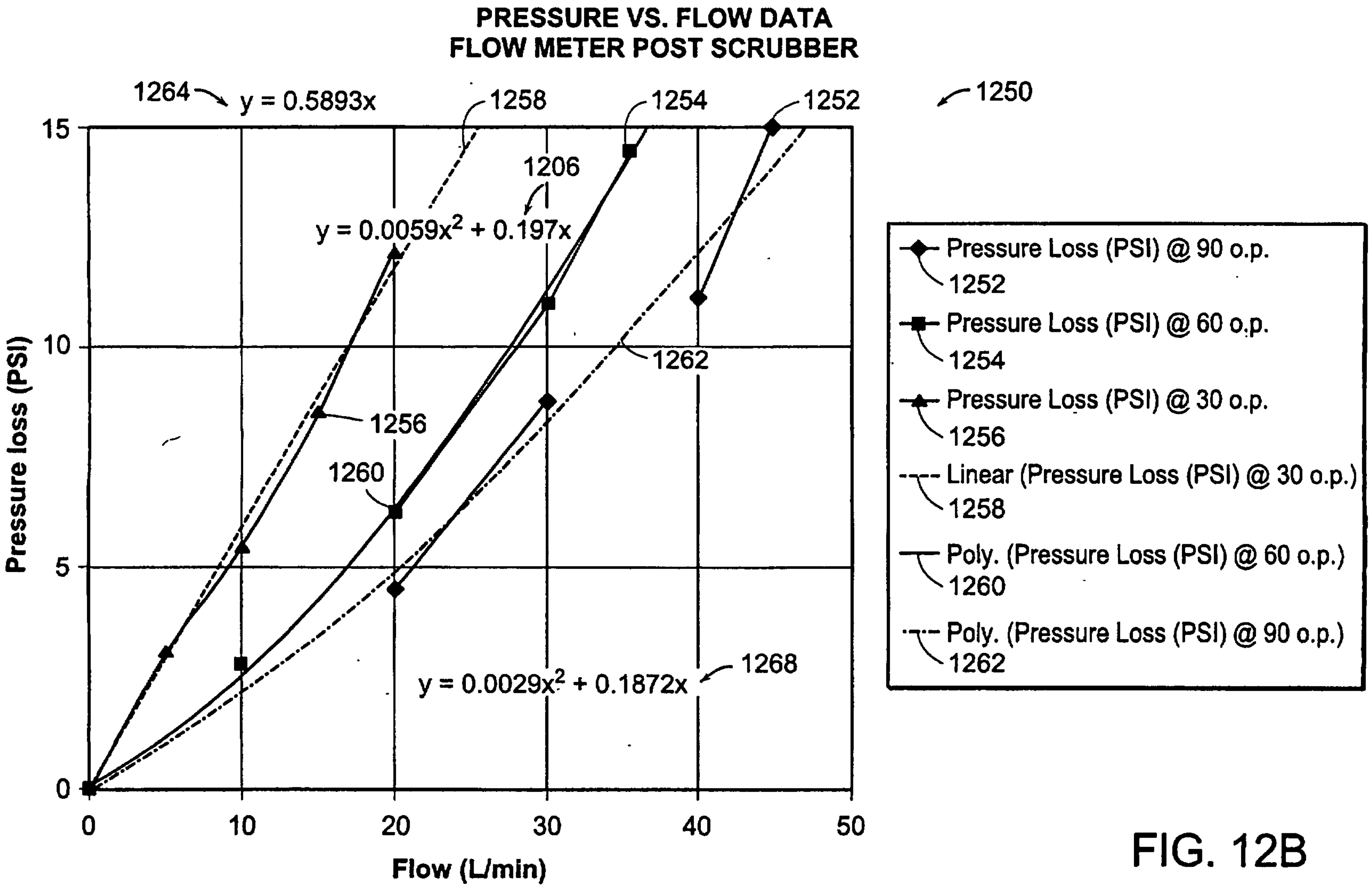

PRESSURE VS. FLOW DATA
FLOW METER POST SCRUBBER
1250
1264
y = 0.5893x
1258
1254
1252
1206
y = 0.0059x^2 + 0.197x
1262
1256
1260
y = 0.0029x^2 + 0.1872x
1268
Pressure loss (PSI)
0
5
10
15
Flow (L/min)
0
10
20
30
40
50
Pressure Loss (PSI) @ 90 o.p.
1252
Pressure Loss (PSI) @ 60 o.p.
1254
Pressure Loss (PSI) @ 30 o.p.
1256
Linear (Pressure Loss (PSI) @ 30 o.p.)
1258
Poly. (Pressure Loss (PSI) @ 60 o.p.)
1260
Poly. (Pressure Loss (PSI) @ 90 o.p.)
1262

FIG. 12B

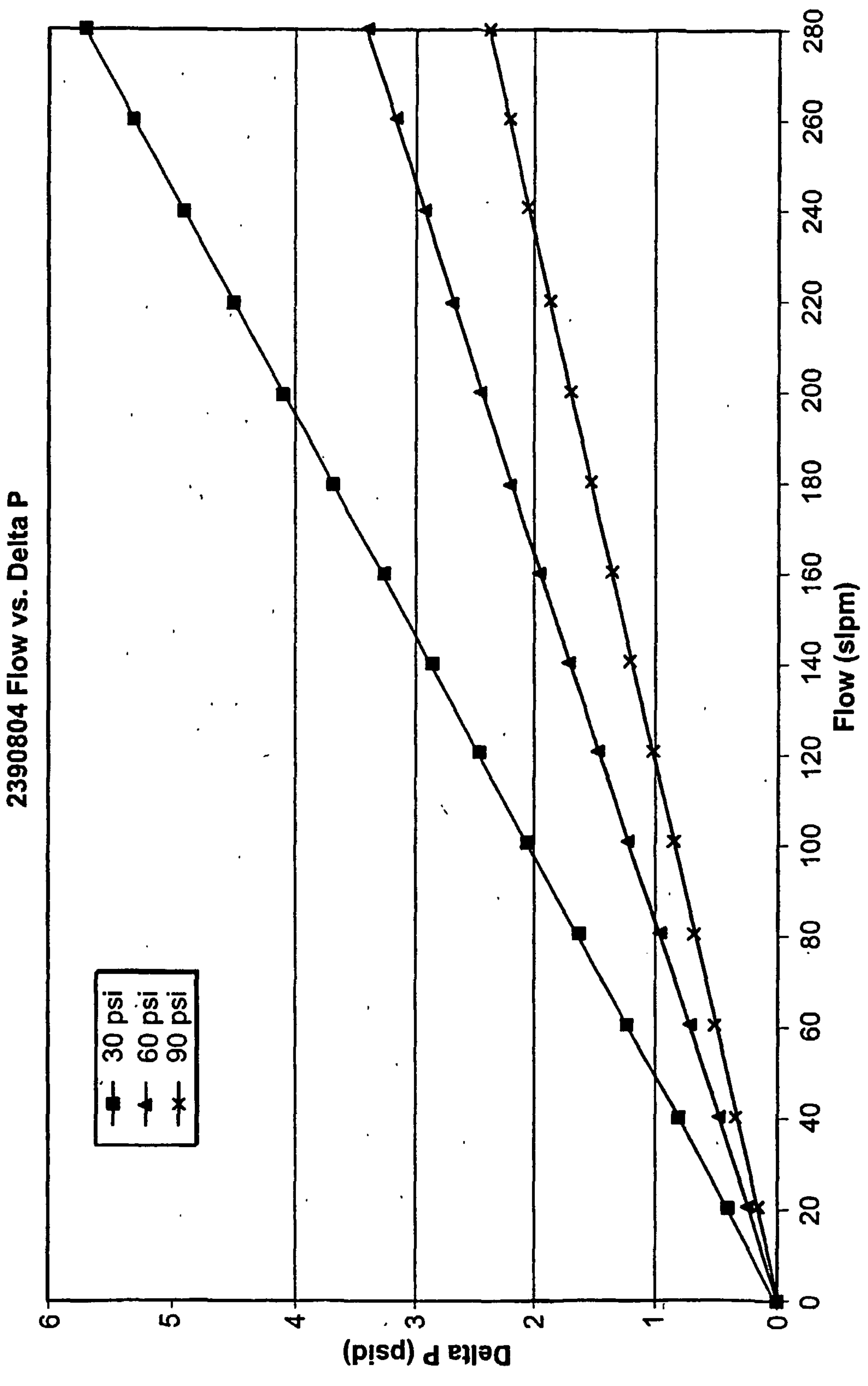

2390804 Flow vs. Delta P
30 psi
60 psi
90 psi
Delta P (psid)
0
1
2
3
4
5
6
Flow (slpm)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280

FIG. 13A

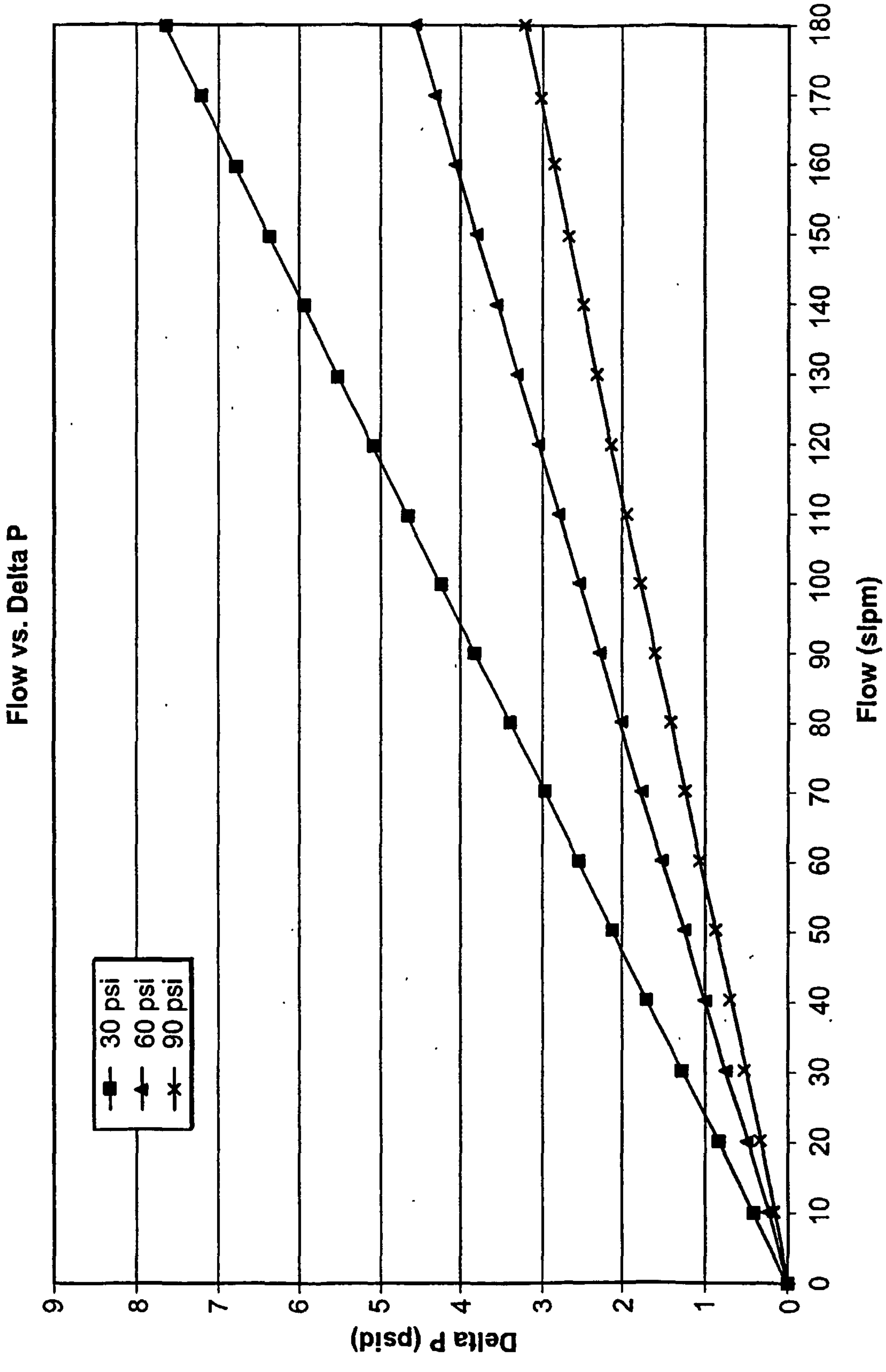

Flow vs. Delta P
30 psi
60 psi
90 psi
Delta P (psid)
0
1
2
3
4
5
6
7
8
9
Flow (slpm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

FIG. 13B

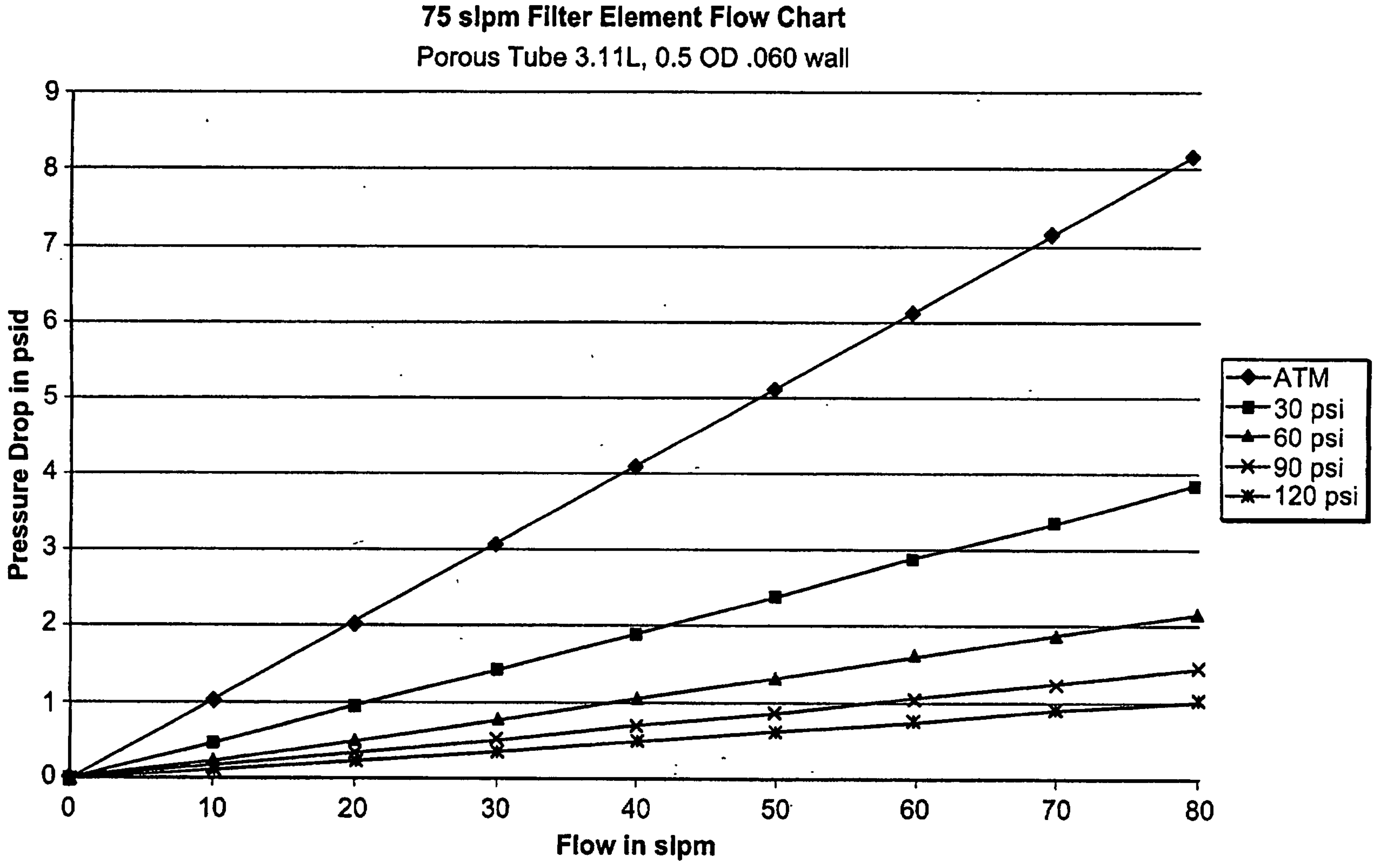

75 slpm Filter Element Flow Chart
Porous Tube 3.11L, 0.5 OD .060 wall
Pressure Drop in psid
0
1
2
3
4
5
6
7
8
9
Flow in slpm
0
10
20
30
40
50
60
70
80
ATM
30 psi
60 psi
90 psi
120 psi

FIG. 13C

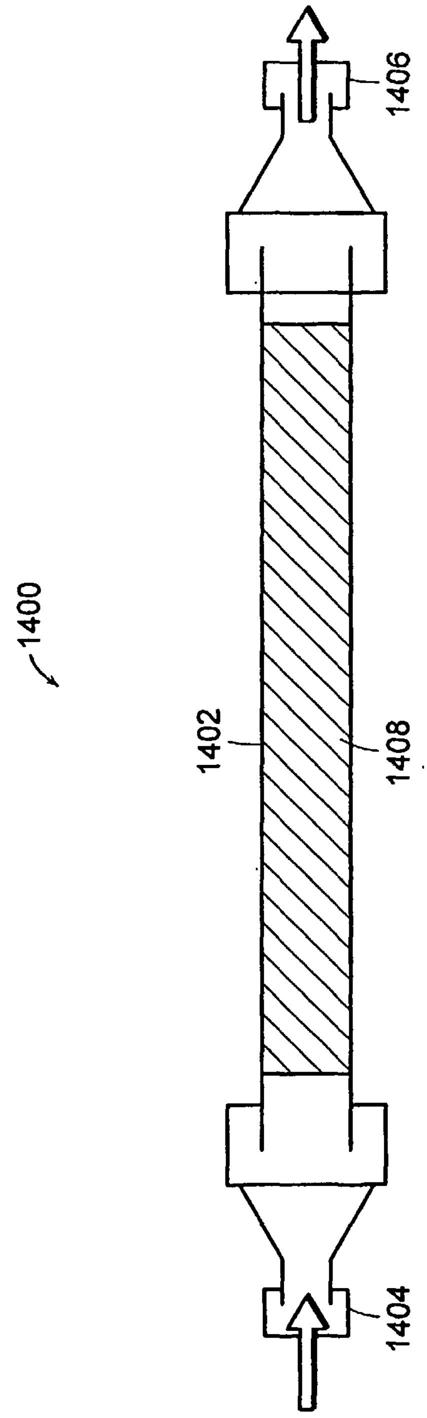


FIG. 14

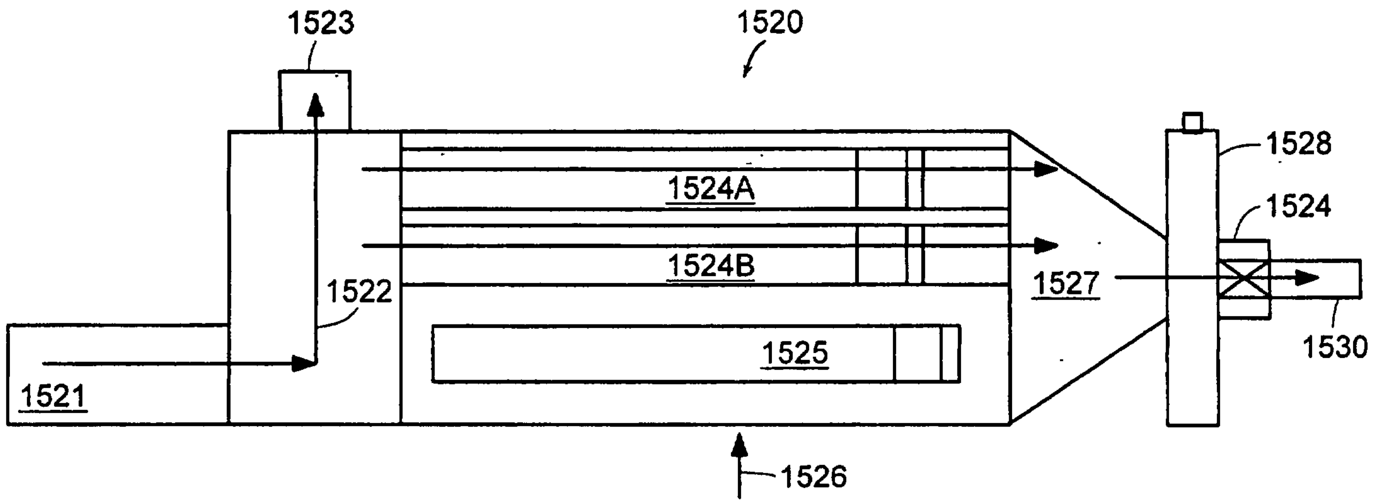

1523
1520
1528
1524
1524A
1524B
1522
1527
1530
1525
1521
1526

FIG. 15

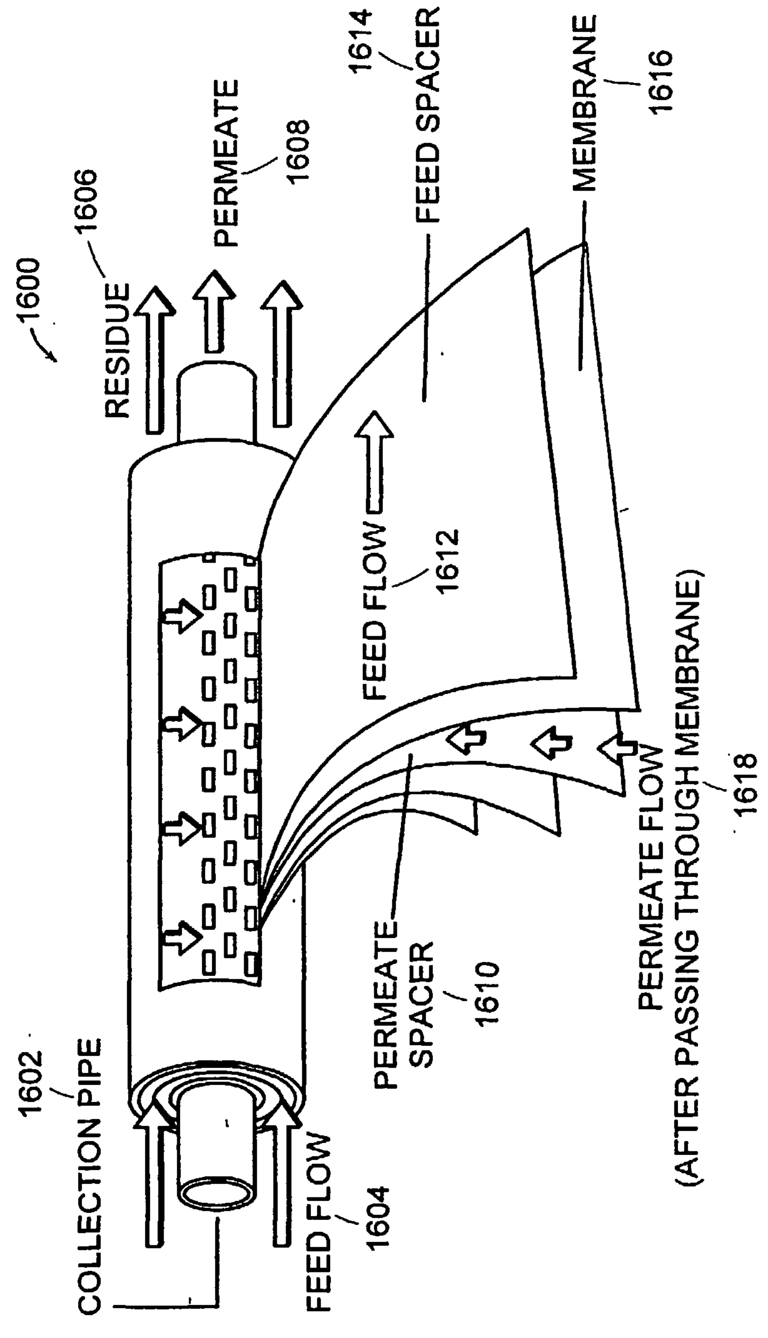

1600
RESIDUE
1606
PERMEATE
1608
1614
FEED SPACER
MEMBRANE
1616
FEED FLOW
1612
COLLECTION PIPE
1602
FEED FLOW
1604
PERMEATE SPACER
1610
PERMEATE FLOW (AFTER PASSING THROUGH MEMBRANE)
1618

FIG. 16

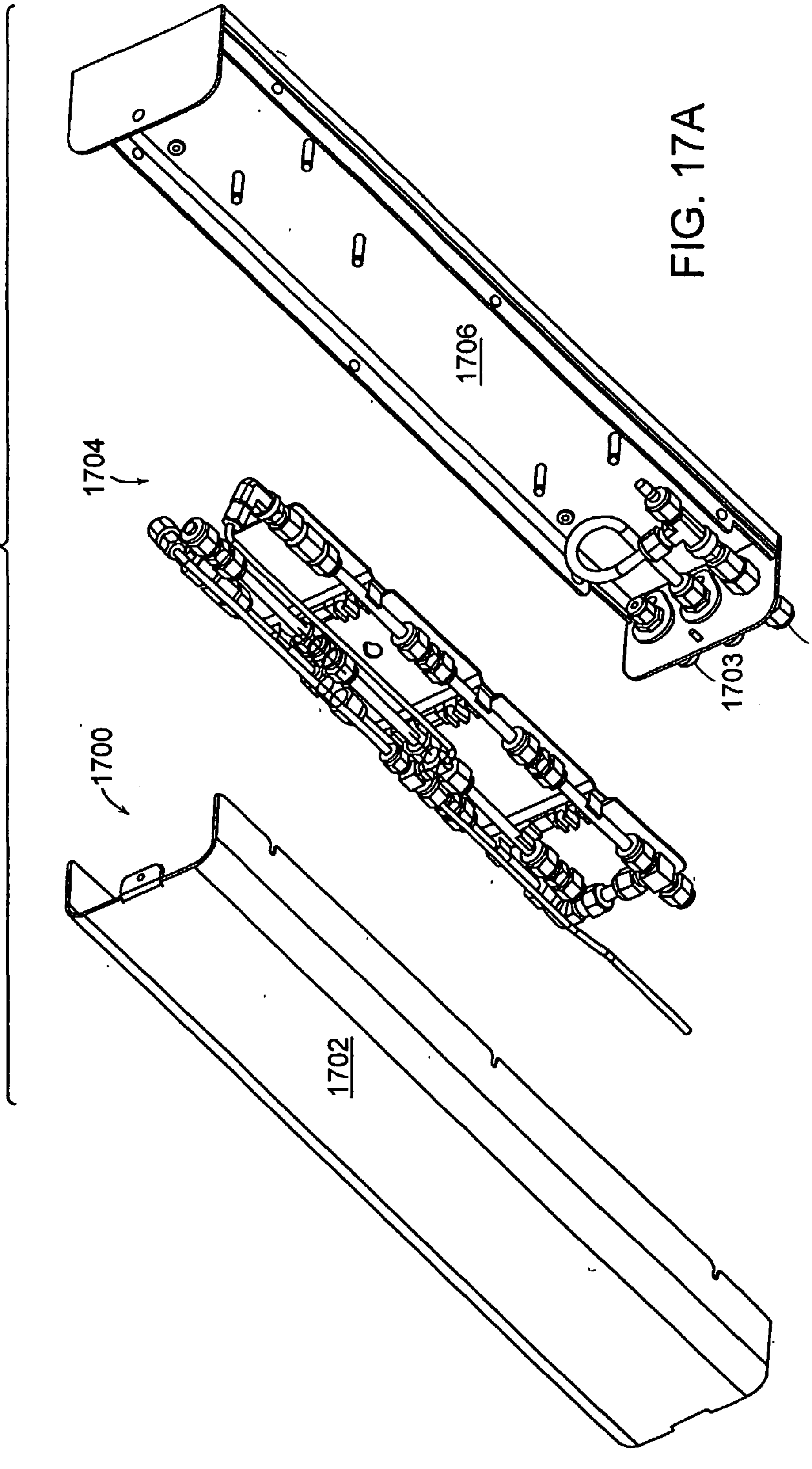


FIG. 17A

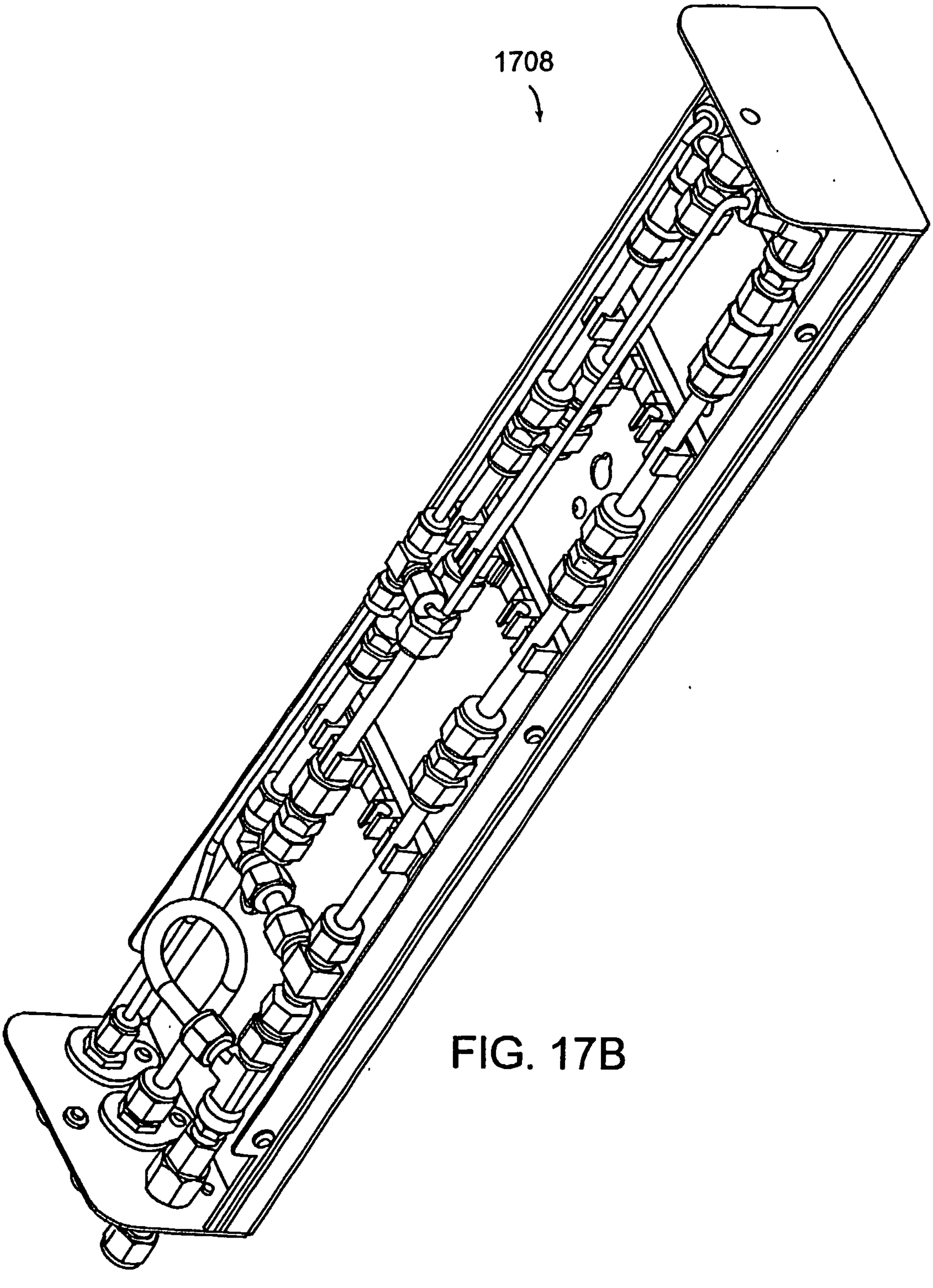


FIG. 17B

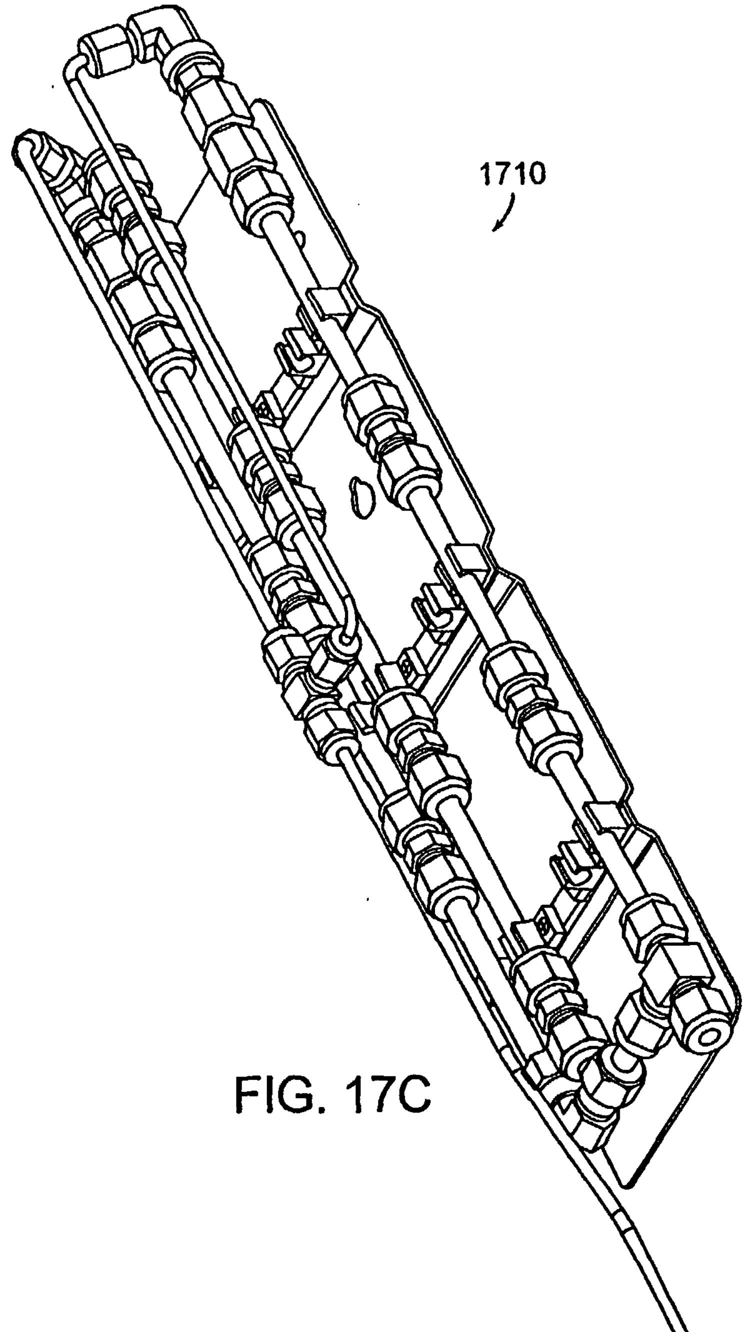


FIG. 17C

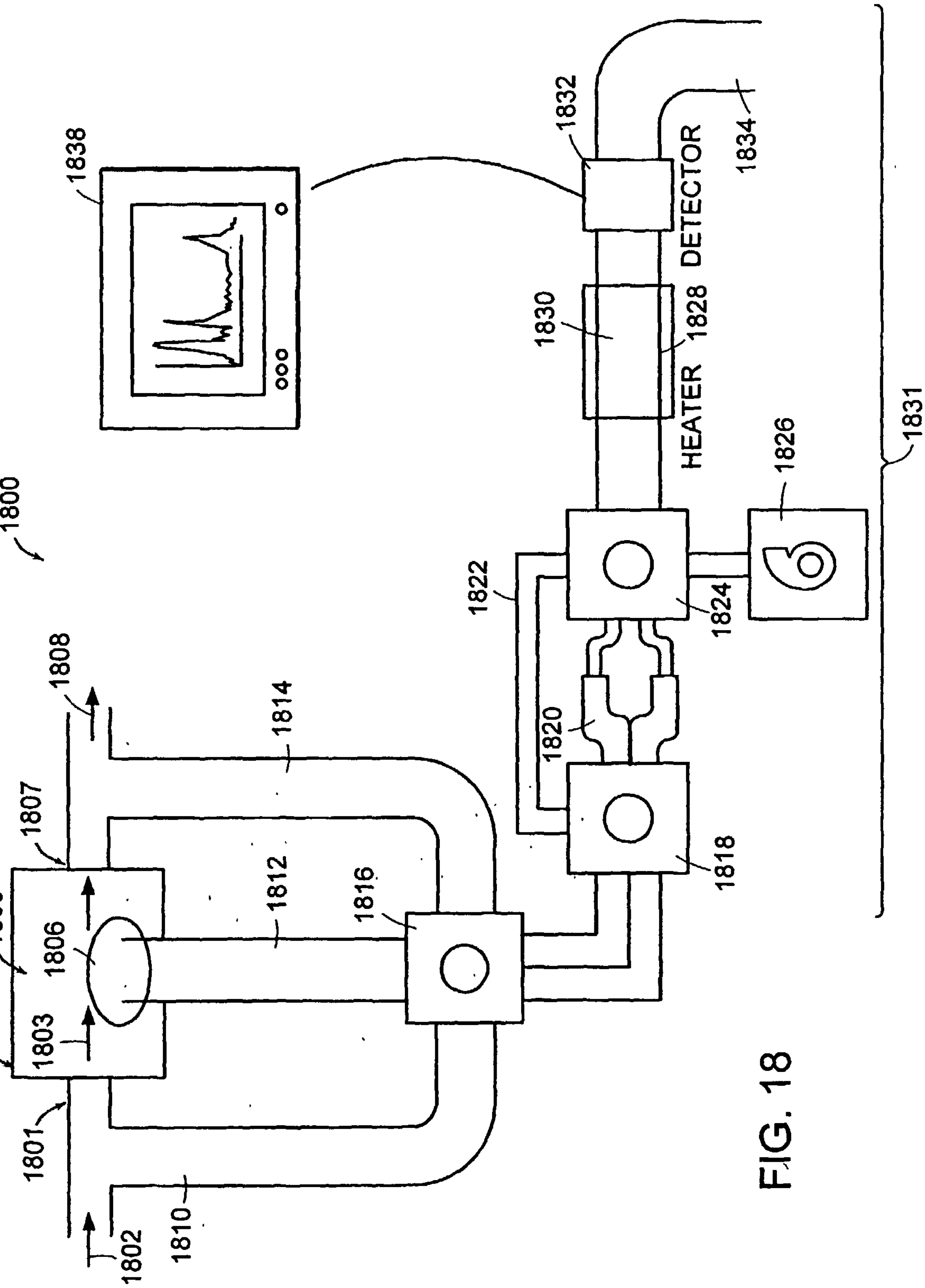

1800
1838
1832
1834
DETECTOR
1830
1828
HEATER
1831
1826
1822
1824
1820
1818
1808
1814
1807
1812
1816
1805
1806
1804
1803
1801
1802
1810

FIG. 18

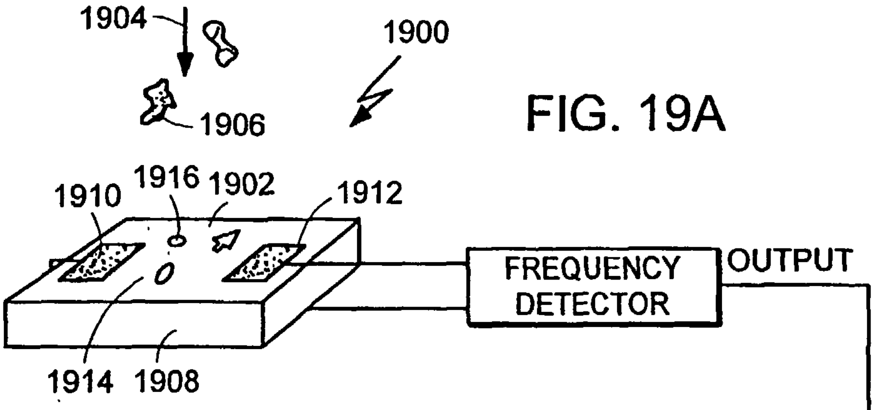


FIG. 19A

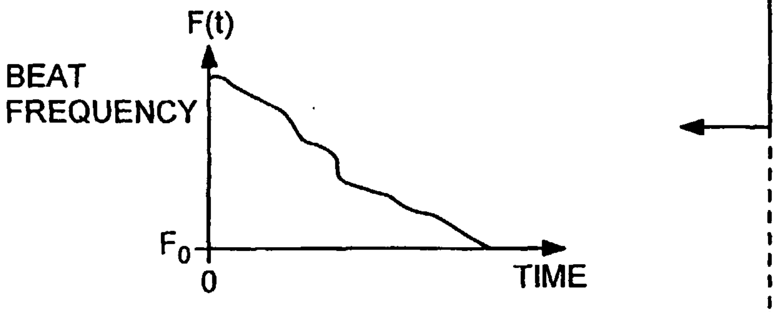


FIG. 19B

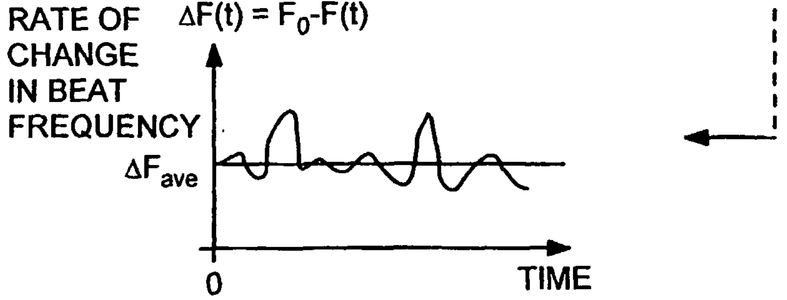


FIG. 19C

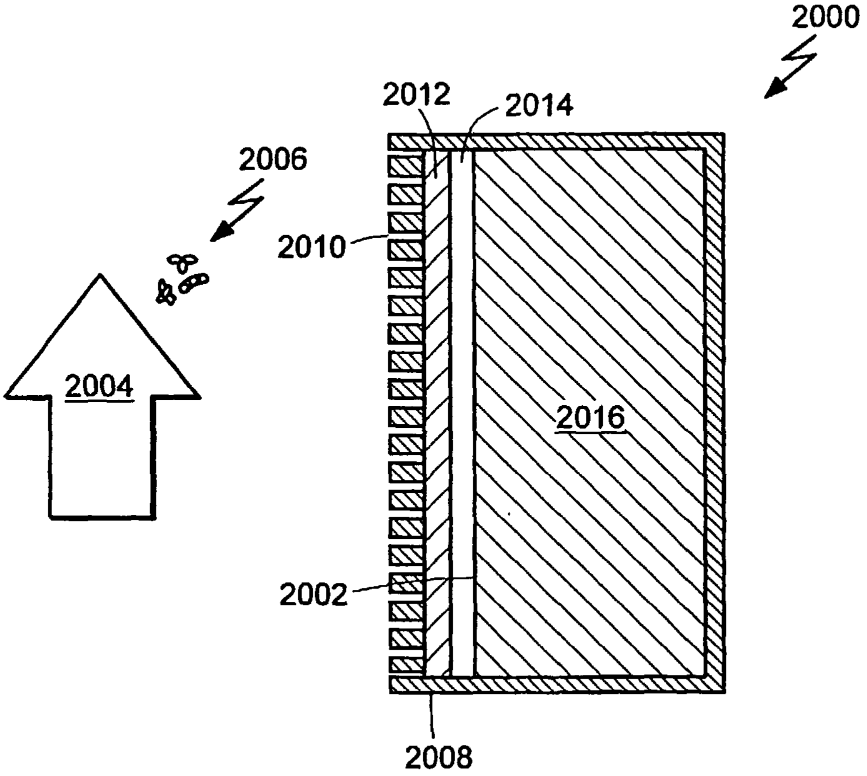


FIG. 20A

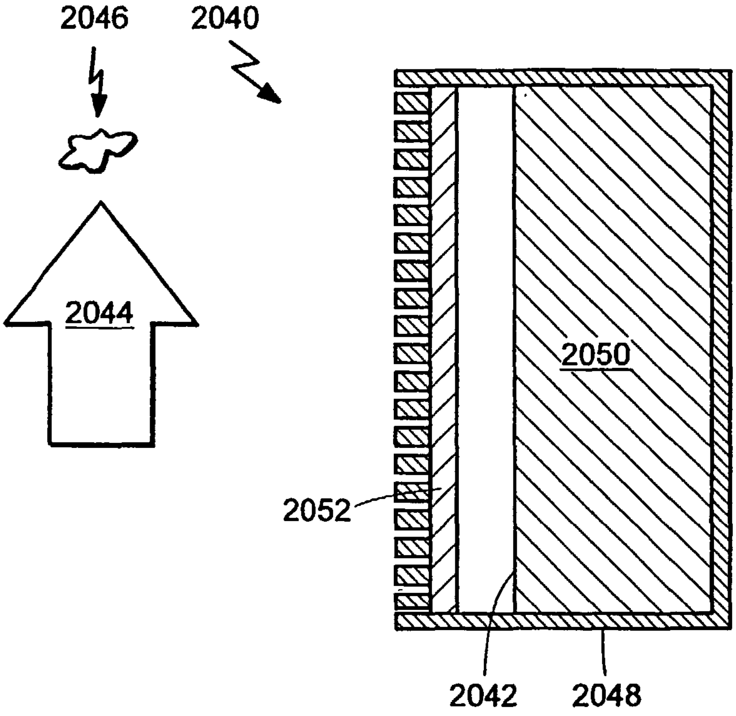


FIG. 20B

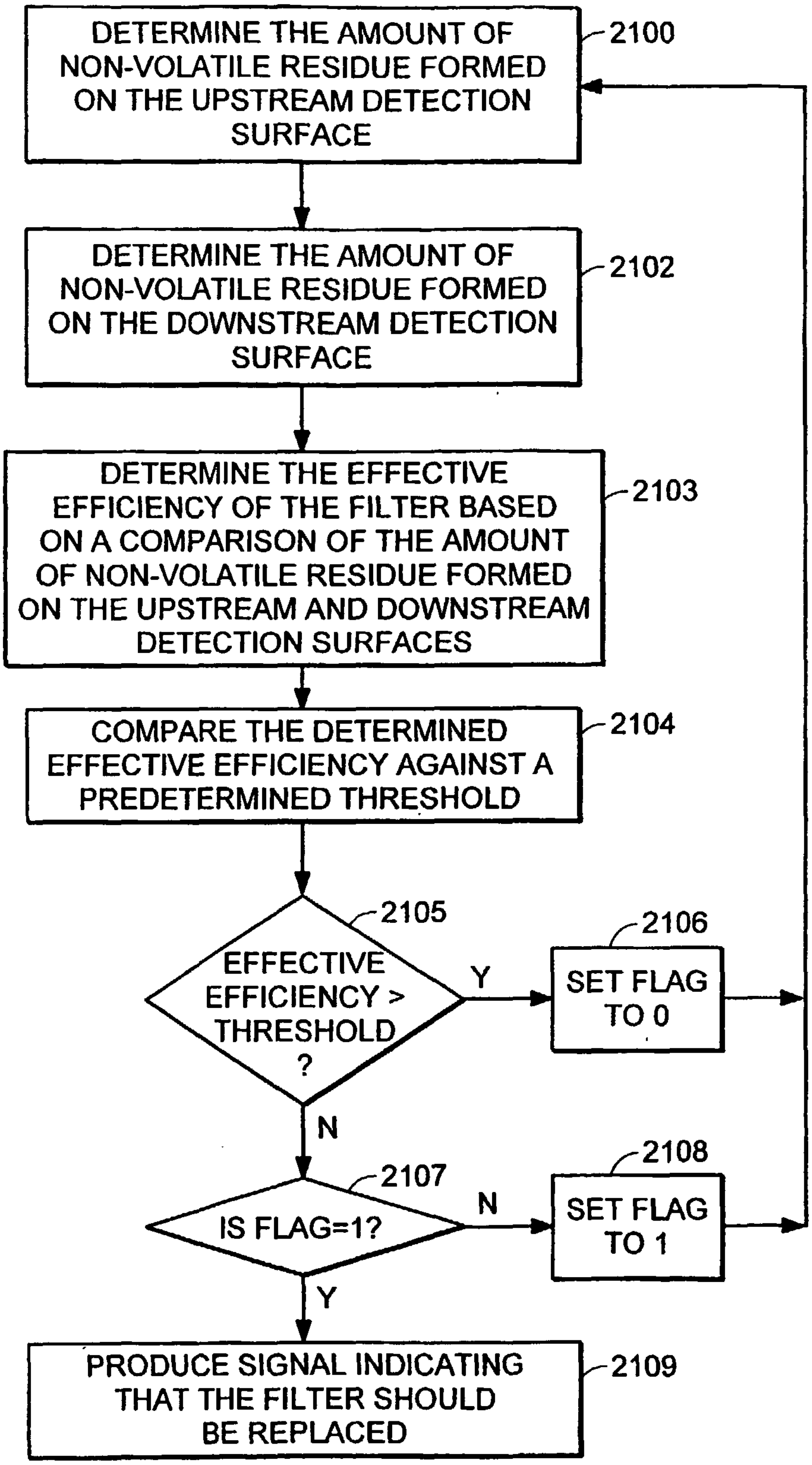

DETERMINE THE AMOUNT OF NON-VOLATILE RESIDUE FORMED ON THE UPSTREAM DETECTION SURFACE
2100
DETERMINE THE AMOUNT OF NON-VOLATILE RESIDUE FORMED ON THE DOWNSTREAM DETECTION SURFACE
2102
DETERMINE THE EFFECTIVE EFFICIENCY OF THE FILTER BASED ON A COMPARISON OF THE AMOUNT OF NON-VOLATILE RESIDUE FORMED ON THE UPSTREAM AND DOWNSTREAM DETECTION SURFACES
2103
COMPARE THE DETERMINED EFFECTIVE EFFICIENCY AGAINST A PREDETERMINED THRESHOLD
2104
EFFECTIVE EFFICIENCY > THRESHOLD ?
2105
Y
SET FLAG TO 0
2106
N
IS FLAG=1?
2107
N
SET FLAG TO 1
2108
Y
PRODUCE SIGNAL INDICATING THAT THE FILTER SHOULD BE REPLACED
2109

FIG. 21

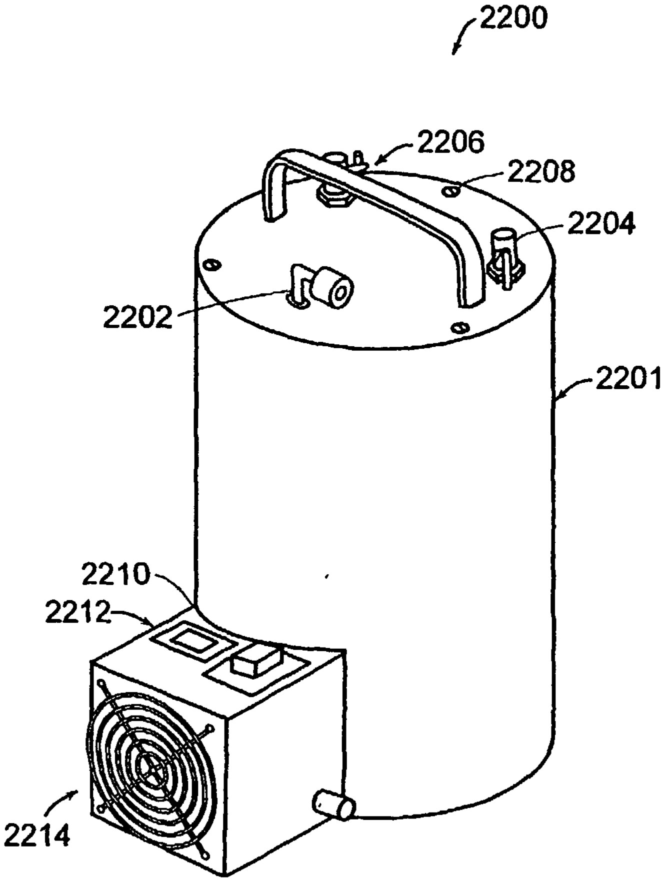


FIG. 22

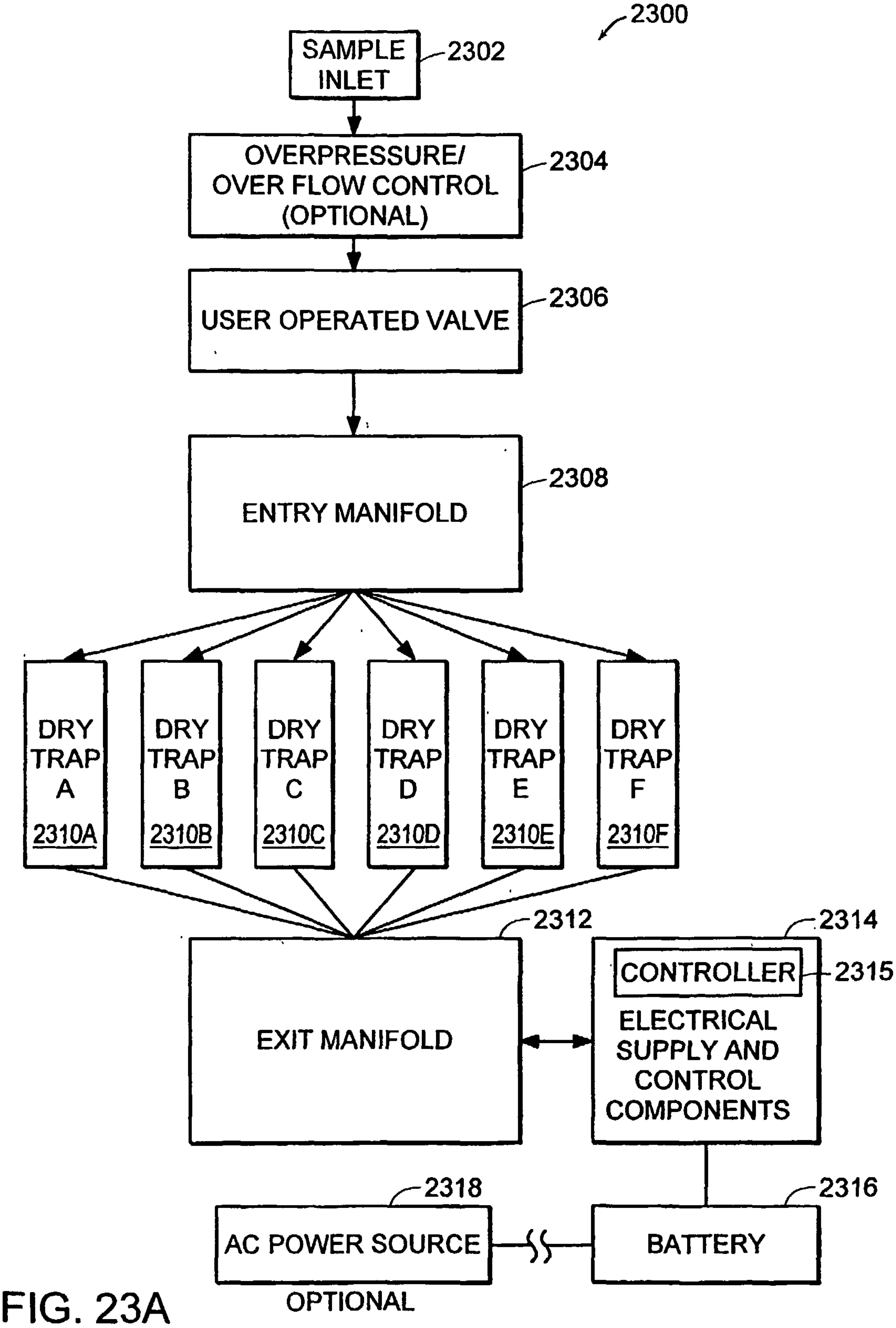

2300
SAMPLE INLET
2302
OVERPRESSURE/ OVER FLOW CONTROL (OPTIONAL)
2304
USER OPERATED VALVE
2306
ENTRY MANIFOLD
2308
DRY TRAP A
2310A
DRY TRAP B
2310B
DRY TRAP C
2310C
DRY TRAP D
2310D
DRY TRAP E
2310E
DRY TRAP F
2310F
EXIT MANIFOLD
2312
2314
CONTROLLER
2315
ELECTRICAL SUPPLY AND CONTROL COMPONENTS
2318
AC POWER SOURCE
OPTIONAL
2316
BATTERY

FIG. 23A

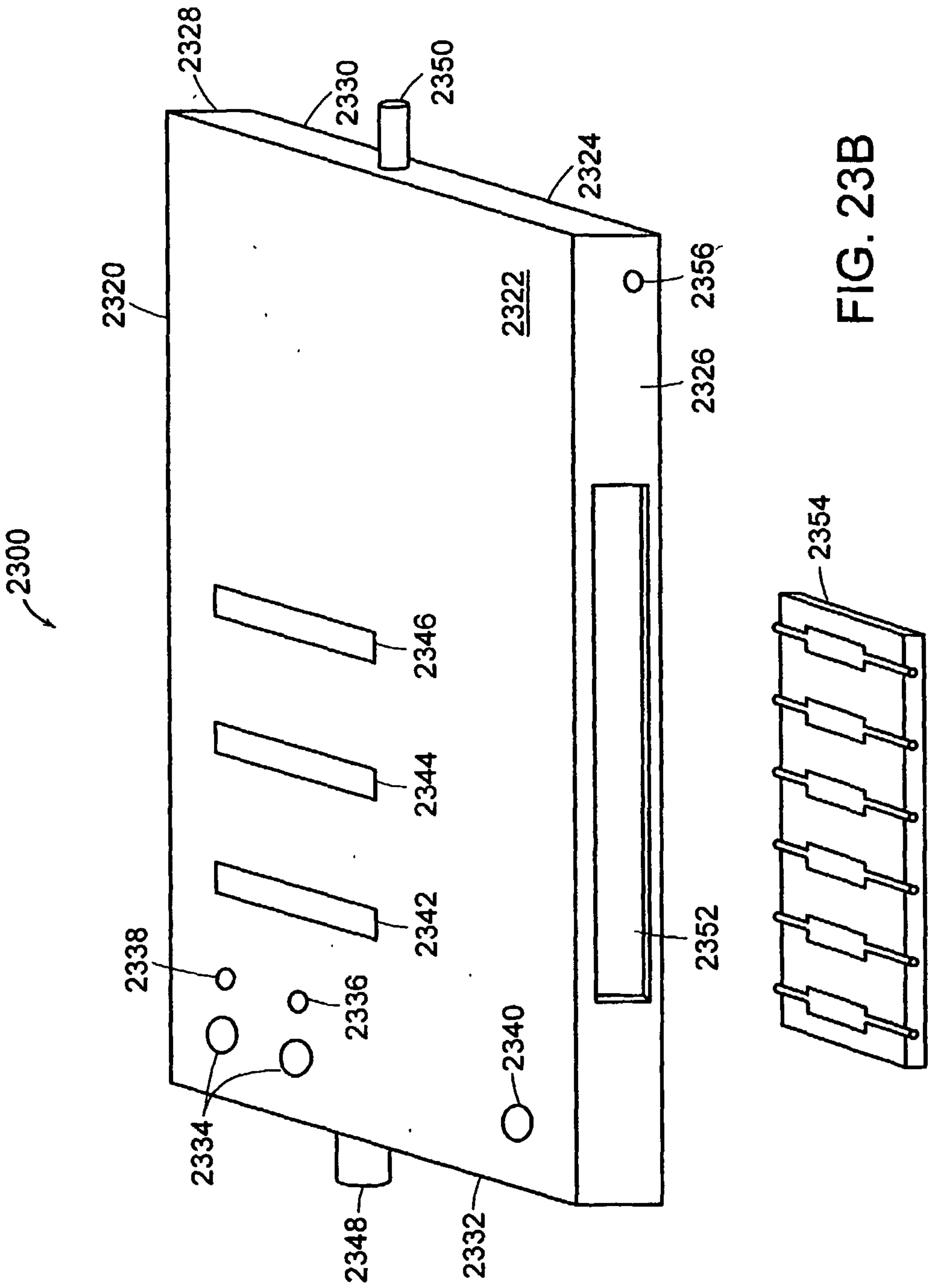

2300
2328
2330
2350
2324
2320
2322
2356
2326
2354
2346
2344
2342
2352
2338
2336
2340
2334
2348
2332

FIG. 23B

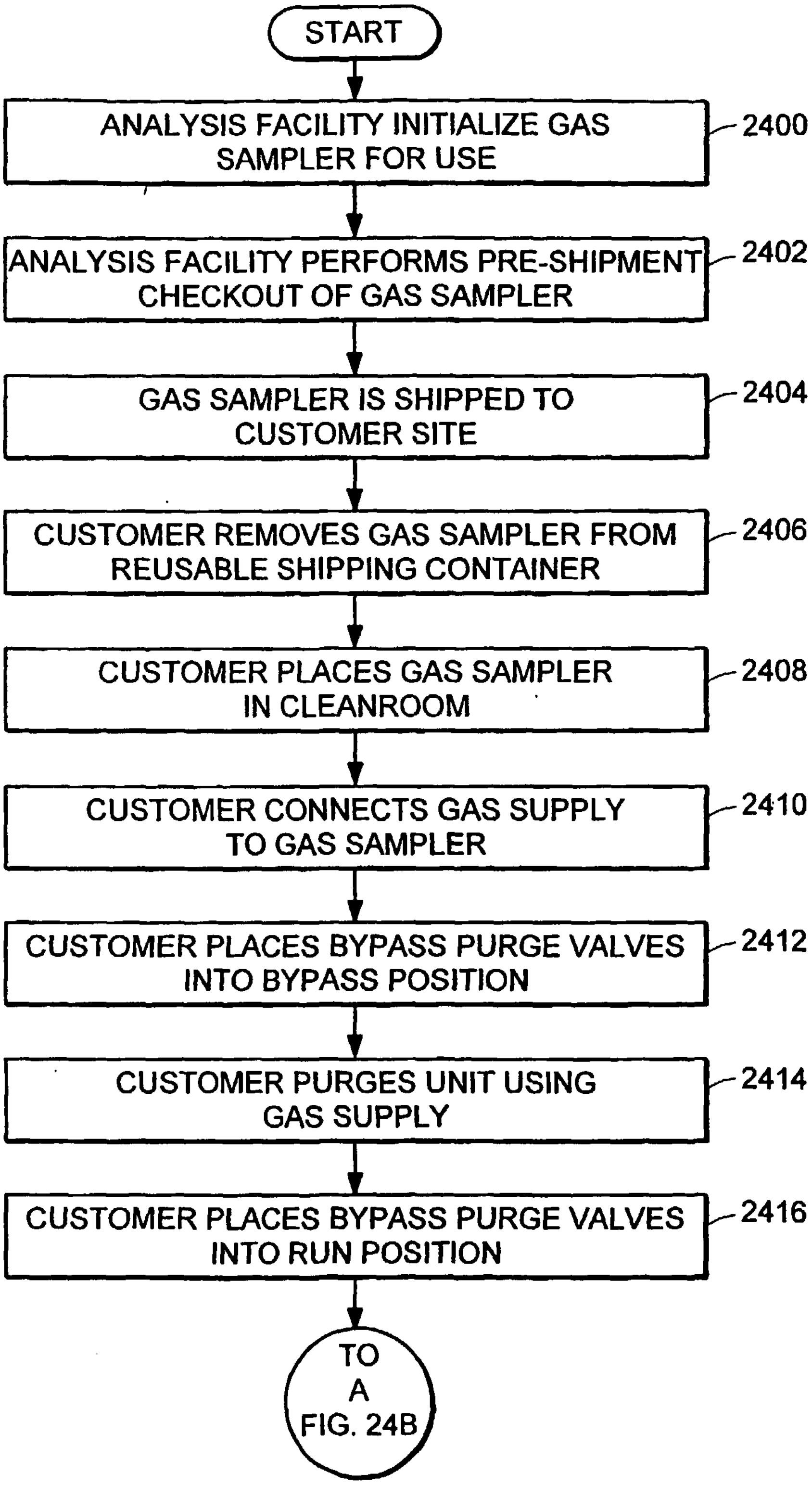

START
ANALYSIS FACILITY INITIALIZE GAS SAMPLER FOR USE
2400
ANALYSIS FACILITY PERFORMS PRE-SHIPMENT CHECKOUT OF GAS SAMPLER
2402
GAS SAMPLER IS SHIPPED TO CUSTOMER SITE
2404
CUSTOMER REMOVES GAS SAMPLER FROM REUSABLE SHIPPING CONTAINER
2406
CUSTOMER PLACES GAS SAMPLER IN CLEANROOM
2408
CUSTOMER CONNECTS GAS SUPPLY TO GAS SAMPLER
2410
CUSTOMER PLACES BYPASS PURGE VALVES INTO BYPASS POSITION
2412
CUSTOMER PURGES UNIT USING GAS SUPPLY
2414
CUSTOMER PLACES BYPASS PURGE VALVES INTO RUN POSITION
2416
TO A FIG. 24B

FIG. 24A

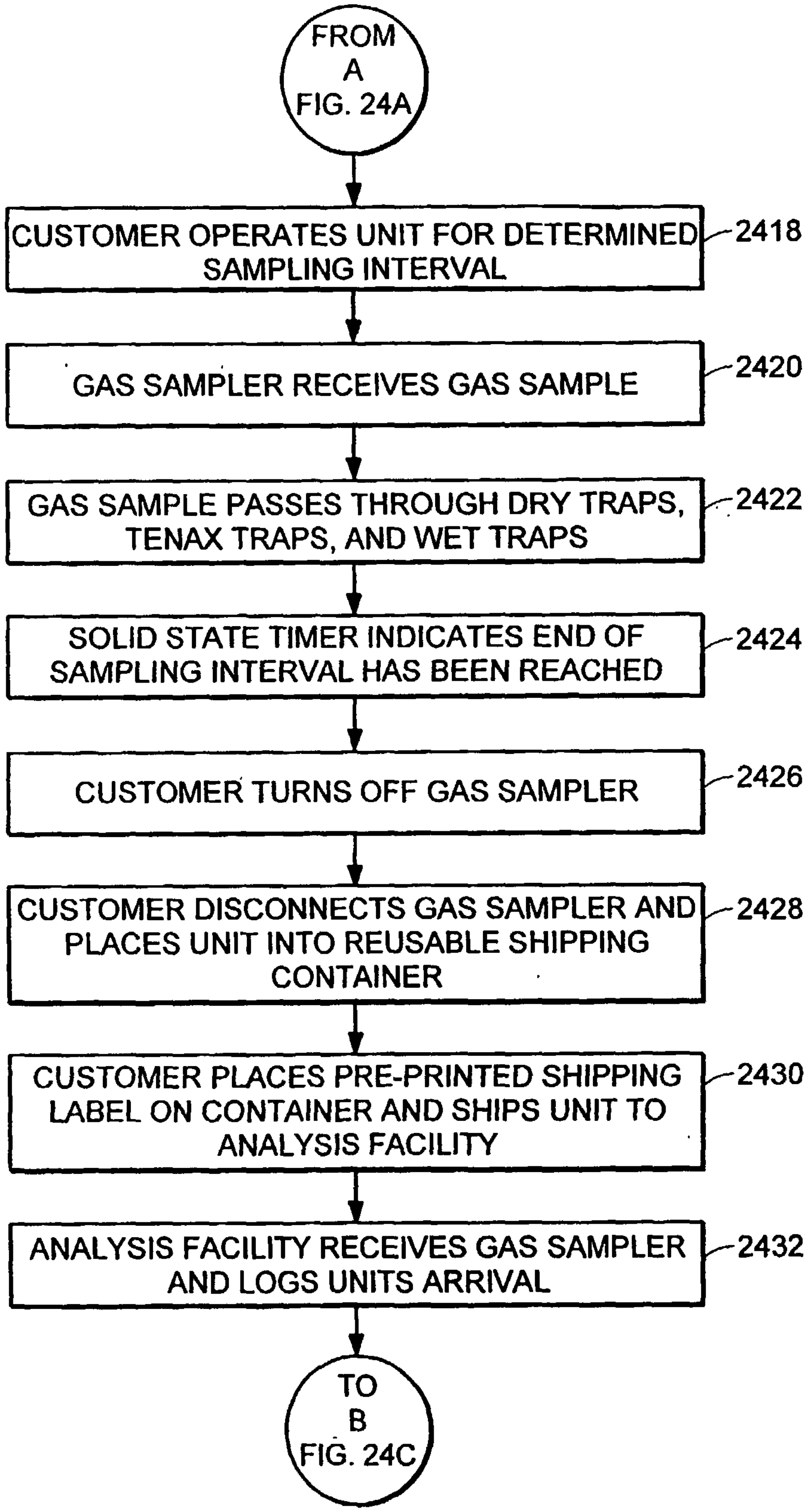

FROM
A
FIG. 24A
CUSTOMER OPERATES UNIT FOR DETERMINED SAMPLING INTERVAL
2418
GAS SAMPLER RECEIVES GAS SAMPLE
2420
GAS SAMPLE PASSES THROUGH DRY TRAPS, TENAX TRAPS, AND WET TRAPS
2422
SOLID STATE TIMER INDICATES END OF SAMPLING INTERVAL HAS BEEN REACHED
2424
CUSTOMER TURNS OFF GAS SAMPLER
2426
CUSTOMER DISCONNECTS GAS SAMPLER AND PLACES UNIT INTO REUSABLE SHIPPING CONTAINER
2428
CUSTOMER PLACES PRE-PRINTED SHIPPING LABEL ON CONTAINER AND SHIPS UNIT TO ANALYSIS FACILITY
2430
ANALYSIS FACILITY RECEIVES GAS SAMPLER AND LOGS UNITS ARRIVAL
2432
TO
B
FIG. 24C

FIG. 24B

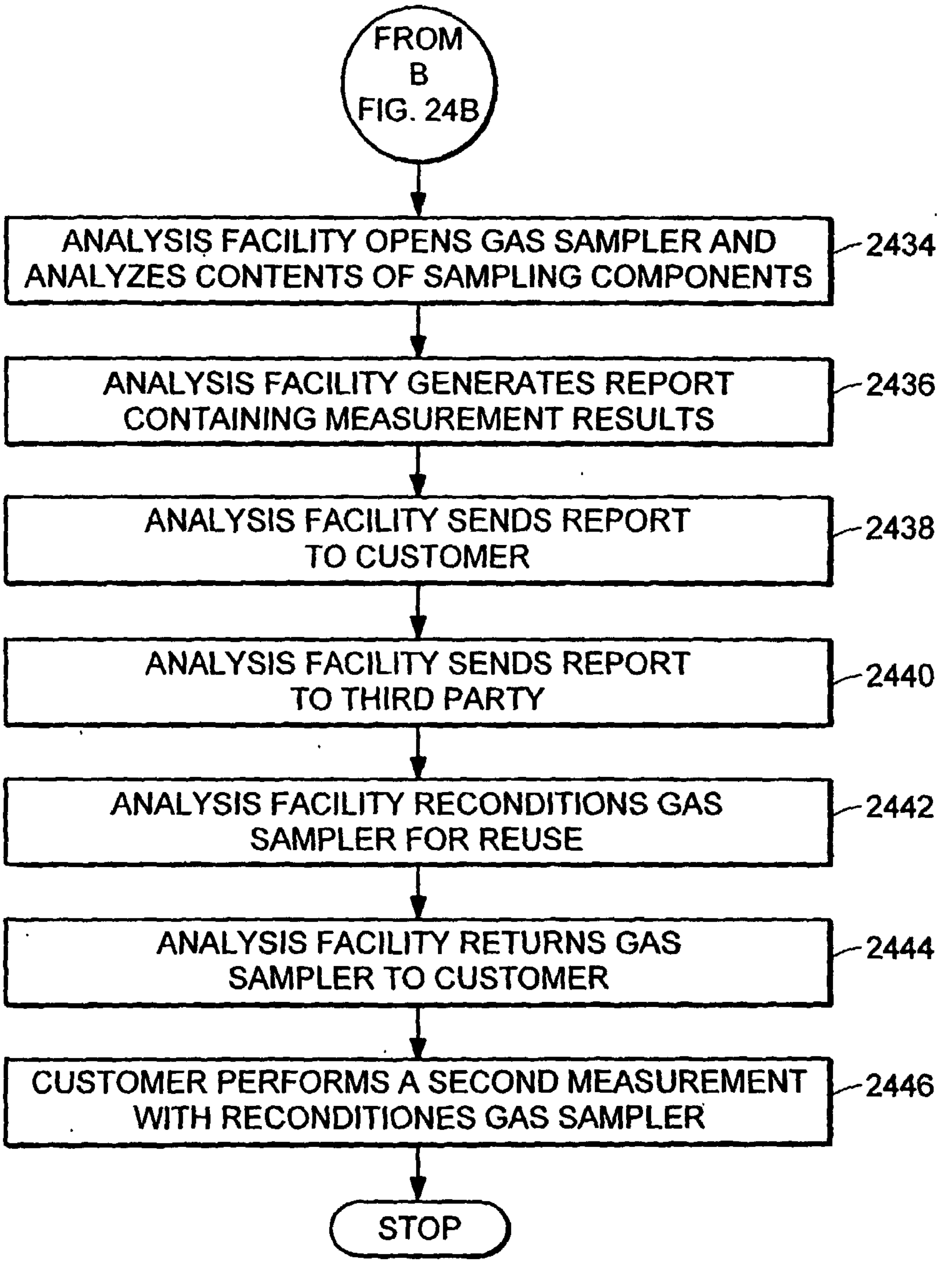

FROM
B
FIG. 24B
ANALYSIS FACILITY OPENS GAS SAMPLER AND ANALYZES CONTENTS OF SAMPLING COMPONENTS
2434
ANALYSIS FACILITY GENERATES REPORT CONTAINING MEASUREMENT RESULTS
2436
ANALYSIS FACILITY SENDS REPORT TO CUSTOMER
2438
ANALYSIS FACILITY SENDS REPORT TO THIRD PARTY
2440
ANALYSIS FACILITY RECONDITIONS GAS SAMPLER FOR REUSE
2442
ANALYSIS FACILITY RETURNS GAS SAMPLER TO CUSTOMER
2444
CUSTOMER PERFORMS A SECOND MEASUREMENT WITH RECONDITIONES GAS SAMPLER
2446
STOP

FIG. 24C

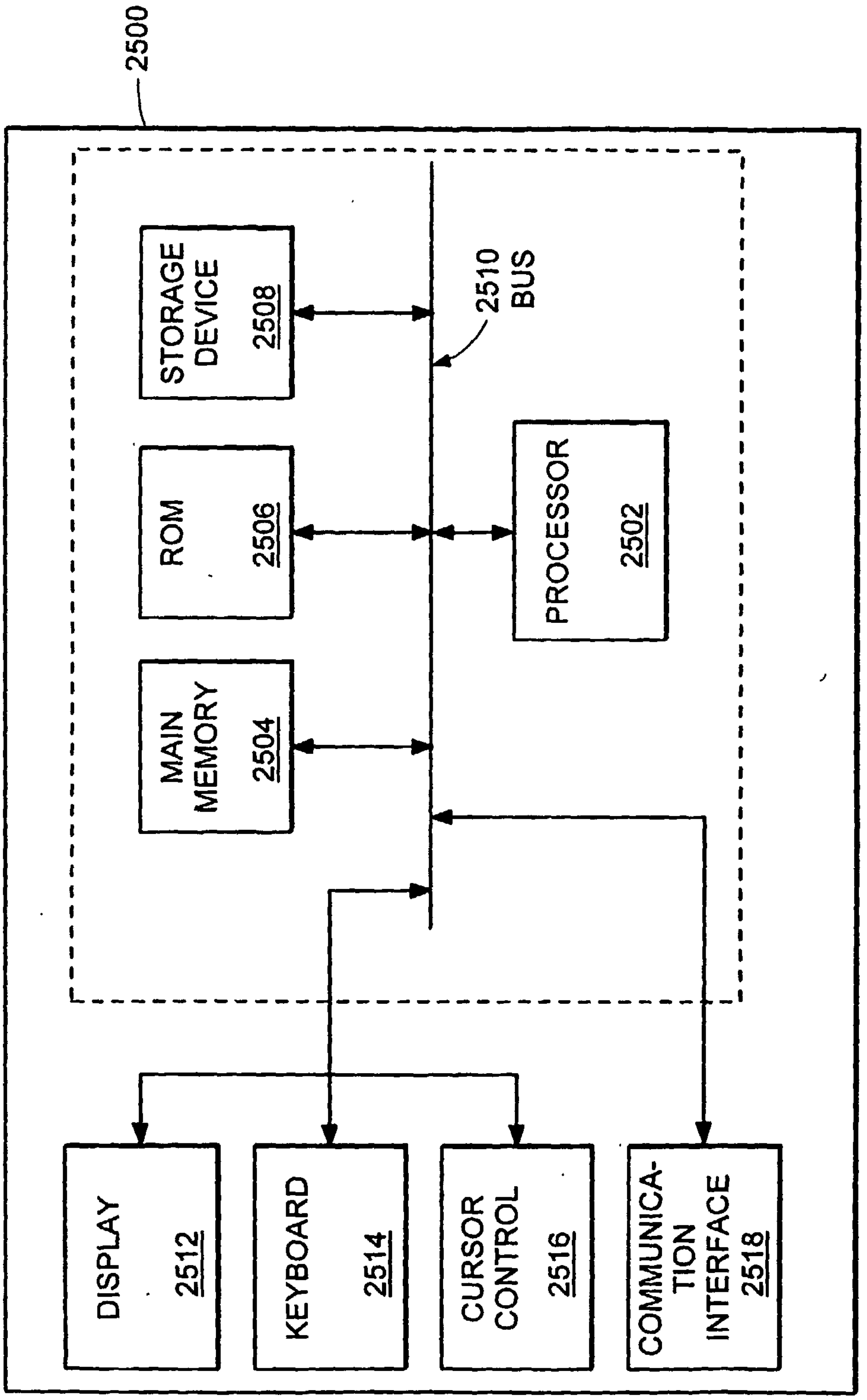

2500
STORAGE DEVICE 2508
ROM 2506
MAIN MEMORY 2504
2510 BUS
PROCESSOR 2502
DISPLAY 2512
KEYBOARD 2514
CURSOR CONTROL 2516
COMMUNICATION INTERFACE 2518

FIG. 25

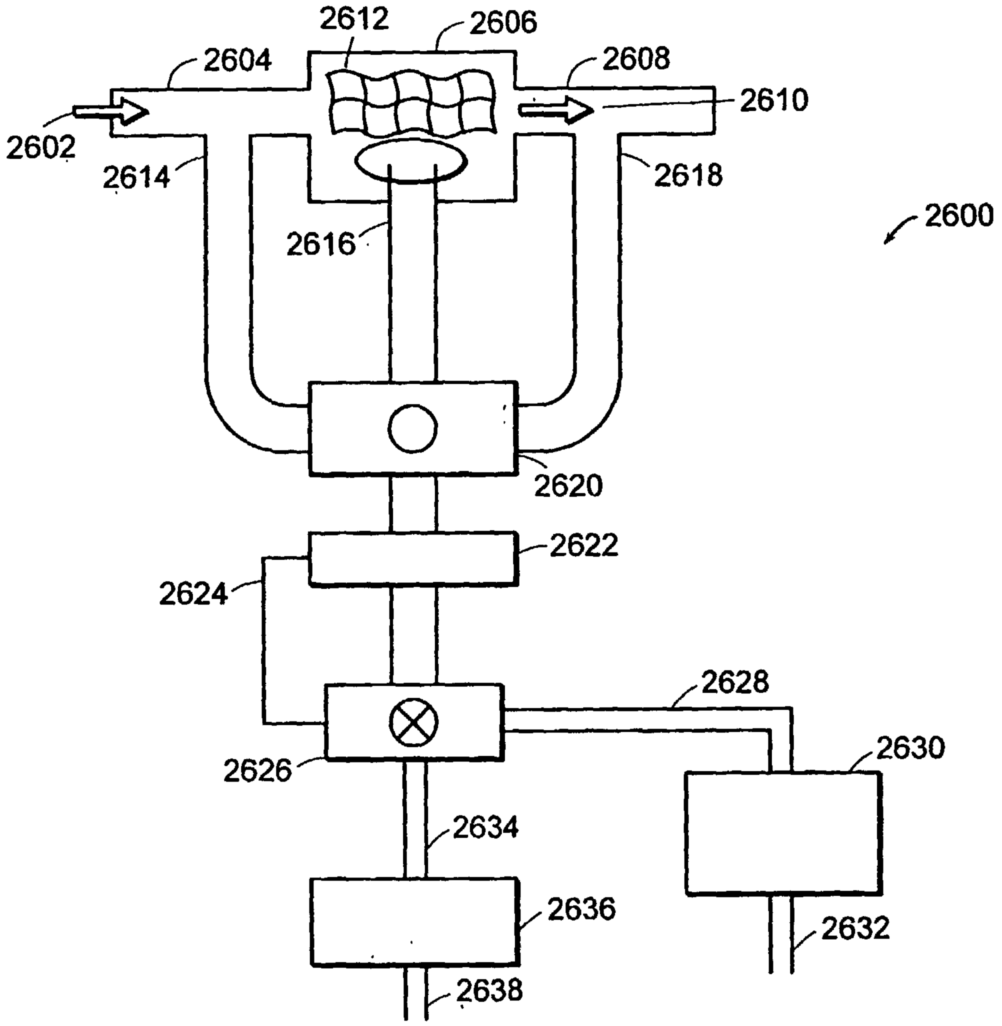

2612
2606
2604
2608
2610
2602
2614
2618
2600
2616
2620
2622
2624
2628
2630
2626
2634
2636
2632
2638

FIG. 26

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/028708

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B01D46/30

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B01D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 00/25896 A (DONALDSON CO INC) 11 May 2000 (2000-05-11) abstract; figures 1-5 page 10, line 1 - page 11, line 4	1,2, 20-22, 40,46, 55,69,70
Y	US 6 096 267 A (KISHKOVICH OLEG P ET AL) 1 August 2000 (2000-08-01) abstract; figure 1 column 1, line 49 - column 2, line 67	1,2, 20-22, 40,46, 55,69,70
A	WO 01/85308 A (GOODWIN WILLIAM M ; KISHKOVICH OLEG P (US); KINKEAD DEVON (US); RUEDE) 15 November 2001 (2001-11-15) abstract; claims 52,63	1-70

-/--

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 November 2004	01/12/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Sembritzki, T

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/028708

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/113943 A1 (GOODWIN WILLIAM M ET AL) 19 June 2003 (2003-06-19) the whole document	1-70
A	US 5 574 230 A (BAUGH STEVEN F) 12 November 1996 (1996-11-12) the whole document	1-70

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US2004/028708

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 0025896	A	11-05-2000	AU	1324700	A	22-05-2000
			WO	0025896	A1	11-05-2000
US 6096267	A	01-08-2000	DE	69816277	D1	14-08-2003
			DE	69816277	T2	03-06-2004
			EP	1365228	A2	26-11-2003
			EP	0963552	A1	15-12-1999
			JP	2002517979	T	18-06-2002
			TW	421843	B	11-02-2001
			WO	9838508	A1	03-09-1998
			US	2002090735	A1	11-07-2002
			US	6296806	B1	02-10-2001
WO 0185308	A	15-11-2001	AU	5956801	A	20-11-2001
			CA	2406703	A1	15-11-2001
			EP	1357998	A2	05-11-2003
			JP	2003533339	T	11-11-2003
			WO	0185308	A2	15-11-2001
			US	2002178923	A1	05-12-2002
			US	2002078828	A1	27-06-2002
US 2003113943	A1	19-06-2003	US	2003068834	A1	10-04-2003
			US	2004023419	A1	05-02-2004
			US	2004166679	A1	26-08-2004
			CA	2461153	A1	03-04-2003
			EP	1438118	A1	21-07-2004
			WO	03026774	A1	03-04-2003
US 5574230	A	12-11-1996	NONE			