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CLERK US DISTRICT COURT
SOUTHERN DISTRICT OF CALIFORNIA

BY ______ DEPUTY

VIA FAX

UNITED STATES DISTRICT COURT

SOUTHERN DISTRICT OF CALIFORNIA

SEQUAL TECHNOLOGIES, INC., a Delaware corporation Plaintiff, v. INOGEN, INC., a Delaware corporation, Defendant.	Case No. '10 CV 0410 WQH RBB **PLAINTIFF, SEQUAL TECHNOLOGIES, INC.'S COMPLAINT** **JURY DEMAND**

Plaintiff SEQUAL TECHNOLOGIES, INC. for its Complaint against Defendant INOGEN, INC. alleges and states as follows:

THE PARTIES

1. Plaintiff SEQUAL TECHNOLOGIES, INC. ("SeQual") is a corporation organized and existing under the laws of the State of Delaware with its principal place of business located at 11436 Sorrento Valley Road, San Diego, California.

2. Defendant INOGEN, INC. ("Inogen") is a corporation organized and existing under the laws of the State of Delaware with its principal place of business located at 326 Bollay Drive, Goleta, California.

JURISDICTION AND VENUE

3. This is a civil action for patent infringement arising under the Patent Laws of the United States, 35 U.S.C. sections 1 et seq. Subject matter jurisdiction is therefore proper under 28 U.S.C. sections 1331 and 1338(a).

4. Venue is proper in this judicial district under 28 U.S.C. sections 1391(b) and (c) and 1400(b) because a substantial part of the events or omissions giving rise to the claims occurred in the district and the defendant resides in this district by virtue of being subject to personal jurisdiction in this judicial district by, among others, its repeatedly availement and direction of its activity toward this district, and engaging in acts of infringement in this judicial district.

FIRST CLAIM FOR RELIEF

INFRINGEMENT OF U.S. PATENT NO. 5,593,478

5. SeQual realleges all allegations in this Complaint as if stated herein.

6. On January 14, 1997, United States Patent Number 5,593,478 ('478 Patent) entitled "Fluid Fractionator," was duly and legally issued to SeQual, who has the right to enforce this patent. A true and correct copy of this Patent is attached hereto as Exhibit 1 and incorporated herein by reference.

7. Inogen has infringed and continues to infringe (literally and under the doctrine of equivalents) the '478 Patent by making, using, selling, offering for sale, importing, and/or actively inducing others to use (for example, end users of their products by providing instructions and/or

manuals) ambulatory oxygen systems, such as the Inogen One, covered by one or more claims of the '478 Patent, and is thus liable for patent infringement pursuant to 35 U.S.C. § 271.

8. Inogen has also announced a new product, the Inogen One G2 Portable Oxygen Concentrator, for which Inogen has said that the changes from the Inogen One to this new product are minor. SeQual is informed and believes that Inogen has not publicly released the Inogen One G2 as of yet, but on information and belief, Inogen has used this product and infringed the '478 Patent.

9. Inogen's infringement of the '478 Patent has caused and continues to cause damage to SeQual in an amount to be determined at trial.

10. Inogen's infringement of the '478 Patent has caused and will continue to cause immediate and irreparable harm to SeQual for which there is no adequate remedy at law, unless this Court enjoins and restrains such activities.

11. SeQual is informed and believes and, on that bases alleges, that Inogen knew of the '478 Patent and that Inogen's infringement of the '478 Patent is willful and deliberate, entitling SeQual to enhanced damages pursuant to 35 U.S.C. § 284, and costs incurred prosecuting this action.

SECOND CLAIM FOR RELIEF

INFRINGEMENT OF U.S. PATENT NO. 5,730,778

12. SeQual realleges all allegations in this Complaint as if stated herein.

13. On March 24, 1998, United States Patent Number 5,730,778 ('778 Patent) entitled "Fluid Fractionator," was duly and legally issued to SeQual, who has the right to enforce this patent. A true and correct copy of this Patent is attached hereto as Exhibit 2 and incorporated herein by reference.

14. Inogen has infringed and continues to infringe (literally and under the doctrine of equivalents) the '778 Patent by making, using, selling, offering for sale, importing, and/or actively inducing others to use (for example, end users of their products by providing instructions and/or manuals) ambulatory oxygen systems, such as the Inogen One, covered by one or more claims of the '478 Patent, and is thus liable for patent infringement pursuant to 35 U.S.C. § 271.

15. Inogen has also announced a new product, the Inogen One G2 Portable Oxygen Concentrator, for which Inogen has said that the changes from the Inogen One to this new product are minor. SeQual is informed and believes that Inogen has not publicly released the Inogen One G2 as of yet, but on information and belief, Inogen has used this product and infringed the '778 Patent.

16. Inogen's infringement of the '778 Patent has caused and continues to cause damage to SeQual in an amount to be determined at trial.

17. Inogen's infringement of the '778 Patent has caused and will continue to cause immediate and irreparable harm to SeQual for which there is no adequate remedy at law, unless this Court enjoins and restrains such activities.

18. SeQual is informed and believes and, on that bases alleges, that Inogen knew of the '778 Patent and that its infringement of the '778 Patent is willful and deliberate, entitling SeQual to enhanced damages pursuant to 35 U.S.C. § 284, and costs incurred prosecuting this action.

THIRD CLAIM FOR RELIEF

INFRINGEMENT OF U.S. PATENT NO. 6,691,702

19. SeQual realleges all allegations in this Complaint as if stated herein.

20. On February 17, 2004, United States Patent Number 6,691,702 ('702 Patent) entitled "Portable Oxygen Concentration System and Method of Using the Same," was duly and legally issued to SeQual and Teijin Limited, with SeQual having the right to enforce this patent. A true and correct copy of this Patent is attached hereto as Exhibit 3 and incorporated herein by reference.

21. Inogen has infringed and continues to infringe (literally and under the doctrine of equivalents) the '702 Patent by making, using, selling, offering for sale, importing, and/or actively inducing others to use (for example, end users of their products by providing instructions and/or manuals) ambulatory oxygen systems, such as the Inogen One, covered by one or more claims of the '702 Patent, and is thus liable for patent infringement pursuant to 35 U.S.C. § 271.

22. Inogen has also announced a new product, the Inogen One G2 Portable Oxygen Concentrator, for which Inogen has said that the changes from the Inogen One to this new product are minor. SeQual is informed and believes that Inogen has not publicly released the Inogen One

G2 as of yet, but on information and belief, Inogen has used this product and infringed the '702 Patent.

23. Inogen's infringement of the '702 Patent has caused and continues to cause damage to SeQual in an amount to be determined at trial.

24. Inogen's infringement of the '702 Patent has caused and will continue to cause immediate and irreparable harm to SeQual for which there is no adequate remedy at law, unless this Court enjoins and restrains such activities.

25. SeQual is informed and believes and, on that bases alleges, that Inogen knew of the '702 Patent and that its infringement of the '702 Patent is willful and deliberate, entitling SeQual to enhanced damages pursuant to 35 U.S.C. § 284, and costs incurred prosecuting this action.

PRAYER FOR RELIEF

WHEREFORE, SeQual prays for relief as follows:

1. For judgment entered in favor of SeQual that one or more claims of the '478 Patent, the '778 Patent, and/or the '702 Patent are infringed by Inogen;

2. That SeQual be granted an accounting of all damages incurred from Inogen's infringement;

3. That SeQual be awarded its actual damages along with prejudgment interest according to proof, and enhanced damages pursuant to 35 U.S.C. § 284;

4. For a preliminary and permanent injunction enjoining Inogen's acts of infringement and those of its parents, subsidiaries, officers, directors, agents, employees, licensees, and any persons acting in concert with Inogen, along with related individuals and entities, representatives, OEMs, dealers, distributors, and customers;

5. That SeQual be awarded its attorney's fees and costs pursuant to 35 U.S.C. § 285 or as otherwise provided by law, whether by statute, common law or the Court's inherent power; and

6. For all other and further relief deemed just and proper by the Court.

PRAYER FOR RELIEF

SeQual demands trial by jury on all issues triable as a matter of right at law.

Dated: February 22, 2010

MINTZ LEVIN COHN FERRIS GLOVSKY & POPEO

By: ______________________
Andrew D. Skale, Esq.

Attorneys for Plaintiff
SEQUAL TECHNOLOGIES, INC.

EXHIBIT 1

EXHIBIT 1

US005593478A

United States Patent [19]

Hill et al.

[11] **Patent Number: 5,593,478**

[45] **Date of Patent: Jan. 14, 1997**

[54] **FLUID FRACTIONATOR**

[75] Inventors: Charles C. Hill, Del Mar; Theodore B. Hill, San Diego, both of Calif.

[73] Assignee: Sequal Technologies, Inc., San Diego, Calif.

[21] Appl. No.: 314,213

[22] Filed: Sep. 28, 1994

[51] Int. Cl.[6] B01D 53/053

[52] U.S. Cl. 96/111; 96/115; 96/124; 96/130; 96/133; 96/144; 96/149

[58] Field of Search 96/109–117, 124, 96/126–130, 133, 144, 149

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,342,573	8/1982	McCombs et al.	96/109
4,378,982	4/1983	McCombs	96/117
4,491,459	1/1985	Pinkerton	96/113
4,576,616	3/1986	Mottram et al.	96/113 X
4,648,888	3/1987	Rowland	96/110 X
4,802,899	2/1989	Vrana et al.	96/109
4,806,132	2/1989	Campbell	55/16
4,813,979	3/1989	Miller et al.	96/115 X
4,822,384	4/1989	Kato et al.	96/110
4,925,464	5/1990	Rabenau et al.	96/124
5,112,367	5/1992	Hill	96/124 X
5,268,021	12/1993	Hill et al.	96/124 X
5,366,541	11/1994	Hill et al.	96/124
5,441,559	8/1995	Petit et al.	96/130 X
5,496,388	3/1996	Tellier	55/210

FOREIGN PATENT DOCUMENTS

0135921	4/1985	European Pat. Off.	96/109
63-016027	1/1988	Japan	96/113
4-016212	1/1992	Japan	96/109
5-084418	4/1993	Japan	96/109
WO94/15698	7/1994	WIPO	96/130

OTHER PUBLICATIONS

A Design Engineer's Guide to Smart Air Technology, The Marriage of Electronics to Pneumatics; Gast Manufacturing.

Primary Examiner—Robert Spitzer
Attorney, Agent, or Firm—Ellsworth R. Roston; Charles H. Schwartz

[57] **ABSTRACT**

A rotary valve at the inlets of a plurality of columns cyclically (1) selects first columns on a cyclic basis to receive compressed air, adsorb nitrogen and other components in the compressed air and pass oxygen and argon to a user (e.g. patient), second columns to desorb the adsorbed components in such columns and (3) third columns to equalize pressures where the first columns change progressively to the second columns and vice versa. A compressor having adjustable characteristics and regulated in an open or closed loop introduces the compressed air through the valve to the first columns to provide an adjustable air flow for obtaining a prescribed oxygen flow to the user. An indication may be provided when the compressor characteristics regulated for obtaining the prescribed oxygen flow rate are outside particular limits. The valve may have a variable speed related to the compressor flow variations to regulate the air pressure in the columns in accordance with the air flow rate into the columns. A variable orifice in a valve in each column outlet becomes constricted with decreases in the oxygen flow rate in each column, thereby further regulating the oxygen pressure in such column. A porous plug in a closed chamber receiving the desorbed pressurized components releases such components slowly, without pulsatile noise, to the atmosphere. The equipment accordingly produces the desired oxygen flow rate with minimal power consumption, minimal noise and optimal efficiency, reliability and life span. The equipment may be designed to pass other components than oxygen.

72 Claims, 9 Drawing Sheets

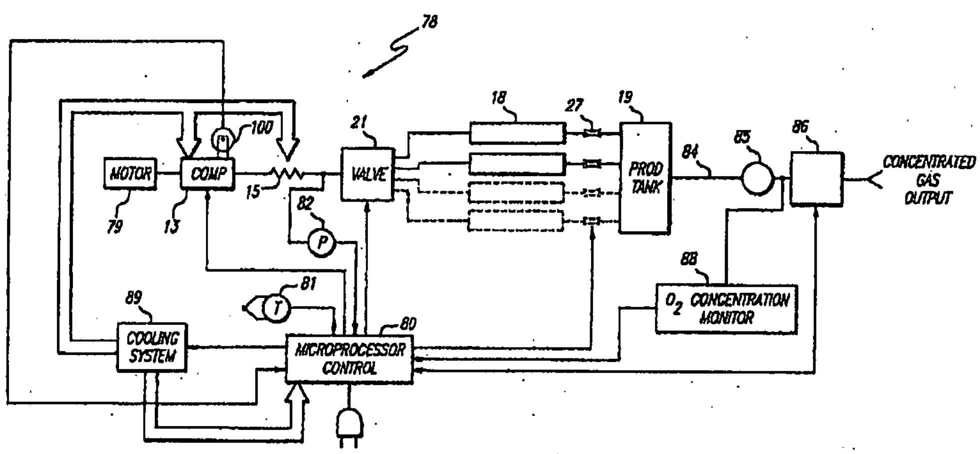
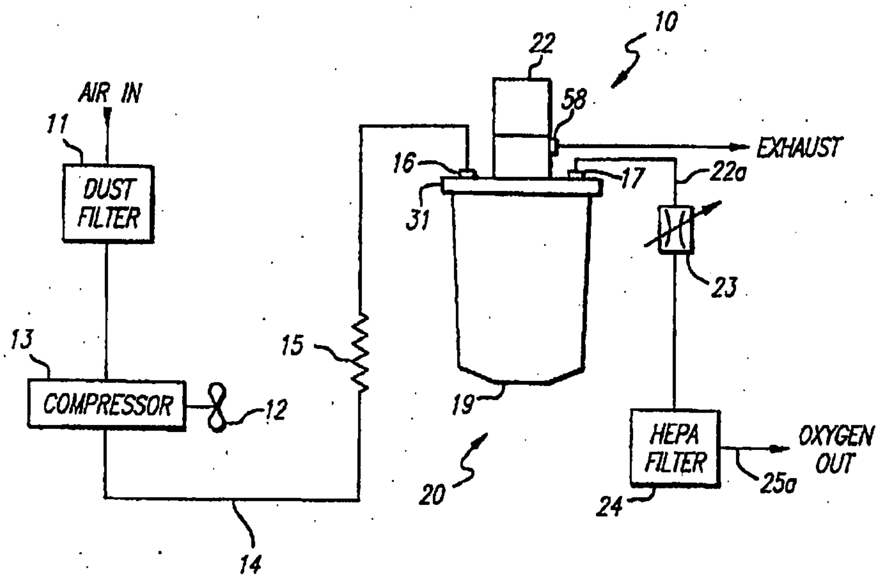


FIG. 1
PRIOR ART



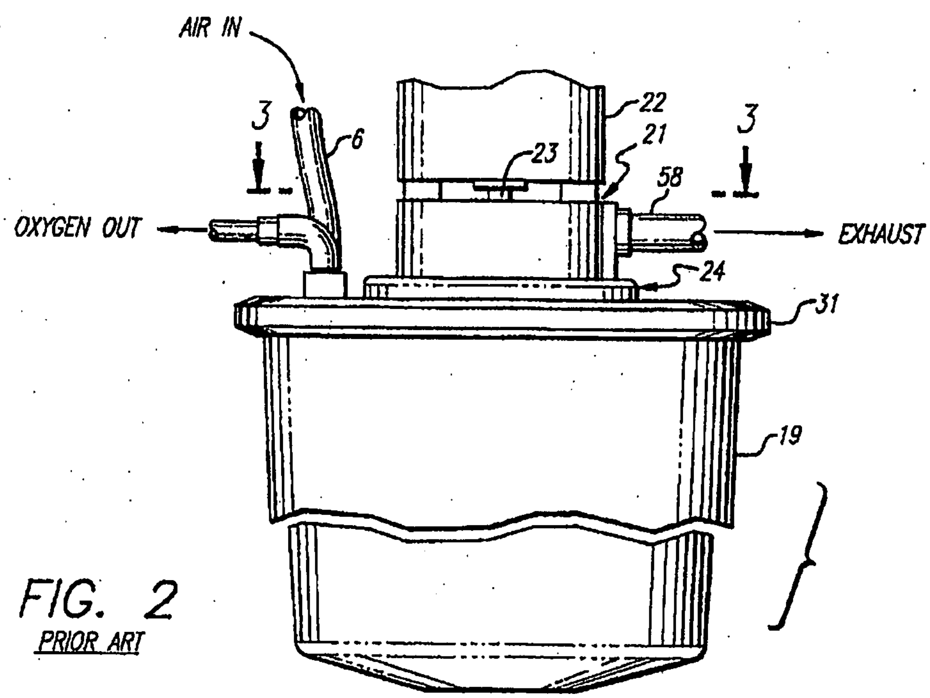


FIG. 2
PRIOR ART

FIG. 3

PRIOR ART

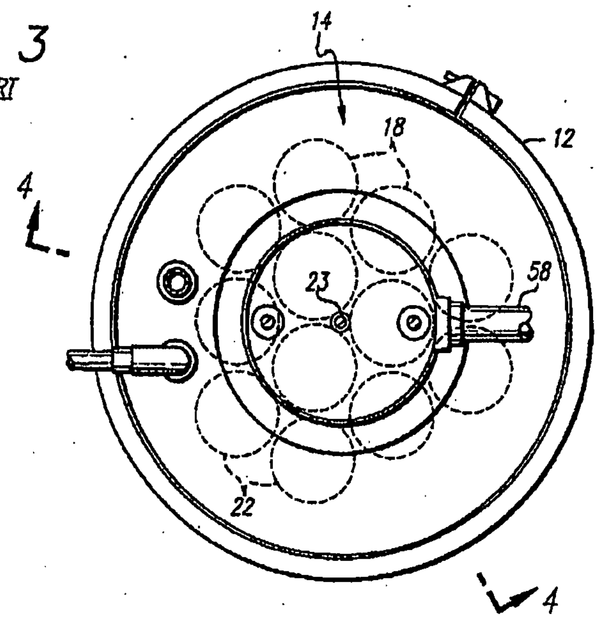


FIG. 13

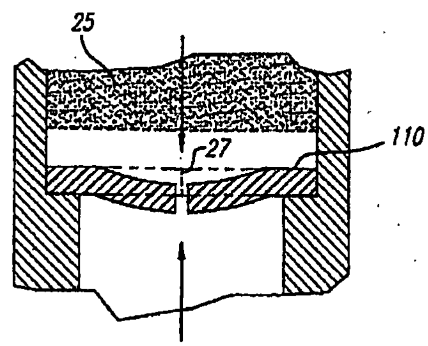
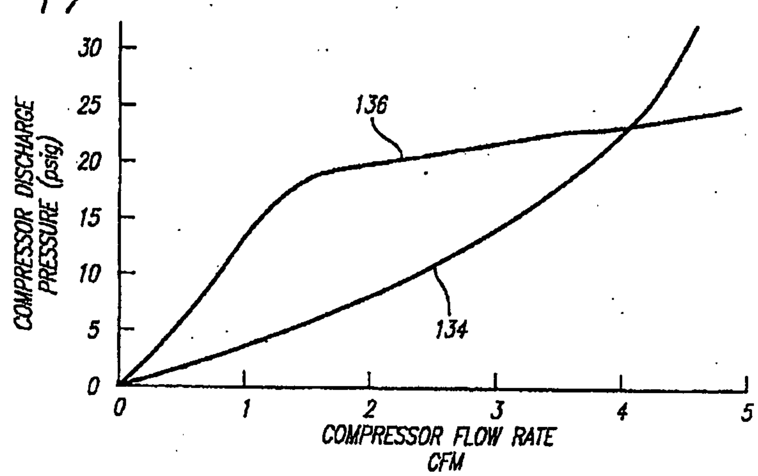


FIG. 17



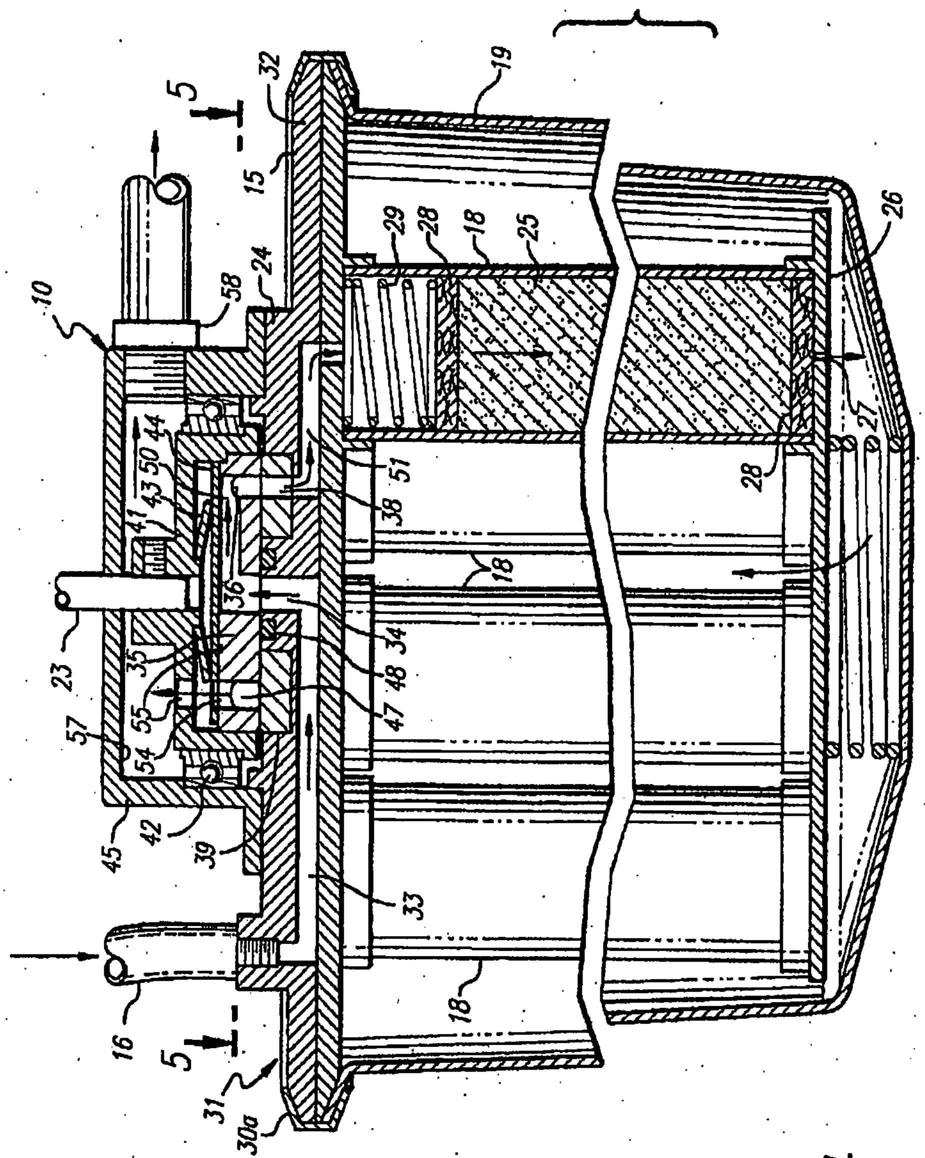


FIG. 4
PRIOR ART

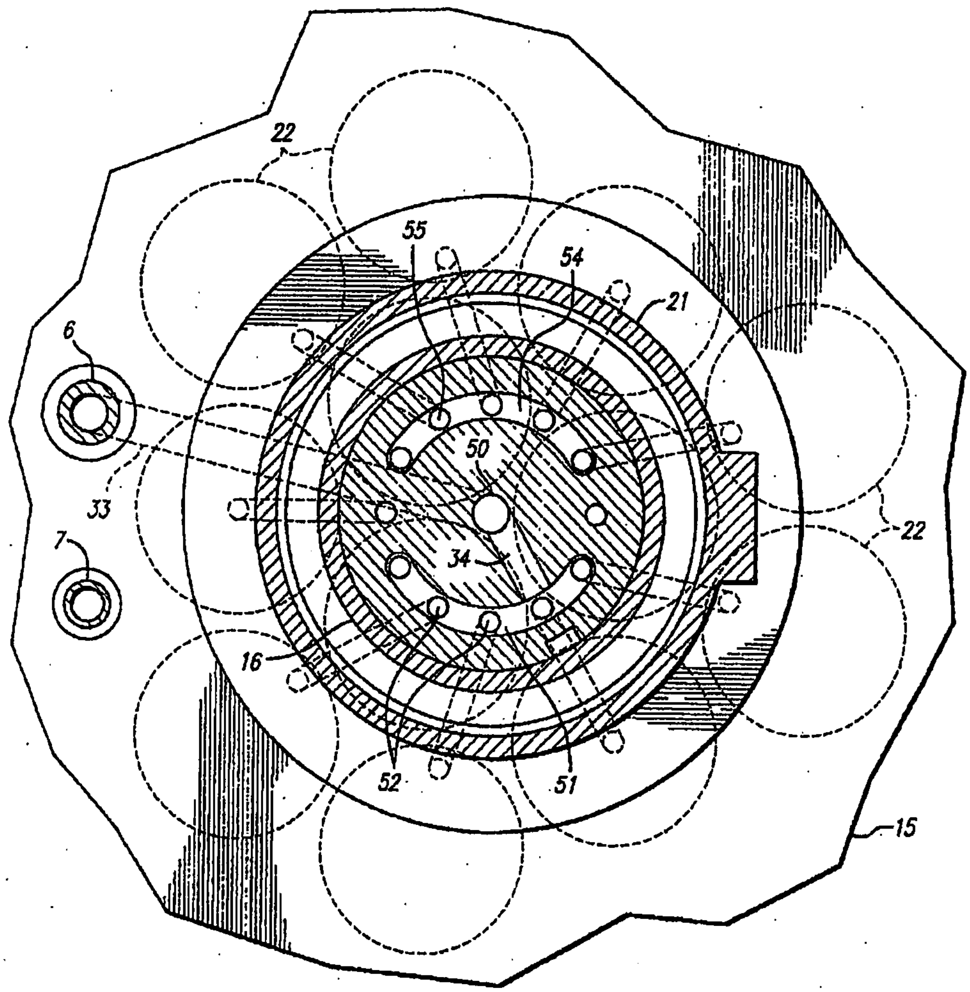


FIG. 5
PRIOR ART

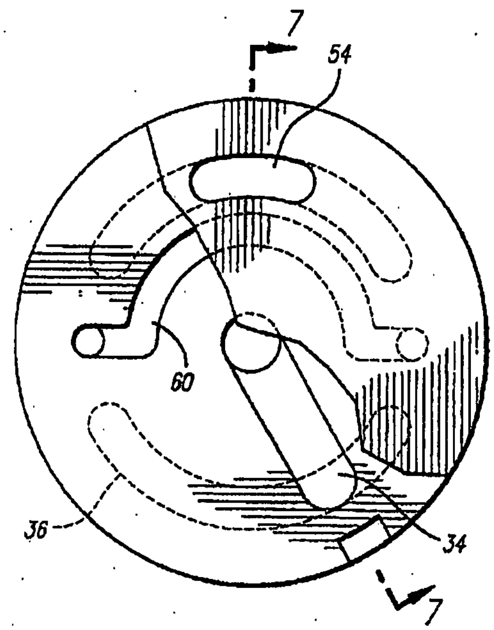


FIG. 6
PRIOR ART

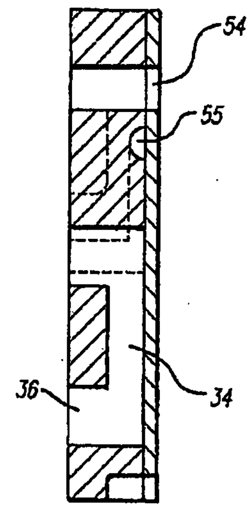


FIG. 7
PRIOR ART

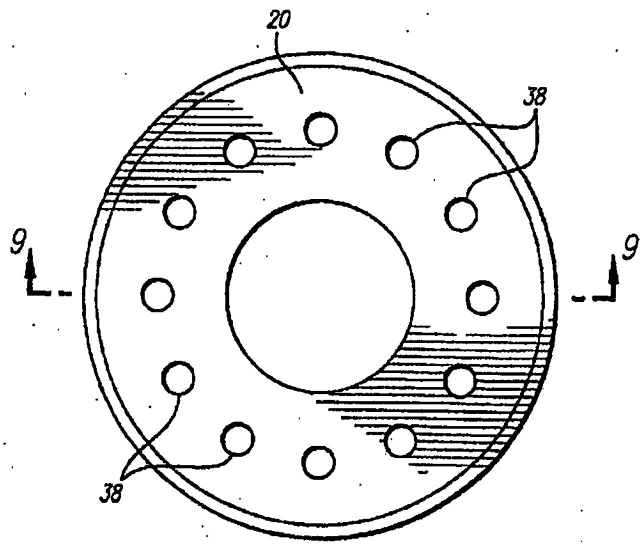


FIG. 8
PRIOR ART

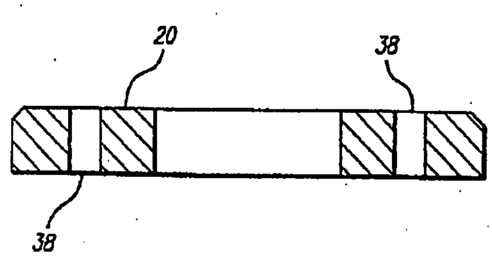
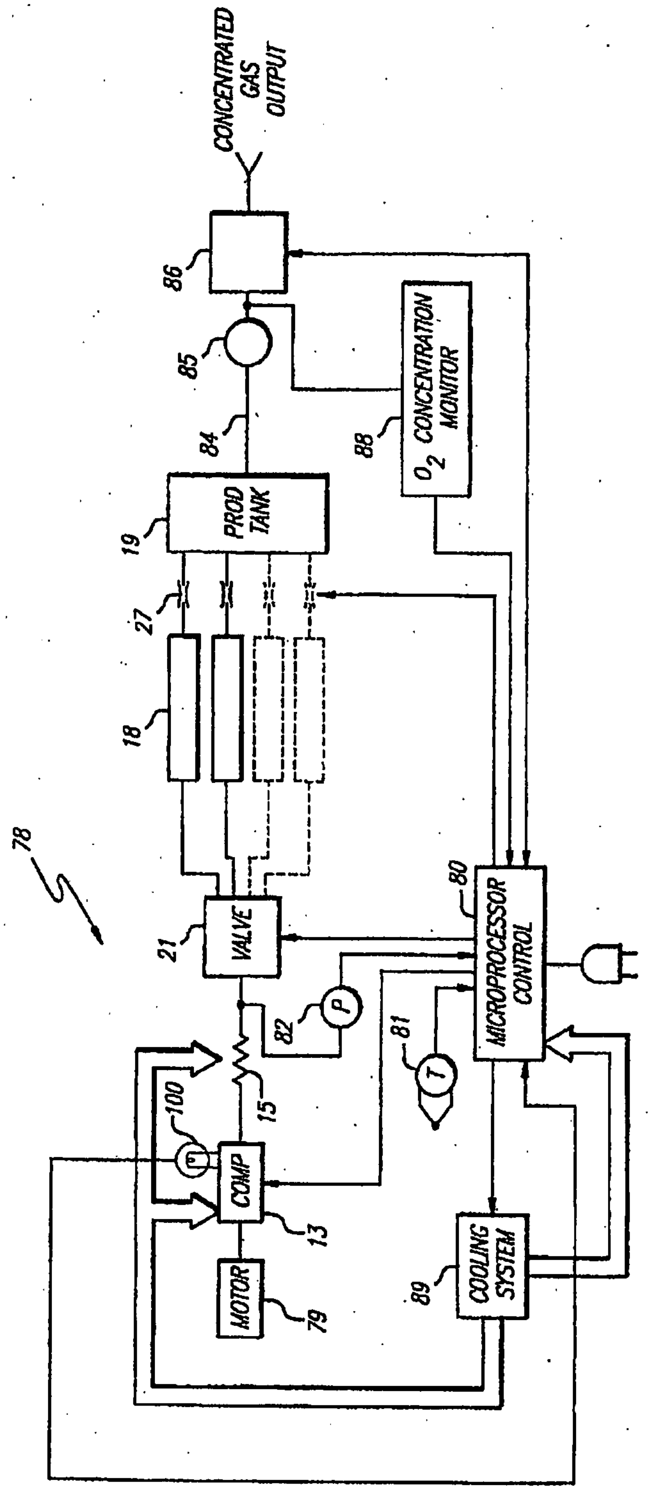


FIG. 9
PRIOR ART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86
85
84
PROD TANK
19
27
18
O_2 CONCENTRATION MONITOR
88
MICROPROCESSOR CONTROL
80
VALVE
21
P
82
T
81
15
100
COMP
13
MOTOR
79
COOLING SYSTEM
89
78

FIG. 10

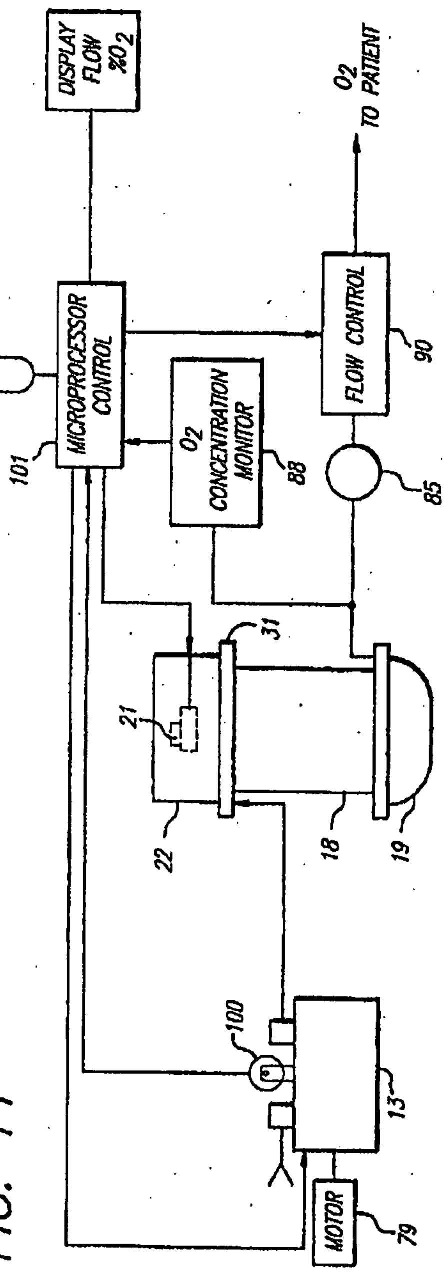
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FIG. 11

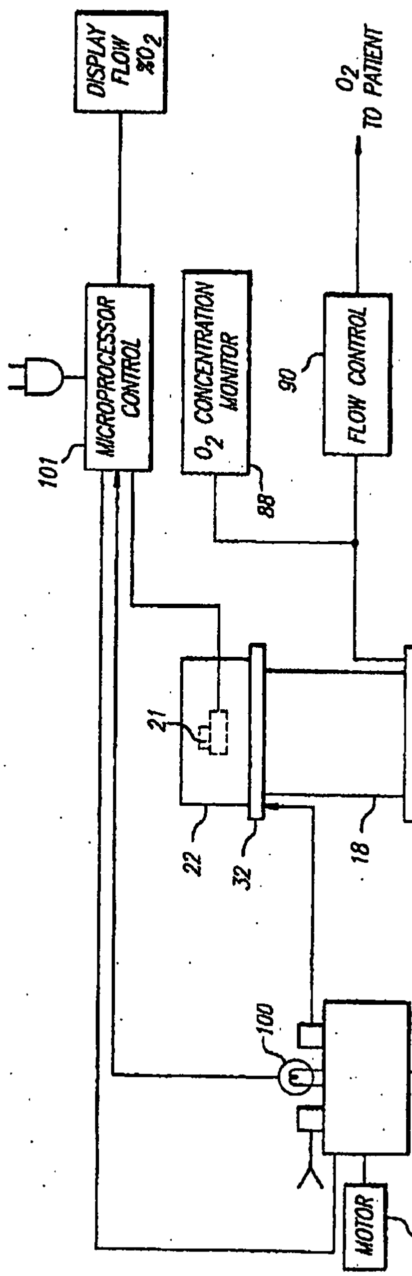
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FIG. 12

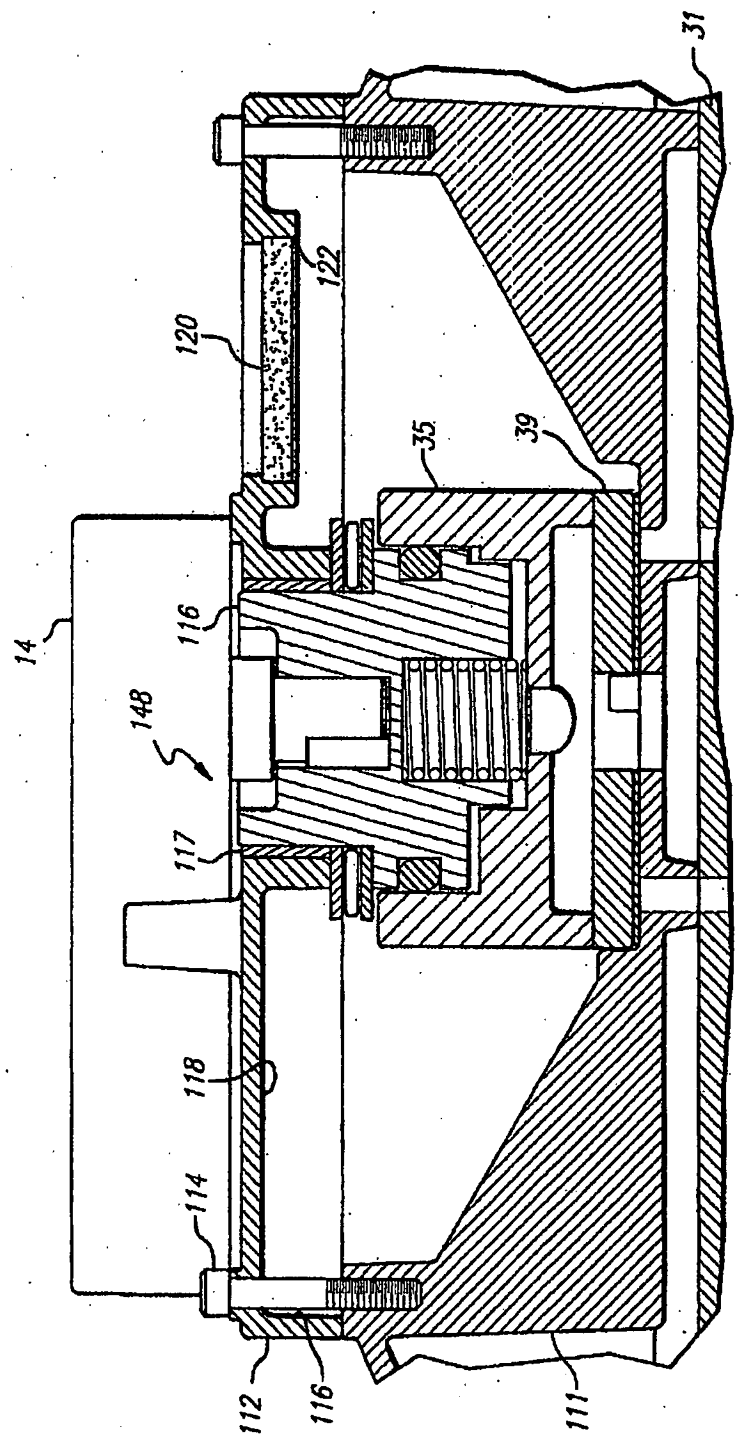


FIG. 14

FIG. 15

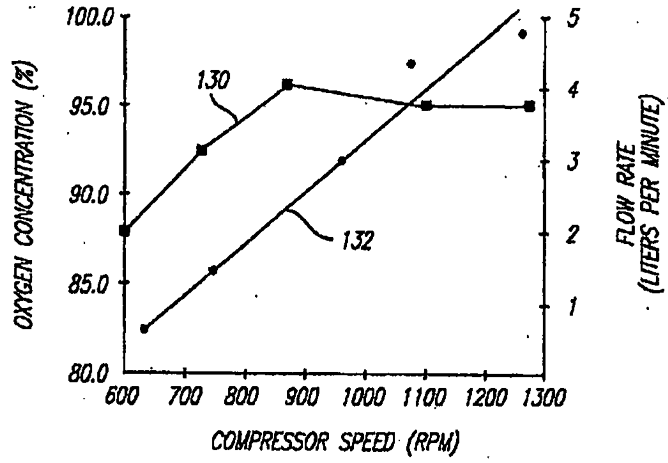
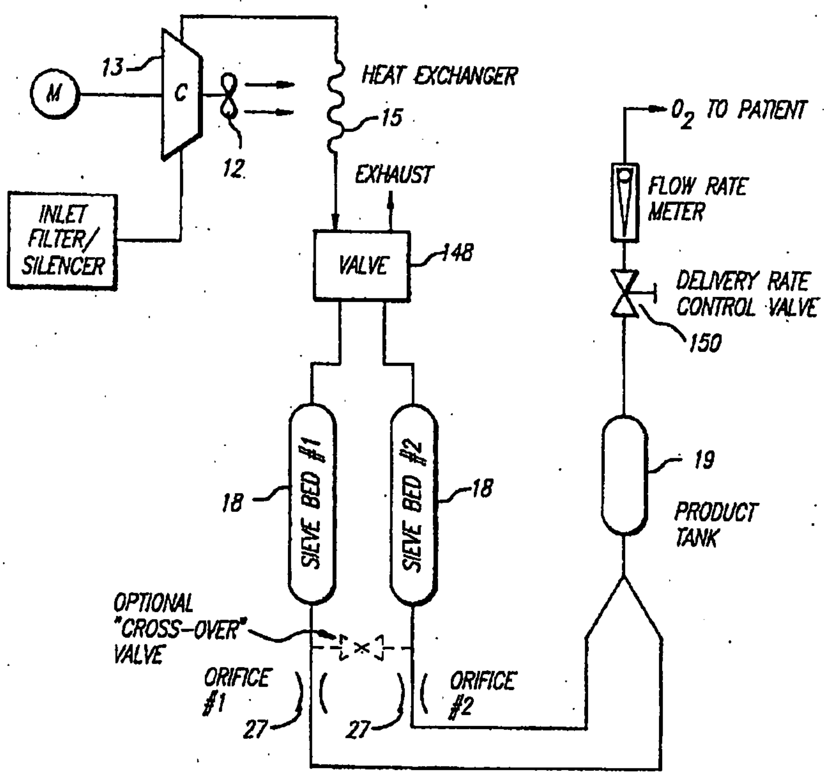


FIG. 16
PRIOR ART



FLUID FRACTIONATOR

This invention relates to apparatus for, and methods of, purifying a fluid by periodically/cyclically passing a particular component in the fluid through a molecular sieve and adsorbing other components in the fluid in the molecular sieve and subsequently periodically/cyclically desorbing such other components from the molecular sieve. The invention further relates to apparatus for, and methods of, passing oxygen in compressed air (and argon) for introduction to a patient and for adsorbing nitrogen and the other components in the compressed air and subsequently desorbing the adsorbed components to the atmosphere. The invention particularly relates to apparatus for providing any prescribed rate of flow of oxygen with minimal power consumption, minimal noise and optimal efficiency, reliability and life span.

Apparatus is in existence for receiving a fluid such as compressed air, for separating the oxygen from the air and for passing the oxygen for subsequent use as by a patient. The apparatus also includes material in a molecular sieve for adsorbing the nitrogen and the other components in the compressed air. When the oxygen separated from the compressed air has been passed, the adsorbed components in the compressed air are desorbed by release to the atmosphere. The apparatus can operate on a cyclic basis to continuously provide oxygen to a user such as a patient.

The oxygen can be used for many purposes. One of the primary uses of the oxygen is for providing oxygen to patients such as the elderly and those having asthma and emphysema. When the apparatus is used for such patients, the apparatus should have certain desirable characteristics. It should be able to provide the oxygen to each patient in a variable delivery rate and high concentration dependent upon the needs of the patient. It should be able to provide this oxygen in an efficient and reliable manner and with a minimal power consumption, particularly since many sick and elderly patients have only limited income and the electric power cost for operating the apparatus is substantial and significant. The apparatus should also operate quietly so as not to be offensive to the patient and to those around the patient. The apparatus should also have a long operative life without any breakdown. These parameters are particularly important because the apparatus operates continuously in the home environment without attendance.

The apparatus now in use fails to completely meet the criteria specified in the previous paragraph. The apparatus includes a compressor for introducing compressed air to columns which include a molecular sieve for passing oxygen and argon and for adsorbing nitrogen and other components in the compressed air and for subsequently desorbing the adsorbed components. In the apparatus now in use, the compressors are operated to deliver a constant maximum flow and concentration of oxygen regardless of the flow of oxygen prescribed for the user. The desired flow of oxygen to the patient is then adjusted by a throttling valve in the product bleed line to the user. As will be appreciated, this is inefficient if less than maximum flow capacity is needed, particularly since the compressor and the motor driving the compressor require a large amount of power.

The compressor generates a large amount of noise as it operates. This results partly from the operation of the motor and the compressor, particularly since the motor and the compressor is driven at a fixed high speed. It also results partly from the desorption to the atmosphere of the compressed fluid which is adsorbed in the columns. This release occurs almost instantaneously, thereby creating a noise/sound pulse every time that the compressed fluid in one of the columns is released to the atmosphere.

This invention provides a system which substantially overcomes the disadvantages in the apparatus of the prior art. In the system of this invention, the compressor operates at a speed, or with displacement characteristics, adjustable in accordance with the desired rate of oxygen flow to the user (e.g. the patient). The apparatus of this invention is also advantageous in that it releases the desorbed fluid to the atmosphere at a steady and controlled rate, thereby significantly reducing the noise generated from such release.

In one embodiment of the invention, a rotary valve at the inlets of a plurality of columns selects first columns on a cyclic basis to receive compressed air, adsorb nitrogen and other components in the compressed air and pass oxygen and argon to a user (e.g. patient). The valve also cyclically selects second columns to desorb the nitrogen and the other components in such columns and cyclically equalizes the pressure in third columns where the first columns change progressively to the second columns and vice versa.

A compressor having adjustable characteristics and regulated in an open or closed loop introduces the compressed air through the valve to the first columns to provide an adjustable air flow for obtaining a prescribed oxygen flow to the user. An indication may be provided when the compressor characteristics regulated for obtaining the prescribed oxygen flow rate are outside particular limits.

The valve may have a variable speed related to the compressor flow variations to regulate the air pressure in the columns in accordance with the air flow rate into the columns. A variable orifice in a valve in each column's outlet becomes constricted with decreases in the oxygen flow rate in each column, thereby further regulating the oxygen pressure in such column.

A porous plug in a closed chamber receiving the desorbed components releases such components slowly, without pulsatile noise, to the atmosphere. The equipment accordingly produces the desired oxygen flow rate with minimal power consumption, minimal noise and optimal efficiency, reliability and life span. The equipment may be designed to pass other components than oxygen.

In the drawings:

FIG. 1 is a schematic representation of a respiratory support system, including a fluid fractionator, of the prior art;

FIG. 2 is a side elevation of a portion of the support system shown in FIG. 1 and particularly shows a fluid fractionator included in such support system;

FIG. 3 is a sectional view of the fractionator as taken on a line 3—3 of FIG. 2;

FIG. 4 is a sectional view of the fluid fractionator as taken on a line 4—4 of FIG. 3;

FIG. 5 is an enlarged sectional view of the fluid fractionator as taken on a line 5—5 of FIG. 4;

FIG. 6 is a top plan view, partially cut away, of a rotor shoe included in the fluid fractionator;

FIG. 7 is a sectional view of the rotor shoe as taken on the line 7—7 of FIG. 6;

FIG. 8 is a top plan view of a port plate included in the fluid fractionator shown in FIGS. 1–7;

FIG. 9 is a sectional view taken on the line 9—9 of FIG. 8;

FIG. 10 is a schematic diagram of a closed loop system constituting one embodiment of an invention for use with the fluid fractionator shown in FIGS. 1–9 for regulating the variable characteristics of a compressor and other components to obtain a desired or prescribed rate of flow and concentration of a particular fluid component such as oxygen;

FIG. 11 is a schematic diagram of a closed loop system constituting another embodiment of the invention for use with the fluid fractionator shown in FIGS. 1–9 for regulating the variable characteristics of a compressor and other components to obtain a desired or prescribed rate of flow and concentration of a particular fluid component such as oxygen;

FIG. 12 is a schematic diagram of an open loop system constituting an additional embodiment of the invention for use with the fluid fractionator shown in FIGS. 1–9 for controlling the variable characteristics of a compressor and other components to obtain a desired or prescribed rate of flow and concentration of a particular fluid component such as oxygen;

FIG. 13 is a schematic sectional view of an orifice which may be used in the respiratory support system of this invention and which provides variable characteristics in accordance with the rate of flow of the particular fluid component such as oxygen;

FIG. 14 is an elevational view, partially in section, of apparatus which may be included in the invention to reduce the noise generated in the system when fluid adsorbed in the fluid fractionator is desorbed;

FIG. 15 provides curves showing (a) the relationship between different compressor speeds and the percentage of concentration of oxygen in the product flow from the fluid fractionator and (b) the relationship between different compressor speeds and the flow rate of oxygen to the product holding tank 19 in liters per minute; and

FIG. 16 is a schematic diagram showing a fluid fractionator which may be considered as a conventional fluid fractionator of the prior art and which may be modified to incorporate the features of this invention; and

FIG. 17 provides curves showing the relationship between compressor flow rates and compressor discharge pressures for a normal system of the prior art and for the system of this invention.

FIGS. 1–9 illustrate an oxygen-concentrating system, generally indicated at 10, which may be used in this invention and which is disclosed in the prior art in U.S. Pat. No. 5,268,021 issued to Charles C. Hill and Theodore B. Hill on Dec. 9, 1993, for an "Improved Fluid Fractionator" and assigned of record to the assignee of record of this application. The embodiment shown in FIGS. 1–9 of this application corresponds to the embodiment shown in FIGS. 1–9 of U.S. Pat. No. 5,268,021. In the prior art system shown in FIGS. 1–9, air is drawn from the atmosphere through an air inlet 6 into a dust filter 11 which removes dust from the air. The air is then compressed in a compressor 13 and the compressed air is introduced through a conduit 14 into a heat exchanger 15 which removes some of the heat produced during the compression. A fan 12 may be driven by the compressor 13 to remove heat from the heat exchanger 15.

The compressed air then passes into the inlet port 16 of a fluid fractionator, generally indicated at 20, which is included in this invention. The fluid fractionator 20 includes a product tank 19. Included in the tank 19 are a plurality of adsorber columns 18 (FIG. 3) the construction and operation of which will be described in detail subsequently. Oxygen (and argon) flow from the product tank 19 through an oxygen outlet 7 in FIG. 2.

Each column 18 separates the oxygen and argon in the compressed air from the other components in the compressed air and passes some of the oxygen and argon through an outlet port 17 (FIG. 1) to a dispensing conduit 22a. The oxygen and argon then pass through a valve 23 (which may be manually controlled) to a filter 24. The filter 24 may be a high efficiency particle arrestor (HEPA). The oxygen and argon then pass to a conduit 25a for use for one of a number of purposes. For example, the oxygen and argon may be introduced to a patient to increase the level of the oxygen in the blood of the patient.

As shown in FIG. 3, the holding tank 19 contains a cluster or array of the adsorber columns 18 within its housing. The columns are preferably disposed in a closely packed configuration. Preferably a plurality, more than two (2), of such columns are provided in a closely packed relationship. Twelve (12) columns are shown in FIG. 3 but it will be appreciated that any other number may be provided. The fluid fractionator 20 also includes a rotary valve distributor assembly generally indicated at 21 (FIG. 2), a gear motor 22 having a drive shaft 23 and a two-piece manifold 24 (FIG. 2).

Each of the columns 18 may be in the form of a cylinder. Each of the columns 18 contains a bed packed with adsorbent material 25 (FIG. 4) which is selective for a particular molecular species of fluid or contaminant. For example, zeolite 5A may constitute the adsorbent material 25 when oxygen is to be separated from air. The packed bed is held in place by a plate 26 at the bottom of the bed. A pressure-dropping means such as a small orifice 27 extends through the plate 26. Perforated plates 28 are disposed at the top and bottom of the bed of the adsorbent material 25, the bottom plate 28 being disposed between the plate 26 and the adsorbent material 25.

A spring 29 is disposed in the column 18 above the upper perforated plate 28 to maintain the plates 28 and the adsorbent material 25 in a packed relationship against the plate 26. When the adsorbent material 25 is zeolite 5A, the material adsorbs all of the components (including nitrogen) in the compressed air and passes argon and oxygen. The oxygen and argon are thus able to pass through the perforated plates 28, the adsorbent material 25 and the orifice 27 in the plate 26.

The rotary valve distributor assembly 21 is affixed to the holding tank 19 by a clamp band 30a (FIG. 4). The rotary distributor valve assembly 21 shown in FIG. 4 includes the two-piece manifold 31 which is ported and channeled. The manifold 31 has a top section 32 which is ported and channeled to receive a stream of fluid through the inlet port 16 and to channel the fluid through an air feed passage 33 into a centrally located inlet port 34 in a ported rotor shoe 35. Subsequently the fluid exiting the rotor shoe 35 is channeled radially from a circular array of inlet ports 38 in a port plate 39 toward each of the columns 18.

The ported rotor shoe 35 is included in a rotor 41. The rotor turns in a circumferential ball bearing unit 42. The rotor is driven by the gear motor 22 (FIG. 2) at a suitable speed such as approximately two (2) revolutions per minute. A conical disc or Belleville spring 43 urges a cover plate 44 and the rotor shoe 35 downwardly to secure the cover plate and the rotor shoe in position. The rotor 41 and its associated components are enclosed within a cover 45 which is suitably attached to the manifold 24.

The port plate 39 is made from a suitably hard material. The port plate 39 is recessed into the top of the manifold 31 and is sealed and immobilized by a slot and a key. The port plate 39 is coaxial with the exit port of an air feed channel 47 in the manifold 31. The port plate 39 has a number of holes equally spaced from one another in a circular pattern. This number is equal to the number of entry ports of channels to the individual columns 18. An air inlet rotary seal 48 is provided in the manifold 31 at a position interior to the port plate 39.

The rotor shoe 35 is made from a material known in the art to be suitable for use with the hardened material of the port plate 39. The rotor shoe 35 slides on the port plate 39. The Belleville spring 43 presses the rotor shoe 35 against the port plate 39 during such sliding movement. There are three (3) channels in the rotor shoe 35. One is a pressurizing channel or air feed channel 50 (FIGS. 4 and 5) which originates at the central fluid inlet port 34. The port 50 radiates into an arcuate slot 51 which provides a conduit simultaneously into several of the annularly positioned ports 52 (FIG. 5) in the port plate 39. As the rotor shoe 35 rotates, each new port 52 communicating with the forward end of the arcuate slot 51 is pressurized by the compressed fluid. At the same time, the port 52 at the rear end of the slot 51 is depressurized.

In a second channel in the rotor shoe 35, an arcuate slot 54 (FIGS. 5 and 6) receives the adsorbed fluid components in the columns 18 which communicate with the exhaust ports. As previously described, when compressed air is the fluid and is introduced to the columns 18, the desorbed fluid components include all of the gases in air except oxygen and argon. The desorbed components in the columns 18 are vented upwardly from the arcuate slot 54 through an exhaust port 55 (FIGS. 4 and 6) in the rotor shoe cover plate 44 into a rotor void space. The desorbed fluid then passes into the atmosphere through an exhaust port 58.

The third channel in the rotor shoe 35 is a cross-port channel 60 (FIG. 6). The channel 60 serves as a conduit between two (2) of the columns 18, these two (2) columns being in transition between the pressurizing and desorbing phases of a cycle. Its function is to apply equalizing pressures in columns transitioning between the adsorbing pressure in each cycle. The equalizing pressure provides for a pressure drop in fluid in each column before such column enters the desorption phase in each cycle. This prevents a very rapid decompression in each column and thus prevents an excessively high flow of the desorbed fluid initially from the column. This enhances the concentration of the particular component such as oxygen and argon in each column.

The apparatus described above is disclosed and claimed in U.S. Pat. No. 5,268,021 issued on Dec. 7, 1993, to Charles C. Hill and Theodore B. Hill for a "Fluid Fractionator" and assigned of record to the assignee of record of this application. It has several important advantages over the prior art. It provides a smoother operation than the prior art because several of the columns 18 are receiving the fluid under pressure at any instant and several of the other columns 18 are exhausting the desorbed fluid to the atmosphere at that instant. Thus, any transition of a column from an adsorbing operation to a desorbing operation at any instant will not produce as great a transitory pulse in operation as in the prior art since several other columns will be adsorbing and several other columns will be desorbing at that instant. Furthermore, the equalization of the pressure in the columns 18 in transition will also tend to reduce transitory pulses. These factors tend to enhance the efficiency in the operation of the apparatus and to reduce the noise in the operation of the apparatus. The reduction in the noise results from the equalization in pressure provided by the channel 60 and the relatively large number of columns.

In spite of the advantages discussed in the previous paragraph, there is room for improvement in the fluid fractionator 20 and in the system 10 including such fluid fractionator. In that system, the positive displacement compressor 13 operates at a constant maximum speed regardless of the flow rate and concentration of the oxygen that the patient desires or needs. The compressor 13 and the motor driving the compressor consume a large amount of power when they operate at a maximum speed. For example, the consumption of a home size oxygen concentrator is on the order of approximately four thousand (4000) kilowatt-hours per year. This amounts to a cost in electricity of several hundred dollars per year. This is a significant amount of money to most families and particularly to families of elderly or retired patients or to patients who are unable to work because of such ailments as asthma or emphysema. The continuous operation of the compressor 13 at a maximum power is also disadvantageous because it limits the operative life of the compressor and the motor driving the compressor.

Home oxygen concentrators generally have a capacity of providing oxygen in a range to approximately six liters per minute (6 LPM) of oxygen flow to the patient. The flow rate of oxygen required by an individual patient is prescribed by the patient's physician. The most common prescription rate is two liters per minute (2 LPM). The prescription is ordinarily for continuous administration twenty four hours (24 hr.) per day year-in and year-out. As the disease of some patients progresses to later stages, the oxygen flow rates prescribed for some patients may be increased. When the flow rate prescribed is less than the maximum rate, the reduced rate is obtained in the prior art by throttling the oxygen flowing to the user (e.g. the patient).

It will be appreciated that not all of the oxygen in the product tank 19 flows to the patient even when the oxygen flows to the patient at a rate of approximately six (6) liters per minute. Even at this flow rate, a substantial portion of the oxygen and the argon in the product tank 19 flows to the columns 18 which are being desorbed. This flow of oxygen and argon facilitates the purging of the desorbed gases in such columns. In this way, the columns are ready to receive the compressed air in the next cycle of operation.

As will be appreciated, oxygen and argon flow through the columns 18 to the product tank. Oxygen constitutes approximately twenty one percent (21%) of air and argon constitutes approximately one percent (1%) of air. When oxygen and argon flow through the columns 18, oxygen comprises approximately ninety four percent (94%) of the product in the oxygen tank. This increased concentration of argon (approximately six percent (6%)) in the product tank 19 has no harmful effect on the patient since argon is a noble, inert gas.

This invention provides a system for adjusting the flow characteristics of the compressor 13 in accordance with the product flow rate desired or prescribed. For example, when the compressor 13 has a variable speed, the speed of the compressor may be varied in accordance with the flow rate desired or prescribed. A variable speed compressor drive may take different forms including the following:

1. An alternating current (AC) induction motor with a variable frequency/variable voltage supply. This may be the preferred embodiment.

2. A direct current motor (brushless preferred).

3. A pole-changing AC induction motor for two (2) or three (3) operating speeds.

4. A fixed speed AC motor with a continuously variable mechanical transmission.

All of the above are considered to be within the scope of the invention. A variable speed motor 79 for the compressor 13 is shown in FIG. 10.

A variable displacement compressor may also be considered to be within the scope of the invention. Such a compressor may include the following:

1. A rotary vane compressor with a variable displacement in an adjustment in the rotor eccentricity.

2. A variable angle swash plate drive for an axial piston compressor.

3. A piston compressor having a crank shaft drive with a variable throw.

FIG. 10 schematically illustrates a system generally indicated at 78 and constituting an embodiment of the invention for regulating the desired flow rate of the oxygen to the patient. The system shown in FIG. 10 includes the heat exchanger 15, the compressor 13, the columns 18, the orifices 27 in the columns and the product tank 19, all shown in FIG. 1, and the rotary valve distributor assembly 21 shown in FIG. 2. The system shown in FIG. 10 also includes a control 80 which is pre-set to any desired value in accordance with the flow rate desired or prescribed for the particular component such as oxygen. This setting may be provided in accordance with the values indicated in a look-up table. The control 80 may preferably be a microprocessor control.

The microprocessor control 80 may be influenced by an indication from a temperature sensor 81 the output of which is introduced to the control. The microprocessor control 80 may be further influenced by an indication from a pressure sensor 82 the output of which is introduced to the control.

The particular component such as oxygen (and argon) flows from the product tank 19 through a line 84. A regulator 85 may be provided in the line 84 to reduce the pressure of the particular component (e.g. oxygen) flowing from the product tank 19 because there may be a significant change in the pressure of the particular component in the product tank over the flow range which may be provided from the compressor 13.

The particular component (e.g. oxygen) then flows through a flow control device 86 to the patient. The flow control device 86 may provide an additional regulation, such as a fine control, over the rate at which the particular component such as oxygen flows to the user such as the patient. The rate of flow of the particular component through the flow control device 86 is introduced to the microprocessor control 80. A concentration monitor 88 may determine the purity of the particular component such as oxygen through the line 84 at each instant and may indicate this determination to the microprocessor.

As will be seen, the microprocessor control 80 is regulated on a closed loop basis by the temperature of the concentrated fluid passing to the columns 18, the pressure of such concentrated fluid, the speed of the compressor 13, the output of the concentration monitor 88 and the rate of flow of the particular component through the flow control device 86. All of these inputs to the microprocessor control 80 cause the control to adjust the speed of the compressor 13 to produce a flow of the particular fluid component to the user at the desired or prescribed rate. The valve 21 is also adjusted to control the rate at which air is introduced into the columns 18.

The regulated output from the control 80 may also be introduced to a cooling system 89 which regulates the temperature of the compressor 13 and the heat exchanger 15. The output from the microprocessor control 80 may also be introduced to the flow control device 86 to regulate the operation of the flow control device in producing the flow of the particular fluid component to the user at the desired or prescribed value. The output of the control 80 may be additionally introduced to the orifices 27 to regulate the size of the orifices. This is desirable since the rate of flow of the particular fluid component can be regulated by regulating the size of the orifices. This will be described in detail subsequently.

The system shown in FIG. 10 and described above has certain important advantages including the following:

1. There is a significant reduction in power consumption because of the reduced speed for the compressor 13 at reduced flow rates of the particular fluid component such as oxygen. The reduction in the power consumption also results from the reduced speed of the motor 79 driving the compressor 13.

2. The amount of noise produced by the fluid fractionator 20 (or oxygen concentrator) is significantly reduced. This results in part from the reduced speed of the compressor 13 and the motor 79. It also results in part from the fact that the desorption of the adsorbed fluid components to the atmosphere is initiated from a reduced pressure of the desorbed fluid components in each column 18.

3. Because of the reduced compression of the fluid in the columns 18, the temperature rise in the compressed fluid is reduced. This provides for a reduction in the operation of the cooling system 89 and a resultant reduction in the power for operating the cooling system.

4. A power supply can be included which operates at all frequencies and voltages in all markets with substantially equal effectiveness in the different markets.

5. The life of the compressor 13 is significantly increased because the compressor is operated at a reduced speed.

6. There is reduced vibration in the system. This also contributes to a long life in the system.

7. The size and weight of the compressor 13 and the motor 79 can be reduced, particularly when the compressor is to be operated at relatively low speeds. Furthermore, if and when the compressor is to be operated at maximum speeds, it would probably be for only relatively short periods of time. This would allow the compressor 13 and the motor 79 to be operated above their rated speed without damaging the compressor 13 or the motor 79. This is another reason why the size and weight of the compressor 13 and the motor 79 can be considerably reduced in most instances.

8. The timing of the rotary valve distributor assembly 21 and the opening of the orifice 27 can be tailored for all flow rates to provide an optimal operation of the system.

9. There is a potential to compensate for a reduced compressor inlet density as a result of a high ambient temperature or a high altitude. This will be discussed in detail subsequently.

The timing of the rotary distributor valve assembly can be provided in various ways. One alternative is that a synchronous motor can be provided with a variable frequency drive as the motor 22 (not shown in FIG. 10 but shown in FIG. 11). Other alternatives involve the use of a stepper motor as the motor 22 or a DC gear motor to drive the rotary valve distributor assembly 21. Another alternative is to provide a pneumatic actuation with speed sensitive to compressor speed. The valve timing can be controlled by a microprocessor for motors responsive to a microprocessor control or by digital/analog circuits in the controller.

Regulating the speed of the rotary distributor valve assembly 21 in accordance with the variations in the speed of the compressor 13 may be desirable under certain circumstances. As the speed of the compressor 13 is decreased while maintaining the speed of the distributor valve assembly 21 constant, the pressure of the fluid in the columns 18 is decreased. This causes the pressure of the nitrogen and the other components adsorbed in the molecular sieves in the columns 18 to decrease.

In FIG. 15, progressive speeds of the compressor are shown on the horizontal axis and progressive concentrations of oxygen in the fluid in the product holding tank 19 are shown on the vertical axis. As will be seen at 130 in FIG. 15, the concentration of the oxygen in the mixture in the product holding tank 19 remains substantially constant at a value of approximately ninety four percent (94%) for compressor speeds between approximately nine hundred revolutions per minute (900 rpm) and thirteen hundred revolutions per minute (1300 rpm). At compressor speeds progressively below approximately nine hundred revolutions per minute (900 rpm), the concentration of the oxygen in the mixture in the product holding tank 19 becomes progressively reduced. At compressor speeds of approximately six hundred revolutions per minute (600 rpm), the concentration of the oxygen in the mixture in the holding tank 19 is approximately eighty eight percent (88%).

It is desirable to maintain the concentration of the oxygen in the mixture in the product holding tank 19 at a value of at least ninety percent (90%) regardless of the speed of the compressor 13. This can be accomplished by decreasing the rotary speed of the distributor valve assembly 21 as the speed of the compressor 13 is decreased. By decreasing the rotary speed of the distributor valve assembly 21, each column 18 is provided with an increased time to receive air under pressure from the compressor 13. As a result, the pressure of the air in each column 18 increases and the pressure of the oxygen and argon in the product holding tank 19 correspondingly increases. This inhibits nitrogen in the columns 18 from passing into the product holding tank 19. In this way, the concentration of the oxygen in the product holding tank 19 can be maintained at a value of at least ninety percent (90%) even as the flow rate of the oxygen and nitrogen into the product holding tank decreases. FIG. 15 also shows at 132 the flow rate of the oxygen at different compressor speeds. As will be seen, the flow rate of the oxygen to the patient in liters per minute increases substantially linearly with increased compressor speeds.

FIG. 17 illustrates at 134 the relationship between flow rates of the fluid from the compressor 13 and the compressor discharge pressure in psig for a normal system of the prior art. FIG. 17 also illustrates at 136 the relationship between flow rates of the fluid from the compressor 13 and the compressor discharge pressure for a system which includes certain features of applicants' system. These include the rotary valve distributor assembly 21 operating at variable speeds and the valve providing a variable orifice as shown in FIG. 13. As shown in FIG. 17, operation of the system of this invention is advantageous over the systems of the prior art because it provides significantly higher compressor discharge rates throughout most of the range of the compressor flow rates.

FIG. 11 illustrates a simplified system for controlling the rate of flow of a fluid such as oxygen to a user such as a patient. The system includes the compressor 13, the columns 18, the product tank 19, a microprocessor control 101 corresponding to the control 80 in FIG. 10, the oxygen concentration monitor 88, the rotary valve distributor assembly 21 and the motor 22 (not shown) for driving the valve distributor assembly 21. The compressor 13 may be a wobble piston compressor and the motor 22 may be a synchronous gear motor. A flow control 90 corresponding to the flow control 85 may be included for controlling the rate of flow of the particular fluid component such as oxygen to a user such as a patient. The flow control 90 may be a standard flow control or it may be electronic. A regulator such as the regulator 85 may be included in the line between the product tank 19 and the flow control device 90.

The system shown in FIG. 11 senses the rate of oxygen flow in the monitor 88 and introduces this sensed rate to the microprocessor control 101. The microprocessor control 101 then varies the operation of the compressor 13, the motor 22 and the flow control 90 to regulate the rate of flow of the oxygen to the patient at the desired or prescribed rate. The system shown in FIG. 11 operates on a closed loop basis to provide the desired regulation of the oxygen flow. As will be seen, the system shown in FIG. 11 does not include such controls as the temperature sensor 81, the pressure sensor 82 and the cooling system 89.

FIG. 12 illustrates an open loop system for regulating the rate of oxygen flow to the patient. As will be seen, the system shown in FIG. 12 is similar to the system shown in FIG. 11 except that it eliminates the lines from the microprocessor control 101 to the oxygen monitor 88, the compressor 13 and the motor 79. In this system, the microprocessor control 101 indicates a desired flow of oxygen to the patient. The compressor 13, the motor 79 and the flow control 90 are then set to desired values for obtaining this desired oxygen flow. The oxygen monitor 88 is then read during the operation of the system. On the basis of this reading, adjustments are made manually in the compressor 13, the motor 79 and the flow control 90 to obtain the desired or prescribed rate of oxygen flow to the patient. These adjustments may be made on the basis of a look-up table establishing individual values for these parameters under different sets of conditions.

The systems shown in FIGS. 10, 11 and 12 may include an indicator 100 for indicating when certain components such as the compressor 13 have to be replaced. As will be appreciated, the operation of the systems shown in FIGS. 10, 11 and 12 may become degraded with time as a result of a number of factors. These include dirty filters, compressor wear, motor wear and pneumatic leaks. The systems shown in FIGS. 10, 11 and 12 compensate for these system degradations by increasing the compressor flow to maintain the purity/concentration of the particular fluid component such as oxygen at the desired or prescribed flow rate. The indicator 100 indicates when the speed or other variable characteristics of the compressor 13 as sensed by the indicator 100 exceed particular limits for the rate of fluid flow desired or prescribed.

As shown in FIG. 13, the orifice 27 in each column 18 may be formed from a molded elastomeric material 110 such as rubber. As the pressure of the particular fluid component such as oxygen flowing through the orifice 27 decreases, the elastomeric material 110 defining the orifice 27 has a decreased flexure. This decreases the size of the orifice 27 in each column 18. In this way, the orifice 27 in each column 18 becomes closed with decreases in the pressure of the fluid such as oxygen. This provides an increase in the pressure of the fluid in the column 18. This is desirable at low rates of oxygen flow to the patient to maintain the oxygen concentration in the oxygen holding tank at a value of at least ninety percent (90%). By decreasing the size of the orifice 27 at these low flow rates, the pressure of the fluid in the columns 18 is increased. The concentration of the oxygen holding tank 19 is accordingly maintained at a value of at least ninety percent (90%).

In the embodiment shown in FIGS. 1–9, the desorbed fluid components are passed through the chamber 57 and the exhaust port 58 to the atmosphere. This causes a relatively loud noise to be produced every time that the desorbed fluid in one of the columns 18 is released to the chamber 57 and from the chamber to the exhaust port 58. FIG. 14 shows an arrangement for significantly reducing the noise produced every time that the adsorbed fluid in one of the columns 18 is desorbed.

The embodiment shown in FIG. 14 includes the port plate 39, the rotor shoe 35, and the manifold 31. The manifold 31 has a cover 111. A bearing carrier 112 is suitably attached to the manifold cover 111 as by screws 114. A rotor shaft 116 is disposed within an opening in the bearing carrier 112 and a bearing 117 is disposed between the bearing carrier 112 and the bearing shaft 116.

The bearing carrier 112 and the manifold cover 111 define a chamber 118 which is enlarged relative to the embodiment shown in FIGS. 1–7. The desorbed fluid from each column 18 passes into the chamber 118 and is retained in the enclosure since an exhaust port corresponding to the exhaust port 58 is not provided in the embodiment shown in FIG. 14. Porous plugs 120 are disposed in apertures 122 in the bearing carrier 112. Since the desorbed fluid in the chamber 118 is under some pressure, it is slowly released to the atmosphere through the porous plugs 120.

The decrease in noise in the operation of the system shown in FIG. 14 results from several factors. One factor is the increased volume of the chamber 118 relative to the corresponding chamber 57 shown in FIG. 4. A second factor is that the desorbed fluid in the chamber 118 is retained within the chamber and is released slowly to the atmosphere through the plugs 120. This is facilitated by the fact that the desorbed fluid in the chamber 118 is not released to the atmosphere through a port such as the port 58 in FIG. 4.

It will be appreciated that all of the features of this invention can be provided in a conventional two (2) column system of the prior art. Such a conventional two (2) column system is shown in FIG. 16. It includes the compressor 13, a distributor valve 148, a pair of the columns 18, the orifices 27, the product holding tank 19 and a control valve 150 for controlling the rate at which the oxygen or argon flow to the user (e.g. the patient).

It will also be appreciated that the systems constituting this invention can be used to provide other fluids than oxygen and to provide such fluids to users other than a patient without departing from the scope of the invention. For example, the system of this invention can be used to provide fluids for industrial purposes. One use illustratively is to provide nitrogen to industrial organizations which provide an inert atmosphere. Another illustrative use is oxygen for welding.

The apparatus constituting this invention has several important advantages. It provides for a controlled and adjustable speed of the compressor 13 to adjust the rate of flow of a fluid such as oxygen to a user (e.g. a patient). The adjustable control of the compressor speed can be either on a closed loop basis or an open loop basis. Furthermore, an indication can be provided as to when the compressor speed has been adjusted out of a normal range of values to obtain a prescribed flow of the fluid, such as oxygen to the user (e.g. patient), at a required purity.

The apparatus of this invention also has other advantages. As the speed of the compressor becomes reduced below a particular value, the concentration of the oxygen tends to become reduced below a desirable value. The apparatus of this invention provides for an adjustment in the rotary speed of the distributor valve assembly 21 in the fluid fractionator 20 to increase the pressure of the fluid in the columns 18 in the fluid fractionator 20. The adjustable orifices 27 at the outlet of the fluid fractionator 20 also tend to close with decreases in the pressure of the fluid in the fluid fractionator 20, thereby maintaining the pressure of the fluid in the columns 18 in the fluid fractionator.

As the speed of the compressor 13 is decreased, the noise generated by the compressor decreases. The noise in the fluid fractionator 20 is also significantly decreased by providing the porous plugs 120 in the bearing carrier 112 and by increasing the size of the chamber 118. In this way, the desorbed components in the chamber 118 provide a minimal noise when they enter the chamber and when they leak slowly into the atmosphere from the chamber.

Although this invention has been disclosed and illustrated with reference to particular embodiments, the principles involved are susceptible for use in numerous other embodiments which will be apparent to persons skilled in the art. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.

We claim:

1. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to provide initially for the introduction of the compressed fluid into such columns and to adsorb the second component of the compressed fluid in such columns and to pass the first component in such columns and constructed to desorb the second component in such columns,

first means for compressing the fluid before the introduction of the compressed fluid into the columns in the plurality,

second means for providing for the introduction of the compressed fluid into at least a first one of the columns in the plurality on a cyclic basis to obtain the adsorption of the second component in such at least first one of the columns and the passage of the first component from such at least first one of the columns and for providing for the passage of the compressed fluid from at least a second one of the columns in the plurality on the cyclic basis to obtain the desorption of the second component from such at least second one of the columns,

third means for collecting the first component passing through the at least first one of the columns in the plurality on the cyclic basis, and

fourth means having variable characteristics for providing for the compression of the fluid by the first means at a variable rate of flow dependent upon the prescribed rate of the first component through the at least first one of the columns in the plurality.

2. In a combination as set forth in claim 1,

the variable characteristics of the fourth means constituting variations in speed,

the fourth means being operatively coupled to the first means for varying the compression provided on the fluid by the first means in accordance with the variations in the speed of the fourth means,

the fourth means being operable at the variable speed to obtain the prescribed rate of flow of the first component through the at least first one of the columns,

the fourth means being operative to obtain the operation of the first means at the variable speed dependent upon the prescribed rate of flow of the first component through the at least first one of the columns in the plurality.

3. In a combination as set forth in claim 1,

the first means including a rotatable member with characteristics variable to vary the rate of flow of the first component through the at least first one of the columns in the plurality, and

the fourth means being operatively coupled to the first means for obtaining a variation in the compression of the fluid by the first means to obtain the prescribed rate of flow of the first component through the at least first one of the columns.

4. In a combination as set forth in claim 1,

means for controlling the desorption of the second component components in the at least second one of the columns in the plurality.

5. In a combination as set forth in claim 1,

means for decreasing the compression of the fluid in the at least first one of the columns in the plurality in accordance with decreases in the rate of flow of the first component through such at least first one of the columns.

6. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns wherein at least a first one of such columns adsorbs the second component in the compressed fluid and passes the first component in the compressed fluid and at least a second one of which desorbs the second component previously adsorbed in such column,

valve means for providing for the selection of the at least first one of the columns in the plurality and the at least second one of the columns in the plurality on a cyclic basis,

compressor means for receiving and compressing the fluid and for introducing the compressed fluid to the at least first one of the columns in the plurality in accordance with the operation of the valve means,

first means for adjusting the operation of the compressor means to the prescribed magnitude of flow rate for the passage of the first component through the at least first one of the columns in the plurality, and

second means for collecting the first component passing through the at least first one of the columns in the plurality.

7. In a combination as set forth in claim 6,

third means for providing a controlled adjustment by the first means in the compression provided by the compressor means in the fluid to adjust the rate of flow of the first component through the at least first one of the columns in the plurality.

8. In a combination as set forth in claim 6,

the compressor means having variable characteristics to adjust the compression provided by the compressor means, and the first means including third means for adjusting the variable characteristics of the compressor means in accordance with the prescribed rate of flow of the first component through at least the first one of the columns in the plurality.

9. In a combination as set forth in claim 8,

a product tank for holding the first component after the passage of the first component through the at least first one of the columns in the plurality, and

means responsive to changes in the concentration of the first component in the at least first one of the columns in the plurality for adjusting the characteristics of the valve means to maintain the concentration of the first component in the product tank at a particular value.

10. In a combination as set forth in claim 6,

at least a third one of the columns in the plurality providing for an equalization of the pressure in the at least first one of the columns and the at least second of the columns when such columns are being transitioned on the cyclic basis between the at least first one of the columns in the plurality and the at least second one of the columns in the plurality.

11. In a combination as set forth in claim 6, the valve means being rotary.

12. In a combination as set forth in claim 6,

the valve means communicating on the cyclic basis with the at least first one of the columns in the plurality and the at least second one of the columns in the plurality at a rate dependent upon the rate of flow of the first component through the at least first one of the columns in the plurality to adjust the compression of the fluid in the at least first one of the columns in the plurality.

13. In a combination as set forth in claim 6,

means for minimizing any noise in the at least second one of the columns in the plurality during the desorption of the second component in the at least second one of the columns in the plurality.

14. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to provide initially for the introduction of compressed fluid into such columns and to adsorb the second component in the compressed fluid and to pass the first component in the compressed fluid through such columns and constructed to desorb the second component in such columns after the passage of the first component through such columns,

compressor means having variable characteristics for compressing the fluid for introduction to the columns in the plurality,

control means for varying the characteristics of the compressor means in accordance with the prescribed rate of flow of the first component through the columns in the plurality, and

rotary valve means for selecting at least a first one of the columns in the plurality on a cyclic basis to provide for the introduction of the compressed fluid into such at least first one of the columns and for selecting at least a second one of the columns in the plurality on the cyclic basis to provide for the desorption of the second component in such at least second one of the columns.

15. In a combination as set forth in claim 14,

means for varying the rotary speed of the rotary valve means in accordance with the prescribed rate of flow of the first component through the at least first one of the columns in the plurality.

16. In a combination as set forth in claim 15,

each individual one of the columns in the plurality having an orifice for passing the first component from such individual one of the columns, the orifice in each individual one of the columns being adjustable in accordance with the rate of flow of the first component through such individual one of the columns.

17. In a combination as set forth in claim 14,

each individual one of the columns in the plurality having an orifice for passing the first component from such individual one of the columns, the orifice in each individual one of the columns being adjustable in accordance with the rate of flow of the first component through such individual one of the columns.

18. In a combination as set forth in claim 14,

the second component in each individual one of the columns being desorbed to the atmosphere at a variable rate, and means for varying the rate at which the second component in each individual one of the columns is desorbed to the atmosphere.

19. In a combination as set forth in claim 14,

means for boosting the pressure of the fluid in the at least first one of the columns in the plurality upon an occurrence of decreases in the rate of flow from the prescribed rate of the first component through the at least first one of the columns in the plurality.

20. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to receive the compressed fluid and to adsorb the second component in the compressed fluid in such columns and to pass the first component in the compressed fluid in such columns and constructed to desorb the second component in such columns after the passage of the first component through such columns,

valve means for selecting at least a first one of the columns in the plurality on a cyclic basis to provide for the introduction of the compressed fluid into such at least first one of the columns on the cyclic basis and the adsorption of the second component in the compressed fluid in the at least first one of the components and the passage of the first component through such at least first one of the columns and for selecting at least a second one of the columns in the plurality on the cyclic basis to provide for the desorption of the second component from such at least second one of the columns,

first means for providing a compression of the fluid passing to the at least first one of the columns in the plurality in accordance with the operation of the valve means, and

second means for varying the rate of flow of the first component through the at least first one of the columns independently of the operation of the valve means and in accordance with variations in the prescribed rate of flow of the first component through the at least first one of the columns in the plurality.

21. In a combination as set forth in claim 20,

means for varying the rate on the cyclic basis, independently of the operation of the first means, at which the at least first one of the columns in the plurality and the at least second one of the columns in the plurality are selected by the valve means.

22. In a combination as set forth in claim 20,

the valve means constituting first valve means,

a plurality of second valve means each disposed in an individual one of the columns in the plurality and each operative in response to variations from the prescribed rate of flow of the first component through the at least first one of the columns in the plurality to vary the pressure of the fluid in the at least first one of the columns in the plurality.

23. In a combination as set forth in claim 20,

third means defining a chamber for receiving the second component in the at least second one of the columns in the plurality, and

fourth means included in the third means for providing a controlled passage of the second component from the chamber.

24. In a combination as set forth in claim 23,

the third means including a cover,

the fourth means including a porous plug disposed in the cover for providing for a controlled flow to the atmosphere of the second component in at least the second one of the columns in the plurality in the chamber.

25. In a combination as set forth in claim 23,

means for varying the rate on the cyclic basis, independently of the operation of the first means, at which the at least first one of the columns in the plurality and the at least second one of the columns in the plurality are selected by the valve means.

26. In a combination as set forth in claim 25,

the valve means constituting first valve means,

a plurality of second valve means each individual one of which is disposed in an individual one of the columns in the plurality and each individual one of which is operative in response to the variations from the prescribed rate of flow of the first component through the at least first one of the columns in the plurality to vary the pressure of the fluid in the at least first one of the columns in the plurality.

27. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to receive the compressed fluid and to adsorb the second component in the compressed fluid in such columns and to pass the first component in the compressed fluid through such columns and constructed to desorb the second component in such columns after the passage of the first component through such columns,

valve means for selecting at least a first one of the columns in the plurality on a cyclic basis to provide for the introduction of the compressed fluid into such at least first one of the columns on the cyclic basis and for selecting at least a second one of the columns in the plurality on the cyclic basis to provide for the desorption of the second component in such second one of the columns,

first means for introducing the compressed fluid into the at least first one of the columns in the plurality,

second means defining a chamber for receiving the desorbed second component in the at least second one of the columns in the plurality, and

third means for providing a controlled release to the atmosphere of the second component in the chamber.

28. In a combination as set forth in claim 27,

the second means including a cover enclosing the valve means and the columns in the plurality, and

the third means including a porous plug communicating at one end with the chamber, and at an opposite end with the atmosphere to pass the second component in the chamber to the atmosphere.

29. In a combination as set forth in claim 28,

fourth means operative independently of the introduction of the compressed fluid by the first means into the at least first one of the columns in the plurality for varying the rate at which the valve means selects the at least first one of the columns in the plurality and the at least second one of the columns in the plurality on the cyclic basis.

30. In a combination as set forth in claim 27,

fourth means for varying the operation of the first means in introducing the compressed fluid into the at least first one of the columns in the plurality independently of the operation of the valve means.

31. In a combination as set forth in claim 27,

fourth means operative independently of the introduction of the compressed fluid by the first means into the at least first one of the columns in the plurality for varying the rate at which the valve means selects the at least first one of the columns in the plurality on the cyclic basis and the at least second one of the columns in the plurality on the cyclic basis.

32. In a combination as set forth in claim 27,

a plurality of valves, each individual one of the valves being disposed in an individual one of the columns in the plurality and each individual one of the valves having a variable orifice to pass the first component in the at least first one of the columns through such individual one of the valves and each individual one of the valves being constructed to vary the orifice in such individual one of the valves, in accordance with changes in the rate of flow of the first component through the orifice in such individual one of the values, in a direction to increase the pressure of the fluid in the individual one of the columns in the plurality,

the valves in the plurality being different from the valve means.

33. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to provide initially for the introduction of the compressed fluid into such columns and to adsorb the second component in the compressed fluid in such columns and to pass the first component through such columns and constructed to desorb the second component in such columns after the passage of the first component through such columns,

first means for compressing the first and second components of the fluid before the introduction of such compressed components of the fluid into the columns in the plurality,

second means for introducing the compressed fluid into at least a first one of the columns in the plurality on a cyclic basis to obtain the adsorption of the second component in the at least first one of the columns and the passage of the first component through such at least first one of the columns and for providing for the desorption of the second component from an at least second one of the columns in the plurality on the cyclic basis, third means for collecting the first component passing through the at least first one of the columns in the plurality on the cyclic basis,

fourth means including a cover defining a closed chamber for receiving the second component in the at least second one of the columns in the plurality, and

fifth means disposed in the cover for controllably releasing to the atmosphere the second component in the closed chamber.

34. In a combination as set forth in claim 33, the fifth means including at least a first porous plug for releasing to the atmosphere the second component in the chamber.

35. In a combination as set forth in claim 33,

the first component being introduced into the at least first one of the columns in the plurality at a variable rate,

sixth means for adjusting to a prescribed rate the variable rate at which the first component is introduced into the at least first one of the columns by the second means.

36. In a combination as set forth in claim 33,

a plurality of orifices, each individual one of the orifices being disposed in an individual one of the columns in the plurality and each individual one of the orifices having a variable constriction and each individual one of the orifices being operative to provide an increasing constriction with decreases in the rate of flow of the first component through the at least first one of the columns in the plurality.

37. In a combination as set forth in claim 33,

means for varying the rate of flow of the first component through the at least first one of the columns in the plurality, and

means for varying the fluid compression provided by the first means in accordance with the variations in the rate of flow of the first component through the at least first one of the columns in the plurality.

38. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to provide initially for the introduction of the compressed fluid into such columns and to adsorb the second component in such columns and to pass the first component and constructed to desorb the second components in such columns after the passage of the first component through such columns,

first means for compressing the first and second components of the fluid before the introduction of such compressed components of the fluid into the columns in the plurality,

second means for introducing the compressed fluid into at least a first one of the columns in the plurality on a cyclic basis to obtain the adsorption of the second component in the at least first one of the columns and the passage of the first component through such at least first one of the columns and for providing for the passage to the atmosphere of the second component from at least a second one of the columns in the plurality on the cyclic basis to obtain the desorption of such second component from the at least second one of the columns,

third means for collecting the first component passing through the at least first one of the columns in the plurality on the cyclic basis,

fourth means for adjusting the concentration of the first component in the at least first one of the columns in the plurality, and

a plurality of valves, each individual one of the valves being disposed in an individual one of the columns in the plurality and each individual one of the valves having an orifice variable in accordance with changes in the rate of flow of the first component through the at least first one of the columns in the plurality.

39. In a combination as set forth in claim 38,

the orifice in the individual one of the valves in the at least first one of the columns being constructed to become constricted with decreases in the rate of flow of the first component through the at least first one of the columns in the plurality from the prescribed rate and with decreases in the compression of the first component in the at least first one of the columns in the plurality to adjust the concentration of the first component in the at least first one of the columns.

40. In a combination as set forth in claim 39,

the fourth means being operative to adjust the rate of flow of the compressed fluid into the at least first one of the columns in the plurality on the cyclic basis to adjust the concentration of the first component in the at least first one of the columns.

41. In a combination as set forth in claim 39,

the second means being operative to adjust the rate of flow of the first component through the at least first one of the columns in the plurality on the cyclic basis and the rate of the passage to the atmosphere of the second component from the at least second one of the columns in the plurality on the cyclic basis.

42. In a combination as set forth in claim 41,

valve means operable on the cyclic basis at a variable rate to increase the compression of the first component in the at least first one of the columns in the plurality in accordance with decreases in the rate of flow of the first component through the individual one of the orifices in such at least first one of the columns.

43. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns constructed to provide initially for the introduction of the compressed fluid into such columns and to adsorb the second component in the fluid in such columns and to pass the first component through such columns and constructed to desorb the second component in such columns after the passage of the first component through such columns,

first means for providing a variable compression of the fluid before the introduction of the compressed fluid to the columns in the plurality, the first means having variable characteristics of providing such compression,

second means for introducing the compressed fluid into at least a first one of the columns in the plurality on a cyclic basis to obtain the adsorption of the second component in such at least first one of the columns and to obtain the passage of the first component through such at least first one of the columns and for providing for the passage of the second component from at least a second one of the columns in the plurality on the cyclic basis to obtain the desorption of the second component from the at least second one of the columns,

third means for adjusting the characteristics of the first means to obtain a particular concentration of the first component in the at least first one of the columns in the plurality, and

fourth means for indicating when the characteristics of the first means are outside of particular limits.

44. In a combination as set forth in claim 43, fifth means defining a closed loop with the first means and the third means for maintaining the particular concentration of the first component in the at least first one of the columns in the plurality.

45. In a combination as set forth in claim 44,

a valve associated with the columns in the plurality for communicating with such columns in the plurality on the cyclic basis to select the at least first one of the columns in the plurality on the cyclic basis and the at least second one of the columns in the plurality on the cyclic basis, and

means for varying the operation of the valve to adjust the time, in accordance with the adjustments in the particular concentration of the first component in the at least first one of the columns in the plurality, in which each individual one of the columns in the plurality operates as the at least first one of the columns in the plurality on the cyclic basis and as the at least second one of the columns in the plurality on the cyclic basis.

46. In a combination as set forth in claim 45,

a plurality of valve means, each individual one of the valve means being associated with an individual one of the columns in the plurality for increasing the compression of the fluid in such individual one of the columns in the plurality in response to a decrease in the rate of flow of the first component through the at least first one of the columns in the plurality,

the valve being different from the plurality of valve means.

47. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns wherein at least a first one of such columns adsorbs the second component in the compressed fluid and passes the first component in the compressed fluid and at least a second one of such columns desorbs the second component previously adsorbed in such at least second one of the columns,

valve means for selecting the at least first one of the columns on a cyclic basis and the at least second one of the columns on a cyclic basis,

compressor means having variable characteristics for receiving and compressing the fluid in accordance with the variations in such characteristics and for introducing the compressed fluid to the at least first one of the columns in the plurality in accordance with the selection of the first one of the columns by the valve means on the cyclic basis,

first means for indicating variations in the temperature of the fluid in the at least first one of the columns, and

second means for varying the characteristics of the compressor means in accordance with the variations in the temperature indicated by the first means to maintain the flow of the first component in the compressed fluid to the user at the prescribed rate.

48. In a combination as set forth in claim 47,

third means for adjusting the times for the selection of the at least first one of the columns on the cyclic basis and the at least second one of the columns on the cyclic basis in accordance with the variable characteristics of the compressor means by the second means.

49. In a combination as set forth in claim 47,

a plurality of orifices, each individual one of the orifices being disposed in an individual one of the columns in the plurality and being variable in size, and

third means for varying the size of the orifices in the plurality in accordance with variations in the compression of the fluid in the columns in the plurality.

50. In a combination as set forth in claim 47,

third means for indicating the variations in the pressure of the fluid in the columns in the plurality,

the second means being responsive to the indications by the third means of the variations in the pressure of the fluid in the columns in the plurality for varying the characteristics of the compressor means.

51. In a combination as set forth in claim 47,

third means associated with the columns in the plurality for defining a chamber for receiving the second component desorbed from the columns in the plurality, and fourth means included in the third means for providing a controlled release of the second component in the chamber to an atmospheric pressure.

52. In a combination as set forth in claim 47,

a plurality of orifices, each individual one of the orifices being disposed in an individual one of the columns in the plurality and being variable in size,

third means for varying the size of the orifices in the plurality in accordance with variations in the operation of the compressor means in compressing the fluid in the columns in the plurality,

fourth means for indicating variations in the pressure of the fluid in the columns in the plurality,

the second means being responsive to the indications by the fourth means of the variations in the pressure of the fluid in the columns in the plurality for varying the characteristics of the compressor means,

fifth means associated with the columns in the plurality for defining a chamber for receiving the second component desorbed from the columns in the plurality, and

sixth means included in the fifth means for providing a controlled release of the second component in the chamber to atmospheric pressure.

53. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns wherein at least a first one of such columns adsorbs the second component of the compressed fluid and passed the first component of the compressed fluid through the at least first one of the columns,

valve means for selecting the at least first one of the columns on a cyclic basis and the at least second one of the columns on the cyclic basis,

compressor means having variable characteristics for receiving and compressing the fluid in accordance with the variations in such characteristics and for introducing the compressed fluid to the at least first one of the columns in the plurality in accordance with the selection of the at least first one of the columns by the valve means on the cyclic basis,

flow control means for receiving the first component passing through at least the first one of the columns and for passing the first component to the user at a particular rate dependent upon the operation of the flow control means, and

first means responsive to variations in the rate at which the flow control means passes the first component to the user for varying the characteristics of the compressor means to maintain at the particular rate the passage of the first component from the flow control means to the user.

54. In a combination as set forth in claim 53,

second means for indicating variations in the temperature of the fluid in the at least first one of the columns,

the first means being responsive to the variations in the temperature as indicated by the second means for adjusting the characteristics of the first means to maintain at the particular rate the passage of the first component from the flow control means to the user.

55. In a combination as set forth in claim 53,

second means for adjusting the times for the selection of the at least first one of the columns on the cyclic basis and the at least second one of the columns on the cyclic basis in accordance with the variations in the characteristics of the compressor means by the first means.

56. In a combination as set forth in claim 55,

the compressor means having a variable speed,

means for increasing the pressure of the first component passing from the least first one of the columns in accordance with decreases in the speed of the compressor means.

57. In a combination as set forth in claim 56,

third means for indicating variations in the temperature of the fluid in the at least first one of the columns,

the first means being responsive to the indications by the third means of the variations in the temperature for adjusting the characteristics of the first means to maintain at the particular rate the passage of the first component from the flow control means to the user,

fourth means for adjusting the times for the selection of the at least first one of the columns on the cyclic basis and the at least second one of the columns on the cyclic basis in accordance with the variations in the characteristics of the compressor means by the first means.

58. In a combination as set forth in claim 53,

a plurality of orifices, each individual one of the orifices being disposed in an individual one of the columns in the plurality and being variable in size, and

second means for varying the size of the orifices in the plurality in accordance with variations in the compression of the fluid in the columns in the plurality.

59. In a combination as set forth in claim 53,

the compressor means having a variable speed,

means for increasing the pressure of the first component passing from the least first one of the columns in accordance with decreases in the speed of the compressor means.

60. In a combination as set forth in claim 53,

second means associated with the columns in the plurality for defining a chamber for receiving the second component desorbed from the columns in the plurality, and

third means included in the second means for providing a controlled release of the second component in the chamber to atmospheric pressure.

61. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns wherein at least a first one of such columns adsorbs the second component of the compressed fluid and passes the first component of the compressed fluid through the at least first one of the columns and at least a second one of such columns desorbs the second component previously adsorbed in the at least first one of the columns,

valve means for selecting the at least first one of the columns on a cyclic basis and the at least second one of the columns on the cyclic basis,

compressor means having variable characteristics for receiving and compressing the fluid in accordance with the variations in such characteristics and for introducing the compressed fluid to the at least first one of the columns in the plurality in accordance with the selection of the at least first one of the columns by the valve means on the cyclic basis,

flow control means for receiving the first component passing through the at least first one of the columns and for passing the first component to the user, the flow control means having variable characteristics, and

first means responsive to the variations in the characteristics of the compressor means for varying the characteristics of the flow control means to maintain the passage of the first component from the flow control means to the user at a particular rate.

62. In a combination as set forth in claim 61,

second means for indicating variation, in the temperature of the fluid in the at least first one of the columns, and

third means responsive to the indications of the variations in the temperature by the second means for varying the characteristics of the compressor means to maintain the passage of the first component to the user at the particular rate.

63. In a combination as set forth in claim 62,

fourth means for indicating variations in the pressure of the fluid in the first component in the at least first one of the columns,

fifth means responsive to the indications of the variations in the pressure by the second means for varying the characteristics of the compressor means to maintain the passage of the first component to the user at the particular rate,

sixth means for indicating the variations in the characteristics of the flow control means, and

the fifth means being responsive to the indication by the sixth means of the variations in the characteristics of the flow control means for varying the characteristics of the compressor means to maintain the passage of the first component from the flow control means to the user at the particular rate.

64. In a combination as set forth in claim 61,

second means for indicating variations in the pressure of the fluid in the at least first one of the components,

third means responsive to the indications of the variations in the pressure by the second means for varying the characteristics of the compressor means to maintain the passage of the first component to the user at the particular rate.

65. In a combination as set forth in claim 61,

second means for indicating the variations in the characteristics of the flow control means, and

third means responsive to the indications by the second means of the variations in the characteristics of the flow control means for varying the characteristics of the compressor means to maintain the passage of the first component from the flow control means to the user at the particular rate.

66. In combination for removing a first component from a compressed fluid also having a second component and for providing for the flow of such first component to a user at a prescribed rate,

a plurality of columns wherein at least a first one of the columns adsorbs the second component of the compressed fluid and passes the first component of the compressed fluid through the at least first one of the columns and at least a second one of the columns desorbs the second component previously adsorbed in the at least first one of the columns,

valve means for selecting the at least first one of the columns on a cyclic basis and the at least second one of the columns on the cyclic basis,

compressor means having variable characteristics for receiving and compressing the fluid in accordance with the variations in such characteristics and for introducing the compressed fluid to the at least first one of the columns in the plurality in accordance with the selection of the at least first one of the columns by the valve means on the cyclic basis,

first means having variable characteristics for cooling the compressor means in accordance with such variable characteristics, and

second means responsive to variations in the characteristics of the compressor means for varying the characteristics of the first means in cooling the compressor means.

67. In a combination as set forth in claim 66,

flow control means for receiving the first component after the passage of the first component through the at least first one of the columns and for passing the first component to the user, the flow control means having variable characteristics, and

third means responsive to the variations in the characteristics of the compressor means for varying the characteristics of the flow control means to maintain the passage of the first component from the flow control means to the user at a particular rate.

68. In a combination as set forth in claim 66,

the second means including a microprocessor,

the variable characteristics of the compressor means constituting changes in speed,

the variable characteristics of the cooling means constituting changes in the rate at which the cooling means cools the compressor means,

the second means including the microprocessor being responsive to the changes in the speed of the compressor means for varying the rate at which the cooling means cools the compressor means.

69. In a combination as set forth in claim 68,

the valve means having variable characteristics for varying the rate at which the valve means selects the at least first one of the columns on the cyclic basis and the at least second one of the columns on the cyclic basis, and

third means including the microprocessor for varying the characteristics of the valve means in accordance with the variations in the speed of the compressor means.

70. In a combination as set forth in claim 68,

third means for indicating variations in the temperature of the compressor means, and

fourth means including the microprocessor for varying the speed of the compressor means in accordance with the indication by the third means of the variations in the temperature of the compressor means.

71. In a combination as set forth in claim 68,

third means for indicating variations in the concentration of the first component in the at least first one of the columns, and

fourth means including the microprocessor for varying the speed of the compressor means in accordance with the indications by the third means of the variations in the concentration of the first component in the at least first one of the columns.

72. In a combination as set forth in claim 68,

flow control means for receiving the first component after the passage of the first component through the at least first one of the columns and for passing the first component to the user, the flow control means having variable characteristics, third means responsive to the variations in the characteristics of the compressor means for varying the characteristics of the flow control means to maintain the passage of the first component from the flow control means to the user at a particular rate,

the valve means having variable characteristics for varying the rate at which the valve means selects the at least first one of the columns on the cyclic basis and the at least second one of the columns on the cyclic basis,

fourth means including the microprocessor for varying the characteristics of the valve means in accordance with the variations in the speed of the compressor means,

fifth means for indicating variations in the temperature of the compressor means, and

sixth means including the microprocessor for varying the speed of the compressor means in accordance with the indication of variations in the temperature of the compressor means,

seventh means for indicating variations in the concentration of the first component in the at least first one of the columns, and

eighth means including the microprocessor for varying the speed of the compressor means in accordance with the indications representing the variations in the concentration of the first component in the at least first one of the columns.

* * * * *

EXHIBIT [illegible]

EXHIBIT 2

US005730778A

United States Patent [19]

Hill et al.

[11] **Patent Number: 5,730,778**

[45] **Date of Patent: Mar. 24, 1998**

[54] **FLUID FRACTIONATOR**

[75] Inventors: Charles C. Hill, Del Mar; Theodore B. Hill, San Diego, both of Calif.

[73] Assignee: SeQual Technologies, Inc., San Diego, Calif.

[21] Appl. No.: 734,203

[22] Filed: Oct. 21, 1996

Related U.S. Application Data

[62] Division of Ser. No. 314,213, Sep. 28, 1994, Pat. No. 5,593,478.

[51] Int. Cl.[6] B01D 53/053

[52] U.S. Cl. 95/12; 95/15; 95/22; 95/23; 95/41; 95/96; 95/130

[58] Field of Search 95/8, 12, 14, 15, 95/19, 22, 23, 39, 96, 130, 138

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,922,149	11/1975	Ruder et al.	95/22
4,323,370	4/1982	Leitgeb	95/23
4,631,073	12/1986	Null et al.	95/8 X
4,648,888	3/1987	Rowland	95/8
4,693,730	9/1987	Miller et al.	95/8
4,927,434	5/1990	Cordes et al.	95/15
5,071,453	12/1991	Hradek et al.	95/8 X
5,112,367	5/1992	Hill	95/130 X
5,258,056	11/1993	Shirley et al.	95/22
5,340,381	8/1994	Vorih	95/130 X
5,474,595	12/1995	McCombs	95/23
5,529,607	6/1996	Tan	95/12
5,531,807	7/1996	McCombs	95/96 X
5,593,478	1/1997	Hill et al.	96/130 X

FOREIGN PATENT DOCUMENTS

57-071804	5/1982	Japan	95/12
06-277433	10/1994	Japan	95/23

Primary Examiner—Robert Spitzer
Attorney, Agent, or Firm—Ellsworth R. Roston; Fulwider Patton Lee & Utecht, LLP

[57] **ABSTRACT**

A rotary valve at the inlets of a plurality of columns cyclically (1) selects first columns on a cyclic basis to receive compressed air, adsorb nitrogen and other components in the compressed air and pass oxygen and argon to a user (e.g. patient), second columns to desorb the adsorbed components in such columns and (3) third columns to equalize pressures where the first columns change progressively to the second columns and vice versa. A compressor having adjustable characteristics and regulated in an open or closed loop introduces the compressed air through the valve to the first columns to provide an adjustable air flow for obtaining a prescribed oxygen flow to the user. An indication may be provided when the compressor characteristics regulated for obtaining the prescribed oxygen flow rate are outside particular limits. The valve may have a variable speed related to the compressor flow variations to regulate the air pressure in the columns in accordance with the air flow rate into the columns. A variable orifice in a valve in each column outlet becomes constricted with decreases in the oxygen flow rate in each column, thereby further regulating the oxygen pressure in such column. A porous plug in a closed chamber receiving the desorbed pressurized components releases such components slowly, without pulsatile noise, to the atmosphere. The equipment accordingly produces the desired oxygen flow rate with minimal power consumption, minimal noise and optimal efficiency, reliability and life span. The equipment may be designed to pass other components than oxygen.

26 Claims, 10 Drawing Sheets

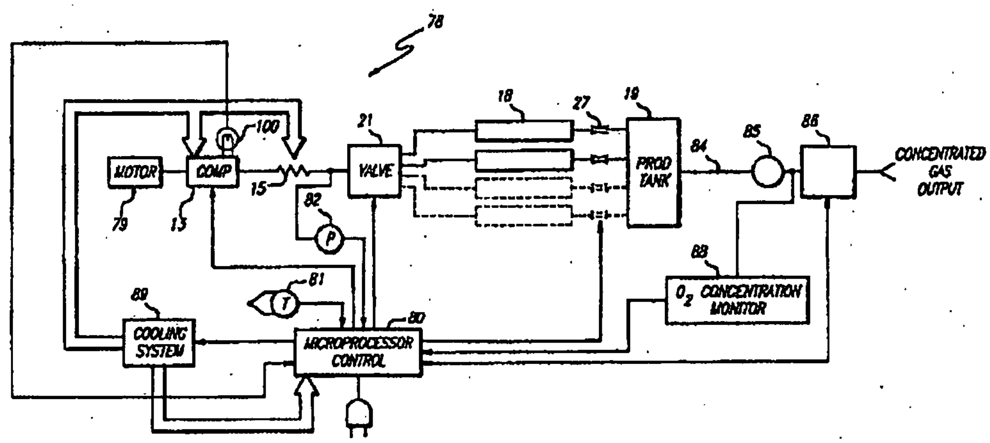
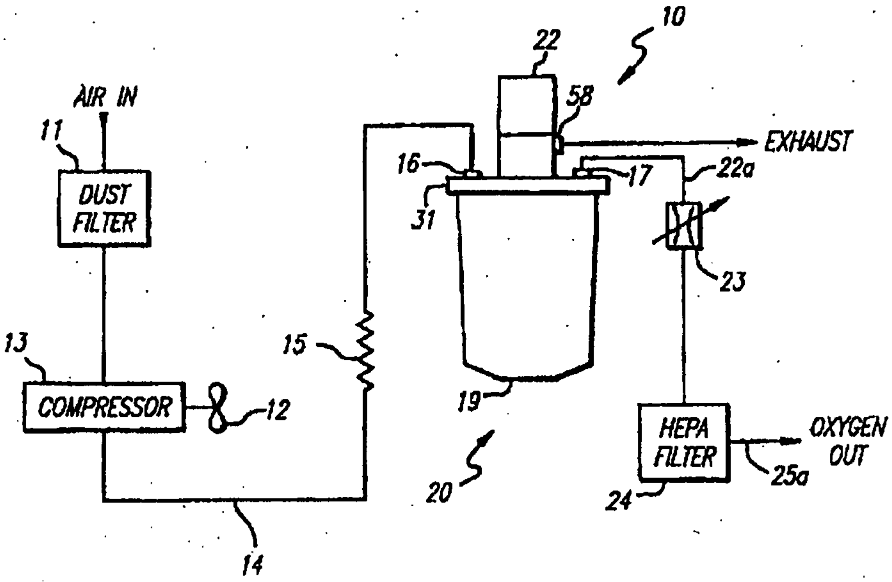


FIG. 1
PRIOR ART



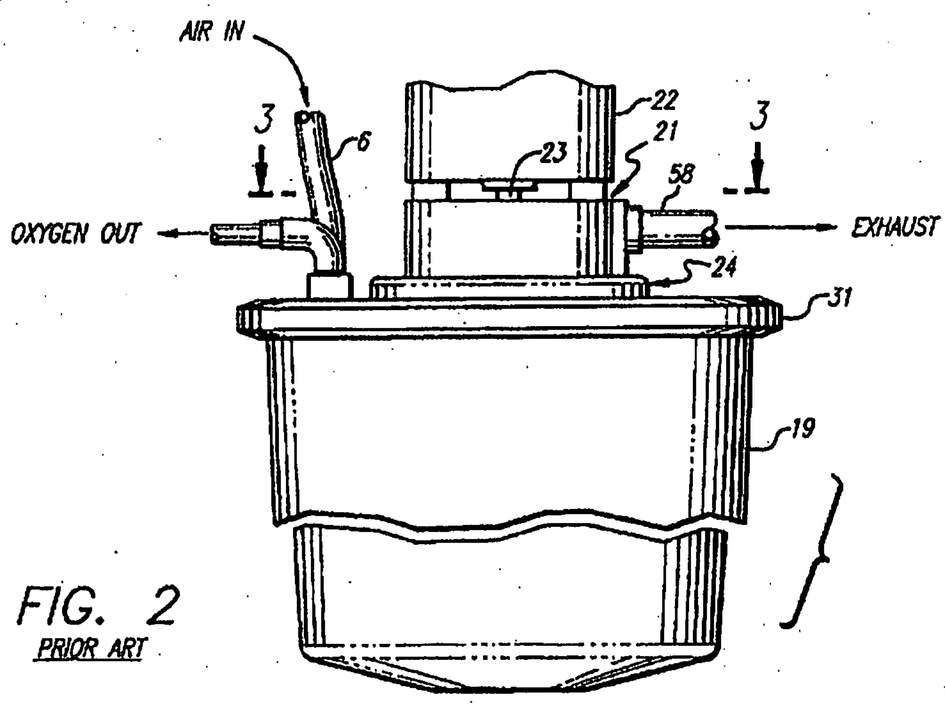


FIG. 2
PRIOR ART

FIG. 3
PRIOR ART

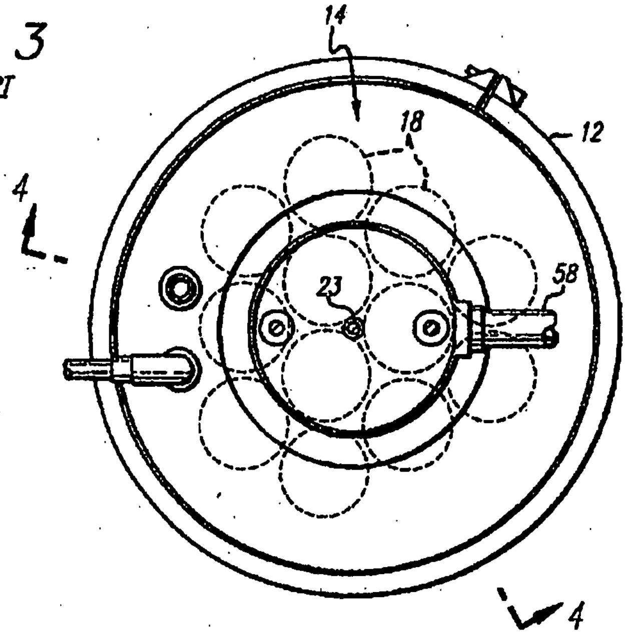


FIG. 13

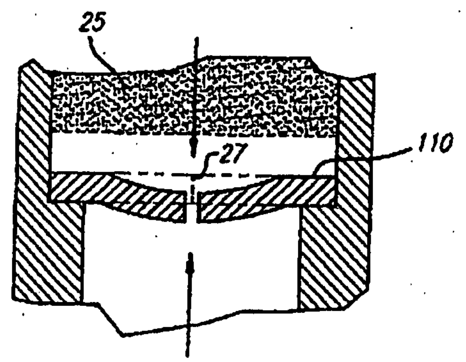
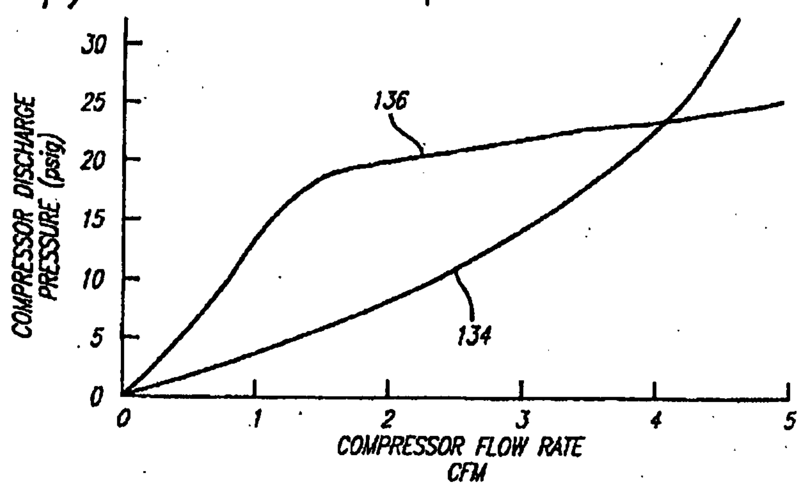


FIG. 17



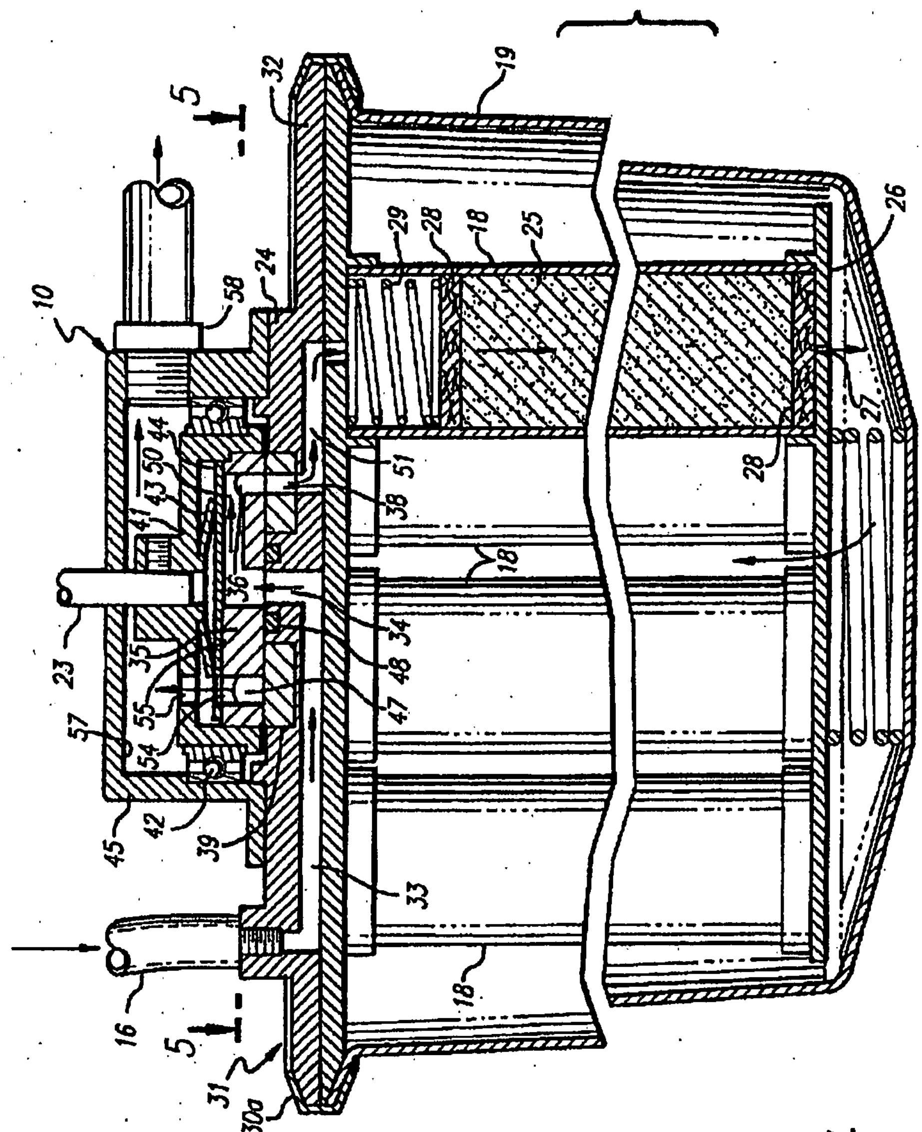


FIG. 4
PRIOR ART

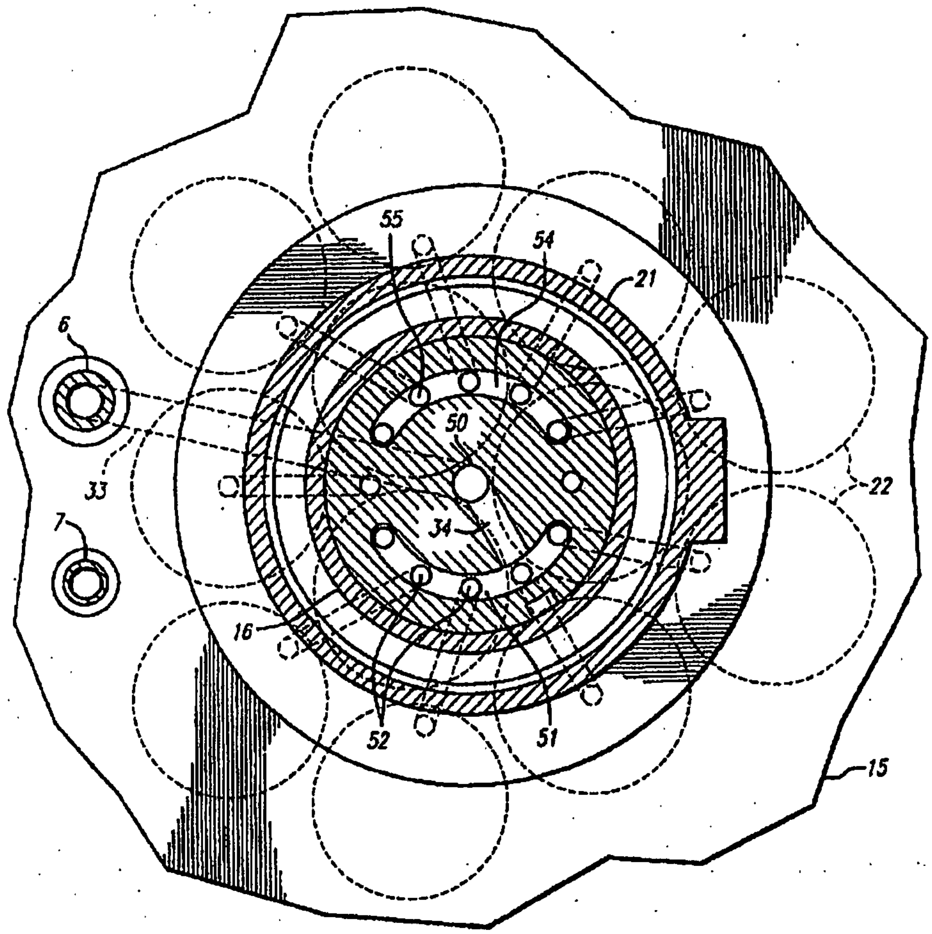


FIG. 5
PRIOR ART

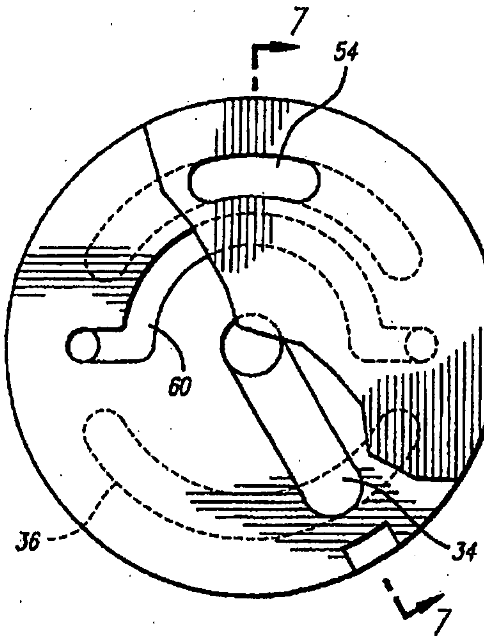


FIG. 6
PRIOR ART

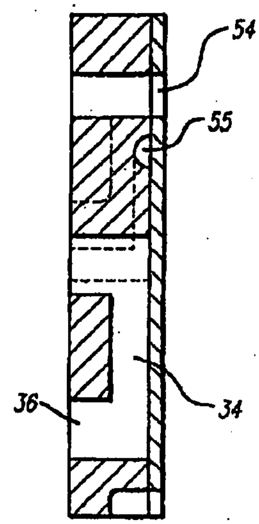


FIG. 7
PRIOR ART

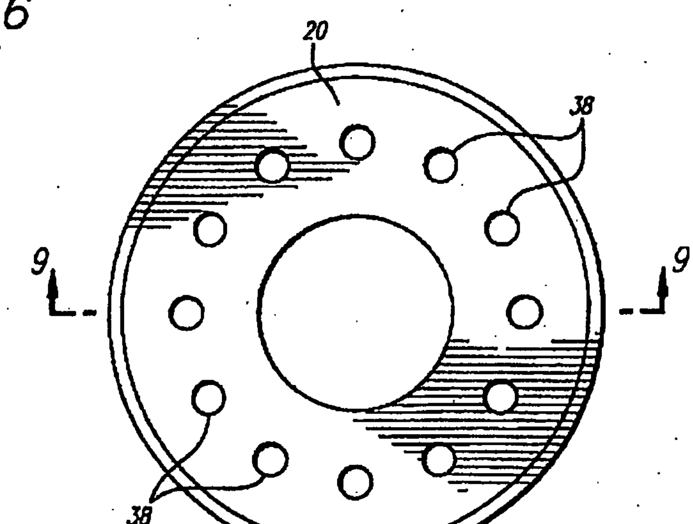


FIG. 8
PRIOR ART

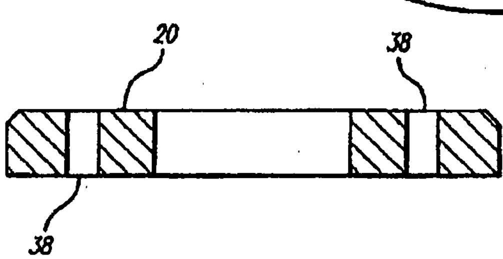


FIG. 9
PRIOR ART

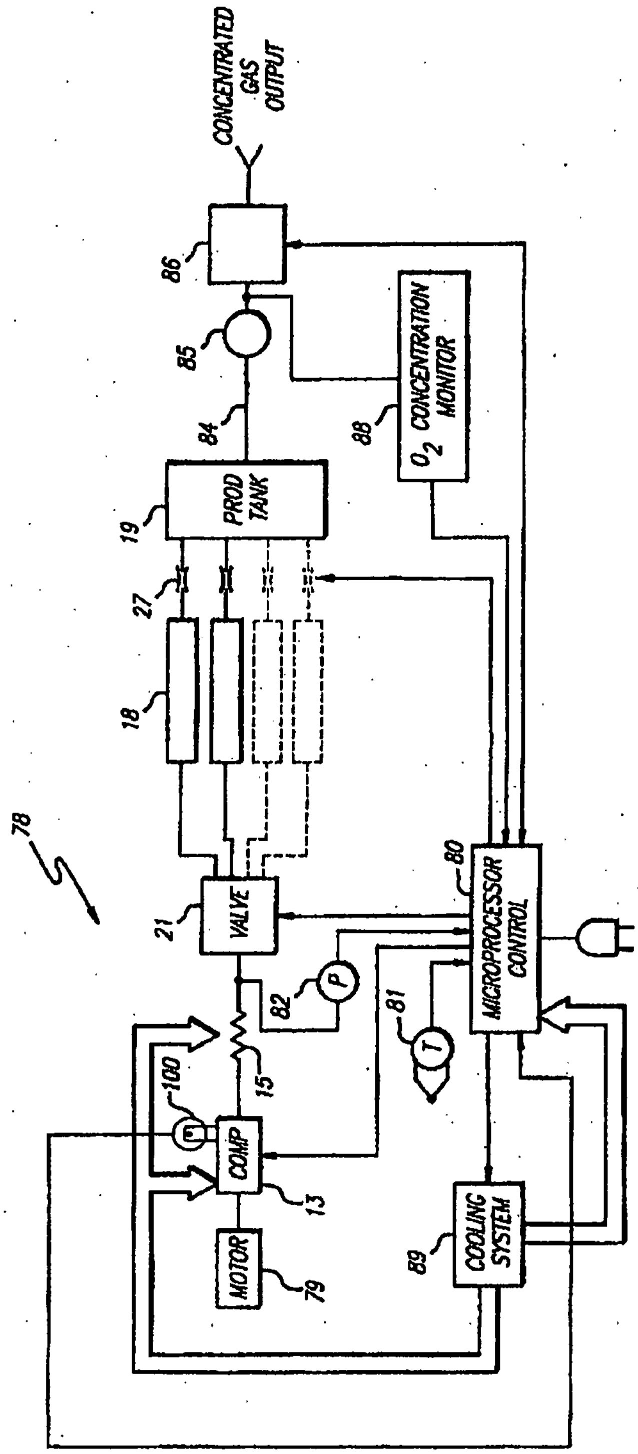

CONCENTRATED GAS OUTPUT
86
85
84
88
O_2 CONCENTRATION MONITOR
PROD TANK
19
27
18
78
VALVE
21
80
MICROPROCESSOR CONTROL
82
P
81
T
15
100
COMP
13
MOTOR
79
COOLING SYSTEM
89

FIG. 10

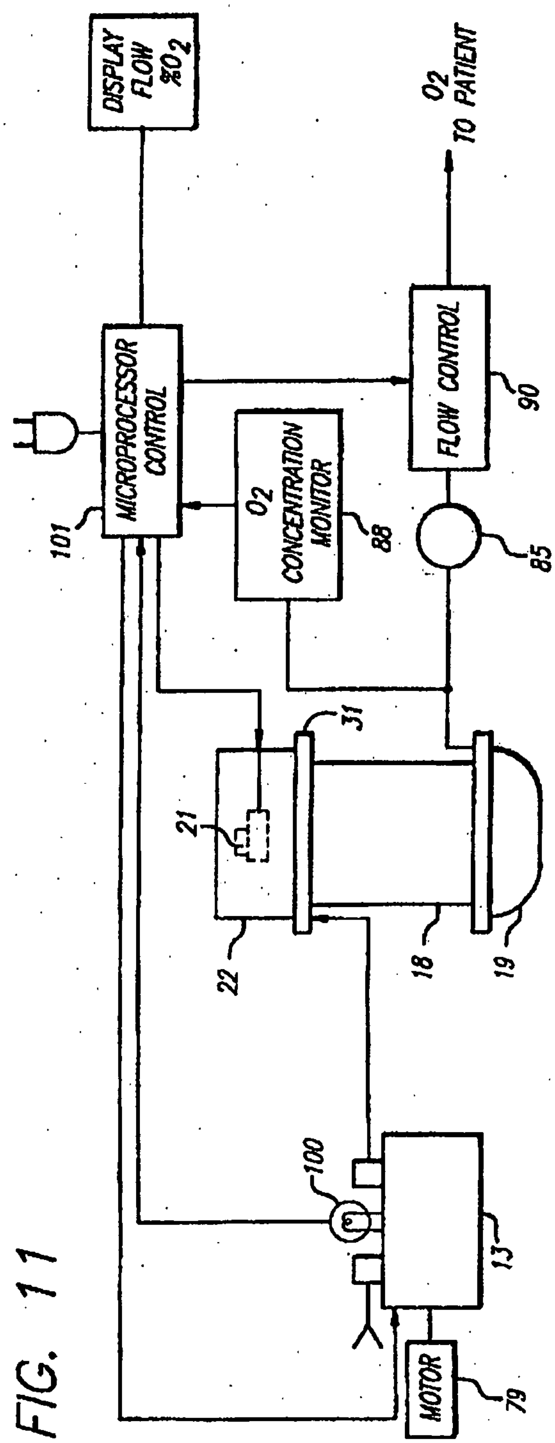

DISPLAY
FLOW
%O2
O2
TO PATIENT
MICROPROCESSOR
CONTROL
FLOW CONTROL
O2
CONCENTRATION
MONITOR
MOTOR
101
88
90
85
31
21
22
18
19
100
13
79

FIG. 11

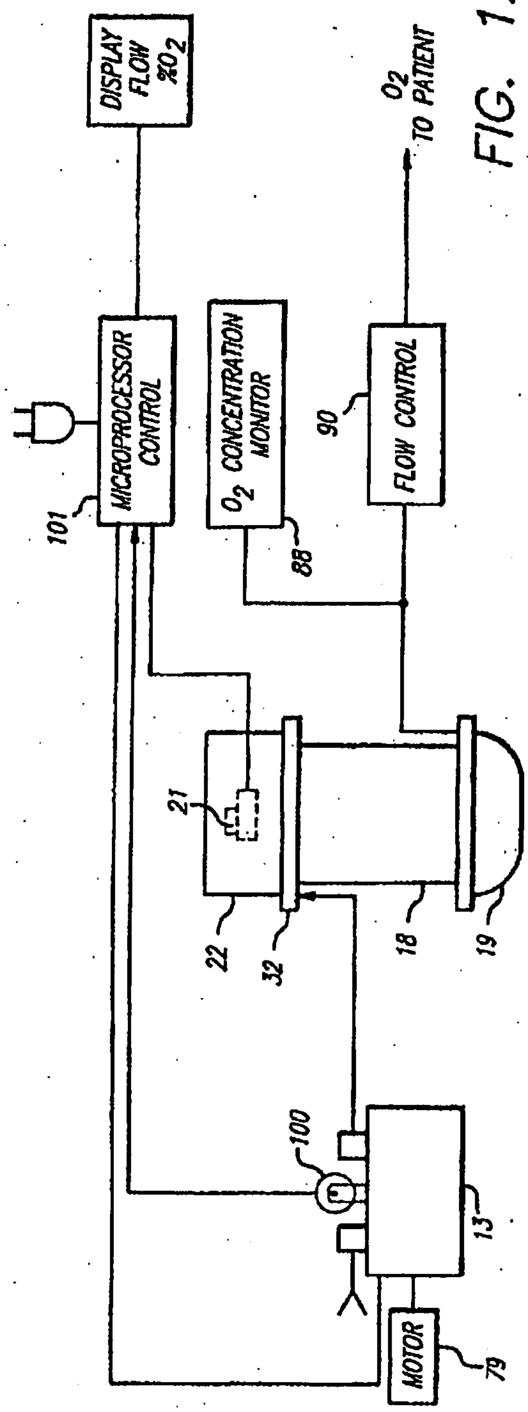

DISPLAY
FLOW
%O2
MICROPROCESSOR
CONTROL
101
O2 CONCENTRATION
MONITOR
88
90
FLOW CONTROL
O2
TO PATIENT
21
22
32
18
19
100
13
MOTOR
79

FIG. 12

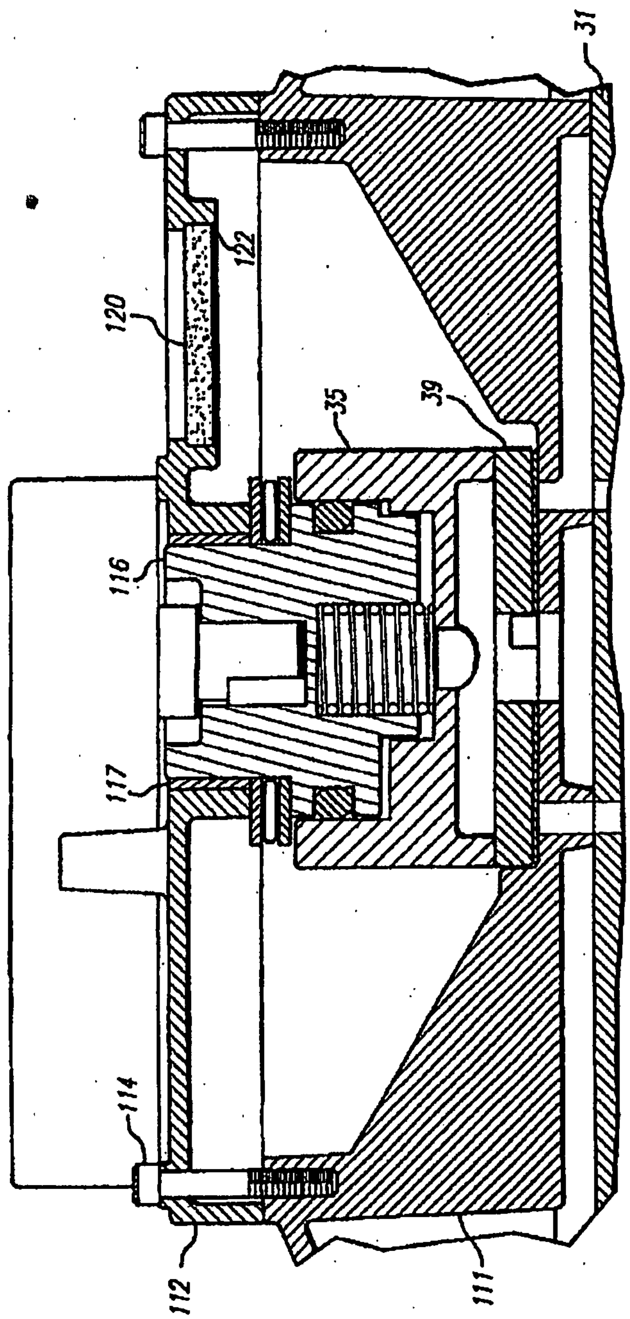


FIG. 14

FIG. 15

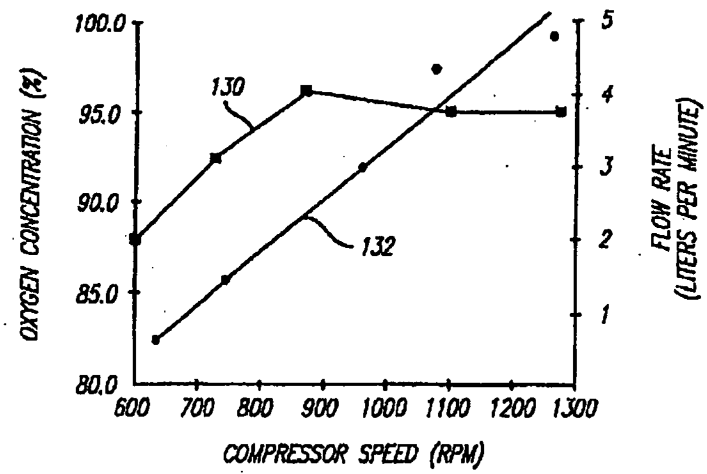
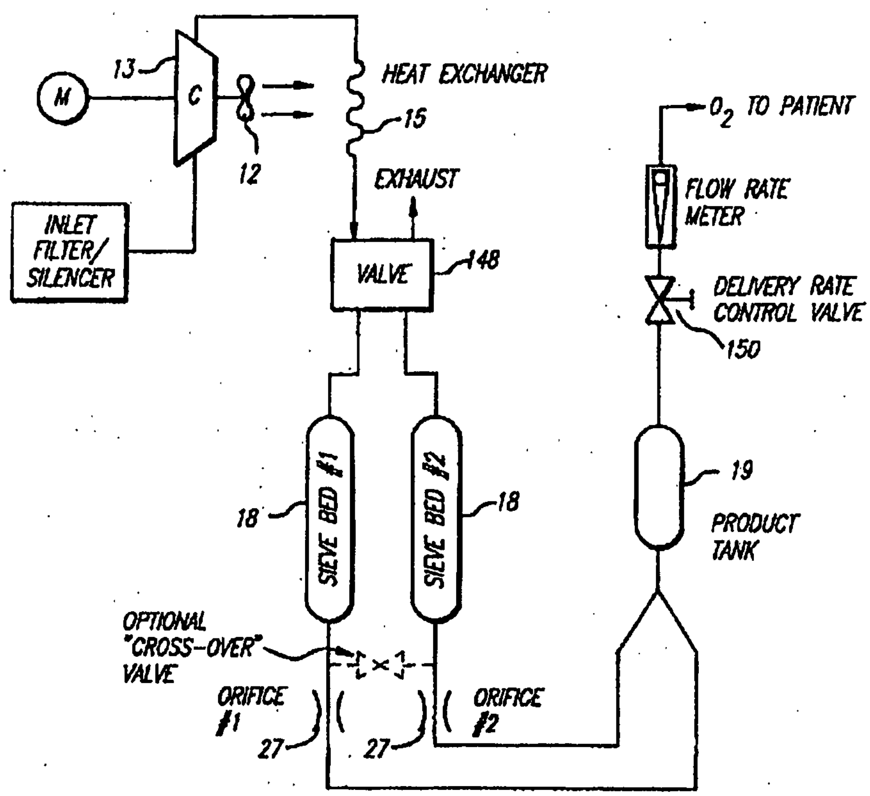


FIG. 16
PRIOR ART



FLUID FRACTIONATOR

This is a division of application Ser. No. 08/314,213 filed, now U.S. Pat. No. 5,593,478 Sep. 28, 1994.

This invention relates to apparatus for, and methods of, purifying a fluid by periodically/cyclically passing a particular component in the fluid through a molecular sieve and adsorbing other components in the fluid in the molecular sieve and subsequently periodically/cyclically desorbing such other components from the molecular sieve. The invention further relates to apparatus for, and methods of, passing oxygen in compressed air (and argon) for introduction to a patient and for adsorbing nitrogen and the other components in the compressed air and subsequently desorbing the adsorbed components to the atmosphere. The invention particularly relates to apparatus for providing any prescribed rate of flow of oxygen with minimal power consumption, minimal noise and optimal efficiency, reliability and life span.

Apparatus is in existence for receiving a fluid such as compressed air, for separating the oxygen from the air and for passing the oxygen for subsequent use as by a patient. The apparatus also includes material in a molecular sieve for adsorbing the nitrogen and the other components in the compressed air. When the oxygen separated from the compressed air has been passed, the adsorbed components in the compressed air are desorbed by release to the atmosphere. The apparatus can operate on a cyclic basis to continuously provide oxygen to a user such as a patient.

The oxygen can be used for many purposes. One of the primary uses of the oxygen is for providing oxygen to patients such as the elderly and those having asthma and emphysema. When the apparatus is used for such patients, the apparatus should have certain desirable characteristics. It should be able to provide the oxygen to each patient in a variable delivery rate and high concentration dependent upon the needs of the patient. It should be able to provide this oxygen in an efficient and reliable manner and with a minimal power consumption, particularly since many sick and elderly patients have only limited income and the electric power cost for operating the apparatus is substantial and significant. The apparatus should also operate quietly so as not to be offensive to the patient and to those around the patient. The apparatus should also have a long operative life without any breakdown. These parameters are particularly important because the apparatus operates continuously in the home environment without attendance.

The apparatus now in use fails to completely meet the criteria specified in the previous paragraph. The apparatus includes a compressor for introducing compressed air to columns which include a molecular sieve for passing oxygen and argon and for adsorbing nitrogen and other components in the compressed air and for subsequently desorbing the adsorbed components. In the apparatus now in use, the compressors are operated to deliver a constant maximum flow and concentration of oxygen regardless of the flow of oxygen prescribed for the user. The desired flow of oxygen to the patient is then adjusted by a throttling valve in the product bleed line to the user. As will be appreciated, this is inefficient if less than maximum flow capacity is needed, particularly since the compressor and the motor driving the compressor require a large amount of power.

The compressor generates a large amount of noise as it operates. This results partly from the operation of the motor and the compressor, particularly since the motor and the compressor is driven at a fixed high speed. It also results partly from the description to the atmosphere of the compressed fluid which is adsorbed in the columns. This release occurs almost instantaneously, thereby creating a noise/sound pulse every time that the compressed fluid in one of the columns is released to the atmosphere.

This invention provides a system which substantially overcomes the disadvantages in the apparatus of the prior art. In the system of this invention, the compressor operates at a speed, or with displacement characteristics, adjustable in accordance with the desired rate of oxygen flow to the user (e.g. the patient). The apparatus of this invention is also advantageous in that it releases the desorbed fluid to the atmosphere at a steady and controlled rate, thereby significantly reducing the noise generated from such release.

In one embodiment of the invention, a rotary valve at the inlets of a plurality of columns selects first columns on a cyclic basis to receive compressed air, adsorb nitrogen and other components in the compressed air and pass oxygen and argon to a user (e.g. patient). The valve also cyclically selects second columns to desorb the nitrogen and the other components in such columns and cyclically equalizes the pressure in third columns where the first columns change progressively to the second columns and vice versa.

A compressor having adjustable characteristics and regulated in an open or closed loop introduces the compressed air through the valve to the first columns to provide an adjustable air flow for obtaining a prescribed oxygen flow to the user. An indication may be provided when the compressor characteristics regulated for obtaining the prescribed oxygen flow rate are outside particular limits.

The valve may have a variable speed related to the compressor flow variations to regulate the air pressure in the columns in accordance with the air flow rate into the columns. A variable orifice in a valve in each column's outlet becomes constricted with decreases in the oxygen flow rate in each column, thereby further regulating the oxygen pressure in such column.

A porous plug in a closed chamber receiving the desorbed components releases such components slowly, without pulsatile noise, to the atmosphere. The equipment accordingly produces the desired oxygen flow rate with minimal power consumption, minimal noise and optimal efficiency, reliability and life span. The equipment may be designed to pass other components than oxygen.

In the drawings:

FIG. 1 is a schematic representation of a respiratory support system, including a fluid fractionator, of the prior art;

FIG. 2 is a side elevation of a portion of the support system shown in FIG. 1 and particularly shows a fluid fractionator included in such support system;

FIG. 3 is a sectional view of the fractionator as taken on a line 3—3 of FIG. 2;

FIG. 4 is a sectional view of the fluid fractionator as taken on a line 4—4 of FIG. 3;

FIG. 5 is an enlarged sectional view of the fluid fractionator as taken on a line 5—5 of FIG. 4;

FIG. 6 is a top plan view, partially cut away, of a rotor shoe included in the fluid fractionator;

FIG. 7 is a sectional view of the rotor shoe as taken on the line 7—7 of FIG. 6;

FIG. 8 is a top plan view of a port plate included in the fluid fractionator shown in FIGS. 1–7;

FIG. 9 is a sectional view taken on the line 9–9 of FIG. 8;

FIG. 10 is a schematic diagram of a closed loop system constituting one embodiment of an invention for use with the fluid fractionator shown in FIGS. 1–9 for regulating the variable characteristics of a compressor and other components to obtain a desired or prescribed rate of flow and concentration of a particular fluid component such as oxygen;

FIG. 11 is a schematic diagram of a closed loop system constituting another embodiment of the invention for use with the fluid fractionator shown in FIGS. 1–9 for regulating the variable characteristics of a compressor and other components to obtain a desired or prescribed rate of flow and concentration of a particular fluid component such as oxygen;

FIG. 12 is a schematic diagram of an open loop system constituting an additional embodiment of the invention for use with the fluid fractionator shown in FIGS. 1–9 for controlling the variable characteristics of a compressor and other components to obtain a desired or prescribed rate of flow and concentration of a particular fluid component such as oxygen;

FIG. 13 is a schematic sectional view of an orifice which may be used in the respiratory support system of this invention and which provides variable characteristics in accordance with the rate of flow of the particular fluid component such as oxygen;

FIG. 14 is an elevational view, partially in section, of apparatus which may be included in the invention to reduce the noise generated in the system when fluid adsorbed in the fluid fractionator is desorbed;

FIG. 15 provides curves showing (a) the relationship between different compressor speeds and the percentage of concentration of oxygen in the product flow from the fluid fractionator and (b) the relationship between different compressor speeds and the flow rate of oxygen to the product holding tank 19 in liters per minute; and

FIG. 16 is a schematic diagram showing a fluid fractionator which may be considered as a conventional fluid fractionator of the prior art and which may be modified to incorporate the features of this invention; and

FIG. 17 provides curves showing the relationship between compressor flow rates and compressor discharge pressures for a normal system of the prior art and for the system of this invention.

FIGS. 1–9 illustrate an oxygen-concentrating system, generally indicated at 10, which may be used in this invention and which is disclosed in the prior art in U.S. Pat. No. 5,268,021 issued to Charles C. Hill and Theodore B. Hill on Dec. 9, 1993, for an "Improved Fluid Fractionator" and assigned of record to the assignee of record of this application. The embodiment shown in FIGS. 1–9 of this application corresponds to the embodiment shown in FIGS. 1–9 of U.S. Pat. No. 5,268,021. In the prior art system shown in FIGS. 1–9, air is drawn from the atmosphere through an air inlet 6 into a dust filter 11 which removes dust from the air. The air is then compressed in a compressor 13 and the compressed air is introduced through a conduit 14 into a heat exchanger 15 which removes some of the heat produced during the compression. A fan 12 may be driven by the compressor 13 to remove heat from the heat exchanger 15.

The compressed air then passes into the inlet port 16 of a fluid fractionator, generally indicated at 20, which is included in this invention. The fluid fractionator 20 includes a product tank 19. Included in the tank 19 are a plurality of adsorber columns 18 (FIG. 3) the construction and operation of which will be described in detail subsequently. Oxygen (and argon) flow from the product tank 19 through an oxygen outlet 7 in FIG. 2.

Each column 18 separates the oxygen and argon in the compressed air from the other components in the compressed air and passes some of the oxygen and argon through an outlet port 17 (FIG. 1) to a dispensing conduit 22*a*. The oxygen and argon then pass through a valve 23 (which may be manually controlled) to a filter 24. The filter 24 may be a high efficiency particle arrestor (HEPA). The oxygen and argon then pass to a conduit 25*a* for use for one of a number of purposes. For example, the oxygen and argon may be introduced to a patient to increase the level of the oxygen in the blood of the patient.

As shown in FIG. 3, the holding tank 19 contains a cluster or array of the adsorber columns 18 within its housing. The columns are preferably disposed in a closely packed configuration. Preferably a plurality, more than two (2), of such columns are provided in a closely packed relationship. Twelve (12) columns are shown in FIG. 3 but it will be appreciated that any other number may be provided. The fluid fractionator 20 also includes a rotary valve distributor assembly generally indicated at 21 (FIG. 2), a gear motor 22 having a drive shaft 23 and a two-piece manifold 24 (FIG. 2).

Each of the columns 18 may be in the form of a cylinder. Each of the columns 18 contains a bed packed with adsorbent material 25 (FIG. 4) which is selective for a particular molecular species of fluid or contaminant. For example, zeolite 5A may constitute the adsorbent material 25 when oxygen is to be separated from air. The packed bed is held in place by a plate 26 at the bottom of the bed. A pressure-dropping means such as a small orifice 27 extends through the plate 26. Perforated plates 28 are disposed at the top and bottom of the bed of the absorbent material 25, the bottom plate 28 being disposed between the plate 26 and the adsorbent material 25.

A spring 29 is disposed in the column 18 above the upper perforated plate 28 to maintain the plates 28 and the adsorbent material 25 in a packed relationship against the plate 26. When the adsorbent material 25 is zeolite 5A, the material adsorbs all of the components (including nitrogen) in the compressed air and passes argon and oxygen. The oxygen and argon are thus able to pass through the perforated plates 28, the adsorbent material 25 and the orifice 27 in the plate 26.

The rotary valve distributor assembly 21 is affixed to the holding tank 19 by a clamp band 34*a* (FIG. 4). The rotary distributor valve assembly 21 shown in FIG. 4 includes the two-piece manifold 31 which is ported and channeled. The manifold 31 has a top section 32 which is ported and channeled to receive a stream of fluid through the inlet port 16 and to channel the fluid through an air feed passage 33 into a centrally located inlet port 34 in a ported rotor shoe 35. Subsequently the fluid exiting the rotor shoe 35 is channeled radially from a circular array of inlet ports 38 in a port plate 39 toward each of the columns 18.

The ported rotor shoe 35 is included in a rotor 41. The rotor turns in a circumferential ball bearing unit 42. The rotor is driven by the gear motor 22 (FIG. 2) at a suitable speed such as approximately two (2) revolutions per minute. A conical disc or Belleville spring 43 urges a cover plate 44 and the rotor shoe 35 downwardly to secure the cover plate and the rotor shoe in position. The rotor 41 and its associated components are enclosed within a cover 45 which is suitably attached to the manifold 24.

The port plate 39 is made from a suitably hard material. The port plate 39 is recessed into the top of the manifold 31 and is sealed and immobilized by a slot and a key. The port plate 39 is coaxial with the exit port of an air feed channel 47 in the manifold 31. The port plate 39 has a number of holes equally spaced from one another in a circular pattern.

This number is equal to the number of entry ports of channels to the individual columns 18. An air inlet rotary seal 48 is provided in the manifold 31 at a position interior to the port plate 39.

The rotor shoe 35 is made from a material known in the art to be suitable for use with the hardened material of the port plate 39. The rotor shoe 35 slides on the port plate 39. The Belleville spring 43 presses the rotor shoe 35 against the port plate 39 during such sliding movement. There are three (3) channels in the rotor shoe 35. One is a pressurizing channel or air feed channel 50 (FIGS. 4 and 5) which originates at the central fluid inlet port 34. The port 50 radiates into an arcuate slot 51 which provides a conduit simultaneously into several of the annularly positioned ports 52 (FIG. 5) in the port plate 39. As the rotor shoe 35 rotates, each new port 52 communicating with the forward end of the arcuate slot 51 is pressurized by the compressed fluid. At the same time, the port 52 at the rear end of the slot 51 is depressurized.

In a second channel in the rotor shoe 35, an arcuate slot 54 (FIGS. 5 and 6) receives the adsorbed fluid components in the columns 18 which communicate with the exhaust ports. As previously described, when compressed air is the fluid and is introduced to the columns 18, the desorbed fluid components include all of the gases in air except oxygen and argon. The desorbed components in the columns 18 are vented upwardly from the arcuate slot 54 through an exhaust port 55 (FIGS. 4 and 6) in the rotor shoe cover plate 44 into a rotor void space. The desorbed fluid then passes into the atmosphere through an exhaust port 58.

The third channel in the rotor shoe 35 is a cross-port channel 60 (FIG. 6). The channel 60 serves as a conduit between two (2) of the columns 18, these two (2) columns being in transition between the pressurizing and desorbing phases of a cycle. Its function is to apply equalizing pressures in columns transitioning between the adsorbing pressure in each cycle. The equalizing pressure provides for a pressure drop in fluid in each column before such column enters the desorption phase in each cycle. This prevents a very rapid decompression in each column and thus prevents an excessively high flow of the desorbed fluid initially from the column. This enhances the concentration of the particular component such as oxygen and argon in each column.

The apparatus described above is disclosed and claimed in U.S. Pat. No. 5,268,021 issued on Dec. 7, 1993, to Charles C. Hill and Theodore B. Hill for a "Fluid Fractionator" and assigned of record to the assignee of record of this application. It has several important advantages over the prior art. It provides a smoother operation than the prior art because several of the columns 18 are receiving the fluid under pressure at any instant and several of the other columns 18 are exhausting the desorbed fluid to the atmosphere at that instant. Thus, any transition of a column from an adsorbing operation to a desorbing operation at any instant will not produce as great a transitory pulse in operation as in the prior art since several other columns will be adsorbing and several other columns will be desorbing at that instant. Furthermore, the equalization of the pressure in the columns 18 in transition will also tend to reduce transitory pulses. These factors tend to enhance the efficiency in the operation of the apparatus and to reduce the noise in the operation of the apparatus. The reduction in the noise results from the equalization in pressure provided by the channel 60 and the relatively large number of columns.

In spite of the advantages discussed in the previous paragraph, there is room for improvement in the fluid fractionator 20 and in the system 10 including such fluid

fractionator. In that system, the positive displacement compressor 13 operates at a constant maximum speed regardless of the flow rate and concentration of the oxygen that the patient desires or needs. The compressor 13 and the motor driving the compressor consume a large amount of power when they operate at a maximum speed. For example, the consumption of a home size oxygen concentrator is on the order of approximately four thousand (4000) kilowatt-hours per year. This amounts to a cost in electricity of several hundred dollars per year. This is a significant amount of money to most families and particularly to families of elderly or retired patients or to patients who are unable to work because of such ailments as asthma or emphysema. The continuous operation of the compressor 13 at a maximum power is also disadvantageous because it limits the operative life of the compressor and the motor driving the compressor.

Home oxygen concentrators generally have a capacity of providing oxygen in a range to approximately six liters per minute (6 LPM) of oxygen flow to the patient. The flow rate of oxygen required by an individual patient is prescribed by the patient's physician. The most common prescription rate is two liters per minute (2 LPM). The prescription is ordinarily for continuous administration twenty four hours (24 hr.) per day year-in and year-out. As the disease of some patients progresses to later stages, the oxygen flow rates prescribed for some patients may be increased. When the flow rate prescribed is less than the maximum rate, the reduced rate is obtained in the prior art by throttling the oxygen flowing to the user (e.g. the patient).

It will be appreciated that not all of the oxygen in the product tank 19 flows to the patient even when the oxygen flows to the patient at a rate of approximately six (6) liters per minute. Even at this flow rate, a substantial portion of the oxygen and the argon in the product tank 19 flows to the columns 18 which are being desorbed. This flow of oxygen and argon facilitates the purging of the desorbed gases in such columns. In this way, the columns are ready to receive the compressed air in the next cycle of operation.

As will be appreciated, oxygen and argon flow through the columns 18 to the product tank. Oxygen constitutes approximately twenty one percent (21%) of air and argon constitutes approximately one percent (1%) of air. When oxygen and argon flow through the columns 18, oxygen comprises approximately ninety four percent (94%) of the product in the oxygen tank. This increased concentration of argon (approximately six percent (6%)) in the product tank 19 has no harmful effect on the patient since argon is a noble, inert gas.

This invention provides a system for adjusting the flow characteristics of the compressor 13 in accordance with the product flow rate desired or prescribed. For example, when the compressor 13 has a variable speed, the speed of the compressor may be varied in accordance with the flow rate desired or prescribed. A variable speed compressor drive may take different forms including the following:

1. An alternating current (AC) induction motor with a variable frequency/variable voltage supply.

This may be the preferred embodiment.

2. A direct current motor (brushless preferred).
3. A pole-changing AC induction motor for two (2) or three (3) operating speeds.
4. A fixed speed AC motor with a continuously variable mechanical transmission.

All of the above are considered to be within the scope of the invention. A variable speed motor 79 for the compressor 13 is shown in FIG. 10.

A variable displacement compressor may also be considered to be within the scope of the invention. Such a compressor may include the following:

1. A rotary vane compressor with a variable displacement in an adjustment in the rotor eccentricity.
2. A variable angle swash plate drive for an axial piston compressor.
3. A piston compressor having a crank shaft drive with a variable throw.

FIG. 10 schematically illustrates a system generally indicated at 78 and constituting an embodiment of the invention for regulating the desired flow rate of the oxygen to the patient. The system shown in FIG. 10 includes the heat exchanger 15, the compressor 13, the columns 18, the orifices 27 in the columns and the product tank 19, all shown in FIG. 1, and the rotary valve distributor assembly 21 shown in FIG. 2. The system shown in FIG. 10 also includes a control 80 which is pre-set to any desired value in accordance with the flow rate desired or prescribed for the particular component such as oxygen. This setting may be provided in accordance with the values indicated in a look-up table. The control 80 may preferably be a microprocessor control.

The microprocessor control 80 may be influenced by an indication from a temperature sensor 81 the output of which is introduced to the control. The microprocessor control 80 may be further influenced by an indication from a pressure sensor 82 the output of which is introduced to the control.

The particular component such as oxygen (and argon) flows from the product tank 19 through a line 84. A regulator 85 may be provided in the line 84 to reduce the pressure of the particular component (e.g. oxygen) flowing from the product tank 19 because there may be a significant change in the pressure of the particular component in the product tank over the flow range which may be provided from the compressor 13.

The particular component (e.g. oxygen) then flows through a flow control device 86 to the patient. The flow control device 86 may provide an additional regulation, such as a fine control, over the rate at which the particular component such as oxygen flows to the user such as the patient. The rate of flow of the particular component through the flow control device 86 is introduced to the microprocessor control 80. A concentration monitor 88 may determine the purity of the particular component such as oxygen through the line 84 at each instant and may indicate this determination to the microprocessor.

As will be seen, the microprocessor control 80 is regulated on a closed loop basis by the temperature of the concentrated fluid passing to the columns 18, the pressure of such concentrated fluid, the speed of the compressor 13, the output of the concentration monitor 88 and the rate of flow of the particular component through the flow control device 86. All of these inputs to the microprocessor control 80 cause the control to adjust the speed of the compressor 13 to produce a flow of the particular fluid component to the user at the desired or prescribed rate. The valve 21 is also adjusted to control the rate at which air is introduced into the columns 18.

The regulated output from the control 80 may also be introduced to a cooling system 89 which regulates the temperature of the compressor 13 and the heat exchanger 15. The output from the microprocessor control 80 may also be introduced to the flow control device 86 to regulate the operation of the flow control device in producing the flow of the particular fluid component to the user at the desired or prescribed value. The output of the control 80 may be additionally introduced to the orifices 27 to regulate the size of the orifices. This is desirable since the rate of flow of the particular fluid component can be regulated by regulating the size of the orifices. This will be described in detail subsequently.

The system shown in FIG. 10 and described above has certain important advantages including the following:

1. There is a significant reduction in power consumption because of the reduced speed for the compressor 13 at reduced flow rates of the particular fluid component such as oxygen. The reduction in the power consumption also results from the reduced speed of the motor 79 driving the compressor 13.
2. The amount of noise produced by the fluid fractionator 20 (or oxygen concentrator) is significantly reduced. This results in part from the reduced speed of the compressor 13 and the motor 79. It also results in part from the fact that the desorption of the adsorbed fluid components to the atmosphere is initiated from a reduced pressure of the desorbed fluid components in each column 18.
3. Because of the reduced compression of the fluid in the columns 18, the temperature rise in the compressed fluid is reduced. This provides for a reduction in the operation of the cooling system 89 and a resultant reduction in the power for operating the cooling system.
4. A power supply can be included which operates at all frequencies and voltages in all markets with substantially equal effectiveness in the different markets.
5. The life of the compressor 13 is significantly increased because the compressor is operated at a reduced speed.
6. There is reduced vibration in the system.

This also contributes to a long life in the system.

7. The size and weight of the compressor 13 and the motor 79 can be reduced, particularly when the compressor is to be operated at relatively low speeds. Furthermore, if and when the compressor is to be operated at maximum speeds, it would probably be for only relatively short periods of time. This would allow the compressor 13 and the motor 79 to be operated above their rated speed without damaging the compressor 13 or the motor 79. This is another reason why the size and weight of the compressor 13 and the motor 79 can be considerably reduced in most instances.
8. The timing of the rotary valve distributor assembly 21 and the opening of the orifice 27 can be tailored for all flow rates to provide an optimal operation of the system.
9. There is a potential to compensate for a reduced compressor inlet density as a result of a high ambient temperature or a high altitude. This will be discussed in detail subsequently.

The timing of the rotary distributor valve assembly 21 can be provided in various ways. One alternative is that a synchronous motor can be provided with a variable frequency drive as the motor 22 (not shown in FIG. 10 but shown in FIG. 11). Other alternatives involve the use of a stepper motor as the motor 22 or a DC gear motor to drive the rotary valve distributor assembly 21. Another alternative is to provide a pneumatic actuation with speed sensitive to compressor speed. The valve timing can be controlled by a microprocessor for motors responsive to a microprocessor control or by digital/analog circuits in the controller.

Regulating the speed of the rotary distributor valve assembly 21 in accordance with the variations in the speed of the compressor 13 may be desirable under certain circumstances. As the speed of the compressor 13 is decreased while maintaining the speed of the distributor valve assembly 21 constant, the pressure of the fluid in the columns 18 is decreased. This causes the pressure of the nitrogen and the other components adsorbed in the molecular sieves in the columns 18 to decrease.

In FIG. 15, progressive speeds of the compressor are shown on the horizontal axis and progressive concentrations of oxygen in the fluid in the product holding tank 19 are shown on the vertical axis. As will be seen at 130 in FIG. 15, the concentration of the oxygen in the mixture in the product holding tank 19 remains substantially constant at a value of approximately ninety four percent (94%) for compressor speeds between approximately nine hundred revolutions per minute (900 rpm) and thirteen hundred revolutions per minute (1300 rpm). At compressor speeds progressively below approximately nine hundred revolutions per minute (900 rpm), the concentration of the oxygen in the mixture in the product holding tank 19 becomes progressively reduced. At compressor speeds of approximately six hundred revolutions per minute (600 rpm), the concentration of the oxygen in the mixture in the holding tank 19 is approximately eighty eight percent (88%).

It is desirable to maintain the concentration of the oxygen in the mixture in the product holding tank 19 at a value of at least ninety percent (90%) regardless of the speed of the compressor 13. This can be accomplished by decreasing the rotary speed of the distributor valve assembly 21 as the speed of the compressor 13 is decreased. By decreasing the rotary speed of the distributor valve assembly 21, each column 18 is provided with an increased time to receive air under pressure from the compressor 13. As a result, the pressure of the air in each column 18 increases and the pressure of the oxygen and argon in the product holding tank 19 correspondingly increases. This inhibits nitrogen in the columns 18 from passing into the product holding tank 19. In this way, the concentration of the oxygen in the product holding tank 19 can be maintained at a value of at least ninety percent (90%) even as the flow rate of the oxygen and nitrogen into the product holding tank decreases. FIG. 15 also shows at 132 the flow rate of the oxygen at different compressor speeds. As will be seen, the flow rate of the oxygen to the patient in liters per minute increases substantially linearly with increased compressor speeds.

FIG. 17 illustrates at 134 the relationship between flow rates of the fluid from the compressor 13 and the compressor discharge pressure in psig for a normal system of the prior art. FIG. 17 also illustrates at 136 the relationship between flow rates of the fluid from the compressor 13 and the compressor discharge pressure for a system which includes certain features of applicants' system. These include the rotary valve distributor assembly 21 operating at variable speeds and the valve providing a variable orifice as shown in FIG. 13. As shown in FIG. 17, operation of the system of this invention is advantageous over the systems of the prior art because it provides significantly higher compressor discharge rates throughout most of the range of the compressor flow rates.

FIG. 11 illustrates a simplified system for controlling the rate of flow of a fluid such as oxygen to a user such as a patient. The system includes the compressor 13, the columns 18, the product tank 19, a microprocessor control 101 corresponding to the control 80 in FIG. 10, the oxygen concentration monitor 88, the rotary valve distributor assembly 21 and the motor 22 (not shown) for driving the valve distributor assembly 21. The compressor 13 may be a wobble piston compressor and the motor 22 may be a synchronous gear motor. A flow control 90 corresponding to the flow control 85 may be included for controlling the rate of flow of the particular fluid component such as oxygen to a user such as a patient. The flow control 90 may be a standard flow control or it may be electronic. A regulator such as the regulator 85 may be included in the line between the product tank 19 and the flow control device 90.

The system shown in FIG. 11 senses the rate of oxygen flow in the monitor 88 and introduces this sensed rate to the microprocessor control 101. The microprocessor control 101 then varies the operation of the compressor 13, the motor 22 and the flow control 90 to regulate the rate of flow of the oxygen to the patient at the desired or prescribed rate. The system shown in FIG. 11 operates on a closed loop basis to provide the desired regulation of the oxygen flow. As will be seen, the system shown in FIG. 11 does not include such controls as the temperature sensor 81, the pressure sensor 82 and the cooling system 89.

FIG. 12 illustrates an open loop system for regulating the rate of oxygen flow to the patient. As will be seen, the system shown in FIG. 12 is similar to the system shown in FIG. 11 except that it eliminates the lines from the microprocessor control 101 to the oxygen monitor 88, the compressor 13 and the motor 79. In this system, the microprocessor control 101 indicates a desired flow of oxygen to the patient. The compressor 13, the motor 79 and the flow control 90 are then set to desired values for obtaining this desired oxygen flow. The oxygen monitor 88 is then read during the operation of the system. On the basis of this reading, adjustments are made manually in the compressor 13, the motor 79 and the flow control 90 to obtain the desired or prescribed rate of oxygen flow to the patient. These adjustments may be made on the basis of a look-up table establishing individual values for these parameters under different sets of conditions.

The systems shown in FIGS. 10, 11 and 12 may include an indicator 100 for indicating when certain components such as the compressor 13 have to be replaced. As will be appreciated, the operation of the systems shown in FIGS. 10, 11 and 12 may become degraded with time as a result of a number of factors. These include dirty filters, compressor wear, motor wear and pneumatic leaks. The systems shown in FIGS. 10, 11 and 12 compensate for these system degradations by increasing the compressor flow to maintain the purity/concentration of the particular fluid component such as oxygen at the desired or prescribed flow rate. The indicator 100 indicates when the speed or other variable characteristics of the compressor 13 as sensed by the indicator 100 exceed particular limits for the rate of fluid flow desired or prescribed.

As shown in FIG. 13, the orifice 27 in each column 18 may be formed from a molded elastomeric material 110 such as rubber. As the pressure of the particular fluid component such as oxygen flowing through the orifice 27 decreases, the elastomeric material 110 defining the orifice 27 has a decreased flexure. This decreases the size of the orifice 27 in each column 18. In this way, the orifice 27 in each column 18 becomes closed with decreases in the pressure of the fluid such as oxygen. This provides an increase in the pressure of the fluid in the column 18. This is desirable at low rates of oxygen flow to the patient to maintain the oxygen concentration in the oxygen holding tank at a value of at least ninety percent (90%). By decreasing the size of the orifice 27 at these low flow rates, the pressure of the fluid in the columns 18 is increased. The concentration of the oxygen holding tank 19 is accordingly maintained at a value of at least ninety percent (90%).

In the embodiment shown in FIGS. 1–9, the desorbed fluid components are passed through the chamber 57 and the exhaust port 58 to the atmosphere. This causes a relatively loud noise to be produced every time that the desorbed fluid in one of the columns 18 is released to the chamber 57 and from the chamber to the exhaust port 58. FIG. 14 shows an arrangement for significantly reducing the noise produced every time that the adsorbed fluid in one of the columns 18 is desorbed.

The embodiment shown in FIG. 14 includes the port plate 39, the rotor shoe 35, and the manifold 31. The manifold 31 has a cover 111. A bearing carrier 112 is suitably attached to the manifold cover 111 as by screws 114. A rotor shaft 116 is disposed within an opening in the bearing carrier 112 and a bearing 117 is disposed between the bearing carrier 112 and the bearing shaft 116.

The bearing carrier 112 and the manifold cover 111 define a chamber 118 which is enlarged relative to the embodiment shown in FIGS. 1–7. The desorbed fluid from each column 18 passes into the chamber 118 and is retained in the enclosure since an exhaust port corresponding to the exhaust port 58 is not provided in the embodiment shown in FIG. 12. Porous plugs 120 are disposed in apertures 122 in the bearing carrier 112. Since the desorbed fluid in the chamber 118 is under some pressure, it is slowly released to the atmosphere through the porous plugs 120.

The decrease in noise in the operation of the system shown in FIG. 14 results from several factors. One factor is the increased volume of the chamber 118 relative to the corresponding chamber 57 shown in FIG. 4. A second factor is that the desorbed fluid in the chamber 118 is retained within the chamber and is released slowly to the atmosphere through the plugs 120. This is facilitated by the fact that the desorbed fluid in the chamber 118 is not released to the atmosphere through a port such as the port 58 in FIG. 4.

It will be appreciated that all of the features of this invention can be provided in a conventional two (2) column system of the prior art. Such a conventional two (2) column system is shown in FIG. 16. It includes the compressor 13, a distributor valve assembly 21, the pair of the columns 18, the orifices 27, the product holding tank 19 and a control valve 150 for controlling the rate at which the oxygen or argon flow to the user (e.g. the patient).

It will also be appreciated that the systems constituting this invention can be used to provide other fluids than oxygen and to provide such fluids to users other than a patient without departing from the scope of the invention. For example, the system of this invention can be used to provide plural fluids for industrial purposes. One use illustratively is to provide nitrogen to industrial organizations which provide an inert atmosphere. Another illustrative use is oxygen for welding.

The apparatus constituting this invention has several important advantages. It provides for a controlled and adjustable speed of the compressor 13 to adjust the rate of flow of a fluid such as oxygen to a user (e.g. a patient). The adjustable control of the compressor speed can be either on a closed loop basis or an open loop basis. Furthermore, an indication can be provided as to when the compressor speed has been adjusted out of a normal range of values to obtain a prescribed flow of the fluid, such as oxygen to the user (e.g. patient), at a required purity.

The apparatus of this invention also has other advantages. As the speed of the compressor becomes reduced below a particular value, the concentration of the oxygen tends to become reduced below a desirable value. The apparatus of this invention provides for an adjustment in the rotary speed of the distributor valve assembly 21 in the fluid fractionator 20 to increase the pressure of the fluid in the columns 18 in the fluid fractionator 20. The adjustable orifices 27 at the outlet of the fluid fractionator 20 also tend to close with decreases in the pressure of the fluid in the fluid fractionator 20, thereby maintaining the pressure of the fluid in the columns 18 in the fluid fractionator.

As the speed of the compressor 13 is decreased, the noise generated by the compressor decreases. The noise in the fluid fractionator 20 is also significantly decreased by providing the porous plugs 120 in the bearing carrier 112 and by increasing the size of the chamber 118. In this way, the desorbed components in the chamber 118 provide a minimal noise when they enter the chamber and when they leak slowly into the atmosphere from the chamber.

Although this invention has been disclosed and illustrated with reference to particular embodiments, the principles involved are susceptible for use in numerous other embodiments which will be apparent to persons skilled in the art. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.

We claim:

1. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns, more than two (2), constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component in the columns after the passage of the first component through the columns,

sequentially selecting at least first ones of the columns on a cyclic basis to pass the first component in such at least first ones of such columns and adsorb the second component in the at least first ones of the columns on a cyclic basis and simultaneously selecting at least second ones of the columns on the cyclic basis to desorb the second component in the at least second ones of the columns on the cyclic basis,

compressing the fluid before the introduction of the fluid to the at least first ones of the columns on the cyclic basis, and

varying the compression of the fluid before the introduction of the compressed fluid to the at least first ones of the columns to maintain the flow of such first component to the user at the prescribed rate.

2. In a method as set forth in claim 1, the steps of:

providing a flow control of the first component after the passage of the first component through the at least first ones of the columns on the cyclic basis and before the passage of the first component to the user,

indicating variations in the rate of flow of the first component through the flow control,

varying the compression of the fluid in accordance with the indications of the variations in the rate of flow of the first component through the flow control, before the introduction of the compressed fluid to the at least first ones of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

3. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component in the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in such at least first one of the columns and adsorb the second component in the at least first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of such first component to the user at the prescribed rate,

indicating variations in the temperature of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the temperature of the fluid in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of such first component to the user at the prescribed rate.

4. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component in the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in such at least first one of the columns and adsorb the second component in the at least first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of such first component to the user at the prescribed rate,

indicating variations in the pressure of the fluid in the at least first one of the columns and

varying the compression of the fluid in accordance with the indications of the variations in the pressure of the fluid in the at least the first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of such first component to the user at the prescribed rate.

5. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component in the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in such at least first one of the columns and adsorb the second component in the at least first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis, and

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of such first component to the user at the prescribed rate,

indicating variations in the concentration of the first component in the at least first one of the columns, and

varying the compression of the fluid in accordance with the variations in the concentration of the first component in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

6. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component in the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in such at least first one of the columns and adsorb the second component in the at least first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis, and

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of such first component to the user at the prescribed rate,

the compression of the fluid being provided by a compressor,

cooling the compressor, and

varying the cooling of the compressor in accordance with the variations in the compression provided on the fluid by the compressor.

7. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component in the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in such at least first one of the columns and adsorb the second component in the at least first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of such first component to the user at the prescribed rate,

indicating variations in the temperature of the fluid in the at least first one of the columns,

varying the compression of the fluid in accordance with the indications of the variations in the temperature of the fluid in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of such first component to the user at the prescribed rate,

indicating variations in the pressure of the fluid in the at least first one of the columns,

varying the compression of the fluid in accordance with the indications of the variations in the pressure of the fluid in the at least the first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of such first component to the user at the prescribed rate,

providing a flow control of the first component after the passage of the first component through the at least first one of the columns on the cyclic basis and before the passage of the first component to the user,

varying the compression of the fluid in accordance with the indications of the variations in the rate of flow of the first component through the flow control, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate,

indicating variations in the rate of flow of the first component through the flow control,

varying the compression of the fluid in accordance with the indications of the variations in the rate of flow of the first component through the flow control, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate,

indicating variations in the concentration of the first component in the at least first one of the columns, and

varying the compression of the fluid in accordance with the variations in the concentration of the first component in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

8. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the

second component in the columns and to desorb the second component from the columns after the passage of the first component through the columns,

selecting at least a first one of the columns on a cyclic basis to pass the first component in such at least first one of the columns and to adsorb the second component in such at least first one of the columns and selecting at least a second one of the columns on the cyclic basis to desorb the second component in the at least second one of the columns,

the selection of the least first one of the columns and the at least second one of the columns including a valve operative on the cyclic basis in a variable time,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of the first component to the user at a prescribed rate, and

varying the time for the operation of the valve on the cyclic basis in accordance with the variations in the compression of the fluid.

9. In a method as set forth in claim 8, the steps of:

desorbing the adsorbed second component in the at least first one of the columns into a chamber after the passage of the first component through the at least first one of the columns, and

providing for a controlled release of the desorbed second component from the chamber into the atmosphere.

10. In a method as set forth in claim 8, the steps of:

providing the compression of the fluid in a compressor,

providing a variable cooling of the compressor, and

varying the cooling of the compressor in accordance with the variations in the compression of the fluid in the compressor.

11. In a method as set forth in claim 8, the steps of:

providing a flow control with variable characteristics for the introduction of the first component to the user after the passage of the first component through the at least first one of the columns, and

varying the characteristics of the flow control in accordance with the variations in the compression of the fluid to maintain the flow of the first component to the user at the prescribed rate.

12. In a method as set forth in claim 8, the steps of:

indicating variations in the concentration of the first component in the at least first one of the columns, and

varying the compression of the fluid, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, in accordance with the indications of the variations in the concentration of the first component in the at least first one of the columns.

13. In a method as set forth in claim 9, the steps of:

desorbing the adsorbed second component in the at least first one of the columns into a chamber,

providing for a controlled release of the desorbed second component from the chamber into the atmosphere,

providing the compression of the fluid in a compressor,

providing a variable cooling of the compressor, and

varying the cooling of the compressor in accordance with the variations in the compression of the fluid in the compressor,

providing a flow control with variable characteristics for the introduction of the first component to the user after the passage of the first component through the at least first one of the columns, and

varying the characteristics of the flow control in accordance with the variations in the compression of the fluid to maintain the flow of the first component to the user at the prescribed rate.

14. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component from the columns after the passage of the first component through the columns,

selecting at least a first one of the columns on a cyclic basis to pass the first component in such at least first one of the columns and to adsorb the second component in such at least first one of the columns and selecting at least a second one of the columns on the cyclic basis to desorb the second component in the at least second one of the columns,

the selection of the least first one of the columns and the at least second one of the columns including a valve operative on the cyclic basis in a variable time,

compressing the fluid before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns to maintain the flow of the first component to the user at a prescribed rate,

varying the time for the operation of the valve on the cyclic basis in accordance with the variations in the compression of the fluid,

providing a plurality of orifices, each individual one of the orifices being disposed in an individual one of the columns and each individual one of the orifices having variable characteristics to pass the first component through the individual one of the columns to the user in accordance with the variations in the characteristics of such individual one of the orifices, and

varying the characteristics of the orifice in the at least first one of the columns in accordance with the variations in the compression of the fluid introduced to the at least first one of the columns on the cyclic basis.

15. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component from the columns after the passage of the first component through the columns,

selecting at least a first one of the columns on a cyclic basis to pass the first component in the least first one of the columns and adsorb the second component in the at least first one of the columns on the cyclic basis and selecting at least a second one of the columns on the cyclic basis to desorb the second component in the at least second one of the columns after the passage of the first component through the at least first one of the columns,

compressing the fluid before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the least first one of the columns to maintain the flow of such first component to the user at the prescribed rate,

controlling the flow of the first component to the user after the passage of the first component through the at least first one of the columns, and

varying the control of the flow of the first component to the user in accordance with the variations in the compression of the fluid, after the passage of the first component through the at least first one of the columns, to maintain the flow of the first component to the user at the prescribed rate.

16. In a method as set forth in claim 15, the steps of:

providing an indication of variations in the temperature of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the temperature of the fluid in the at least first one of the columns, before the introduction of the fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

17. In a method as set forth in claim 16, the steps of:

indicating variations in the pressure of the fluid in the at least first one of the columns,

varying the compression of the fluid in accordance with the indications of the variations in the pressure of the fluid in the at least first one of the columns on the cyclic basis, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate,

indicating variations in the concentration of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the concentration of the fluid in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate,

indicating variations in the rate of flow of the first component to the user after the flow of the first component from the at least first one of the columns on the cyclic basis, and

varying the compression of the fluid in accordance with the indications of the variations in the rate of the flow of the fluid to the user, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the rate of flow of the fluid to the user at the prescribed rate.

18. In a method as set forth in claim 15, the steps of:

indicating variations in the pressure of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the pressure of the fluid in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

19. In a method as set forth in claim 15, the steps of:

indicating variations in the concentration of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the concentration of the fluid in the at least first one of the columns, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

20. In a method as set forth in claim 15, the steps of:

indicating variations in the rate of flow of the first component to the user after the flow of the first component from the at least first one of the columns, and

varying the compression of the fluid in accordance with the variations in the rate of the flow of the fluid to the user, before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis, to maintain the rate of flow of the fluid to the user at the prescribed rate.

21. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at a prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component from the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in the at least first one of the columns and adsorb the second component in at least the first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis after the passage of the first component through the columns,

compressing the fluid in a compressor before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis to maintain the flow of such first component to the user at the prescribed rate,

cooling the compressor, and

varying the cooling of the compressor in accordance with the variations of the compression of the fluid in the compressor.

22. In a method as set forth in claim 21,

indicating variations in the temperature of the fluid in the least first one of the columns, and

varying the compression of the fluid in the at least first one of the columns in accordance with the indications of the variations in the temperature of the fluid in the at least first one of the columns, before the introduction of the compressed fluid into the at least first one of the columns on the cyclic basis, to maintain the flow of such first component to the at least first one of the columns at the prescribed rate.

23. In a method as set forth in claim 21, the steps of:

indicating variations in the pressure of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the pressure of the fluid in the at least first one of the columns, before the introduction of the compressed fluid into the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

24. In a method as set forth in claim 21, the steps of:

indicating variations in the concentration of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indications of the variations in the concentration of the fluid in the at least first one of the columns, before the introduction of the compressed fluid into the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

25. In a method of receiving a first component from a compressed fluid also having a second component and of providing for the flow of such first component to a user at prescribed rate, the steps of:

providing a plurality of columns constructed to pass the first component through the columns and to adsorb the second component in the columns and to desorb the second component from the columns after the passage of the first component through the columns,

selecting at least a first one of the columns to pass the first component in the at least first one of the columns and adsorb the second component in the at least the first one of the columns on a cyclic basis and selecting at least a second one of the columns to desorb the second component in the at least second one of the columns on the cyclic basis after the passage of the first component through the columns,

compressing the fluid in a compressor before the introduction of the fluid to the at least first one of the columns on the cyclic basis,

varying the compression of the fluid before the introduction of the compressed fluid to the at least first one of the columns on the cyclic basis to maintain the flow of such first component to the user at the prescribed rate,

cooling the compressor,

varying the cooling of the compressor in accordance with the variations of the compression of the fluid in the compressor,

passing the first component through a flow control having a variable aperture, after the passage of the first component from the at least first one of the columns on the cyclic basis, for controlling the rate of passage of the first component to the user, and

adjusting the aperture in the flow control in accordance with the variations in the compression of the fluid to maintain the flow of the first component to the user at the prescribed rate.

26. In a method as set forth in claim 25, the steps of:

indicating variations in the temperature of the fluid in the least first one of the columns, and

varying the compression of the fluid in the at least first one of the columns in accordance with the indication of the variations in the temperature of the fluid in the at least first one of the columns, before the introduction of the compressed fluid into the at least first one of the columns on the cyclic basis, to maintain the flow of such first component to the at least first one of the columns,

indicating variations in the pressure of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indication of the variations in the pressure of the fluid in the at least first one of the columns, before the introduction of the compressed fluid into the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate,

indicating variations in the concentration of the fluid in the at least first one of the columns, and

varying the compression of the fluid in accordance with the indication of the variations in the concentration of the fluid in the at least first one of the columns, before the introduction of the compressed fluid into the at least first one of the columns on the cyclic basis, to maintain the flow of the first component to the user at the prescribed rate.

* * * * *

EXHIBIT 3

EXHIBIT 3

US006691702B2

(12) **United States Patent**
Appel et al.

(10) **Patent No.:** **US 6,691,702 B2**
(45) **Date of Patent:** ***Feb. 17, 2004**

(54) **PORTABLE OXYGEN CONCENTRATION SYSTEM AND METHOD OF USING THE SAME**

(75) Inventors: **William Scot Appel**, San Diego, CA (US); **David Phillip Winter**, Encinitas, CA (US); **Brian Kenneth Sward**, San Diego, CA (US); **Masato Sugano**, Tokyo (JP); **Edmund Salter**, Oceanside, CA (US); **James A. Bixby**, La Jolla, CA (US)

(73) Assignees: **SeQual Technologies, Inc.**, San Diego, CA (US); **Teijin Limited**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/134,868**

(22) Filed: **Apr. 29, 2002**

(65) **Prior Publication Data**

US 2003/0005928 A1 Jan. 9, 2003

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/632,099, filed on Aug. 3, 2000.

(51) **Int. Cl.**[7] **A61M 15/00**; A61M 16/00; A62B 7/08; A62B 21/00

(52) **U.S. Cl.** **128/202.26**; 128/201.25; 128/205.11; 128/204.22

(58) **Field of Search** 128/201.25, 205.11, 128/205.18, 204.17, 204.22, 204.21, 202.26, 205.12, 204.18, 204.23, 204.26; 251/283

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,077,779 A 3/1978 Sircar
4,469,494 A 9/1984 Van Weenen

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

DE	197 07 097 A1	2/1997
EP	0 266 051 A1	9/1987
EP	0 757 919 A1	2/1997
EP	0 312 910 A1	10/1998
EP	0 875 277 A1	11/1998
EP	0 884 086 A2	12/1998
EP	0 884 088 A1	12/1998
EP	0 884 086 A3	1/1999
EP	1 044 714 A1	10/2000
EP	1 044 715 A1	10/2000
GB	2 164 568 A	3/1986
WO	WO 97/32692	9/1997

OTHER PUBLICATIONS

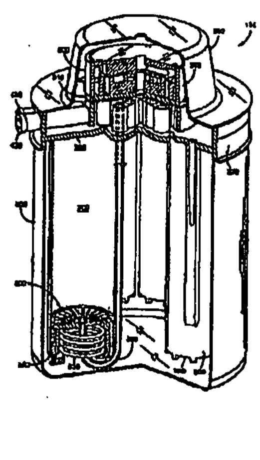
Patent Abstracts from Japan; vol. 2000; No. 02; 29 Feb. 29, 2000 and JP 11 319095A (Sumitomo Bakelite Co., Ltd.); Nov. 24, 1999; Abstract.

Primary Examiner—Weilun Lo
Assistant Examiner—Michael G. Mendoza
(74) *Attorney, Agent, or Firm*—Procopio, Cory, Hargreaves & Savitch, LLP

(57) **ABSTRACT**

A portable oxygen concentrator system adapted to be readily transported by a user includes a rechargeable energy source and a concentrator powered by the energy source. The concentrator converts ambient air into concentrated oxygen gas for the user and includes a plurality of adsorption beds and a rotary valve assembly. The rotary valve assembly is relatively rotatable with respect to the plurality of adsorption beds to provide valving action for selectively transferring fluids through the plurality of adsorption beds for converting ambient air into concentrated oxygen gas for the user. The ratio of adiabatic power to oxygen flow for the concentrator is in the range of 6.2 W/LPM to 23.0 W/LPM.

34 Claims, 17 Drawing Sheets



U.S. PATENT DOCUMENTS

4,477,264 A		10/1984	Kratz et al.	
4,491,459 A		1/1985	Pinkerton	
4,576,616 A	*	3/1986	Mottram et al.	95/96
4,801,308 A		1/1989	Keefer	
4,859,217 A		8/1989	Chao	
4,925,464 A		5/1990	Rabenau et al.	
4,968,329 A		11/1990	Keefer	
4,971,609 A		11/1990	Pawlos	
5,074,892 A		12/1991	Leavitt	
5,112,367 A		5/1992	Hill	
5,114,441 A		5/1992	Kanner et al.	
5,268,021 A	*	12/1993	Hill et al.	95/98
5,366,541 A	*	11/1994	Hill et al.	96/124
5,413,625 A		5/1995	Chao et al.	
RE35,099 E		11/1995	Hill	
5,593,478 A	*	1/1997	Hill et al.	96/111
5,626,151 A		5/1997	Linden	
5,730,778 A	*	3/1998	Hill et al.	95/12
5,807,423 A		9/1998	Lemcoff et al.	
5,814,130 A		9/1998	Lemcoff et al.	
5,814,131 A		9/1998	Lemcoff et al.	
5,820,656 A		10/1998	Lemcoff et al.	
5,827,358 A	*	10/1998	Kulish et al.	96/115
5,882,380 A	*	3/1999	Sircar	95/98
5,890,490 A		4/1999	Aylsworth et al.	
5,891,217 A		4/1999	Lemcoff et al.	
5,893,944 A		4/1999	Dong	
5,912,422 A		6/1999	Bomard et al.	
5,928,189 A		7/1999	Phillips	
6,010,317 A		1/2000	Maget	
6,010,555 A		1/2000	Smolarek et al.	
6,051,050 A		4/2000	Keefer et al.	
6,056,804 A	*	5/2000	Keefer et al.	95/96
6,068,680 A	*	5/2000	Kulish et al.	95/98
6,143,056 A		11/2000	Smolarek et al.	
6,152,991 A		11/2000	Ackley	
6,176,897 B1	*	1/2001	Keefer	95/98
6,253,778 B1		7/2001	Smolarek et al.	
6,311,719 B1	*	11/2001	Hill et al.	137/312
6,346,139 B1		2/2002	Czabala	
6,395,065 B1	*	5/2002	Murdoch et al.	95/22
6,471,744 B1	*	10/2002	Hill	95/19
6,514,319 B2	*	2/2003	Keefer et al.	95/101
6,521,562 B1	*	2/2003	Clem et al.	502/214
6,551,384 B1	*	4/2003	Ackley et al.	95/96
2001/0023640 A1		9/2001	Keefer	

* cited by examiner

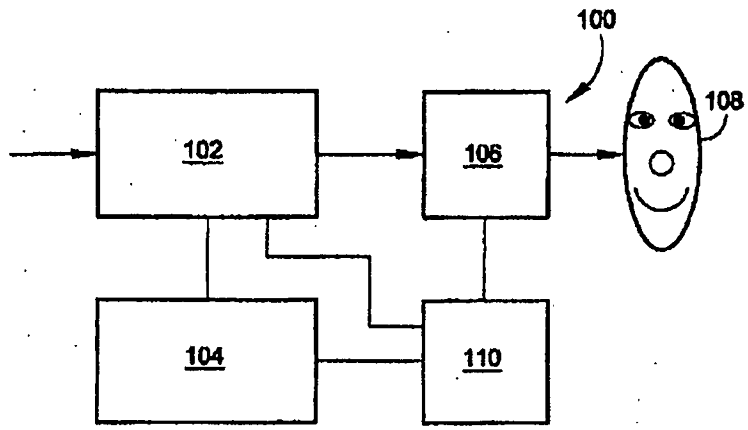

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FIG. 1

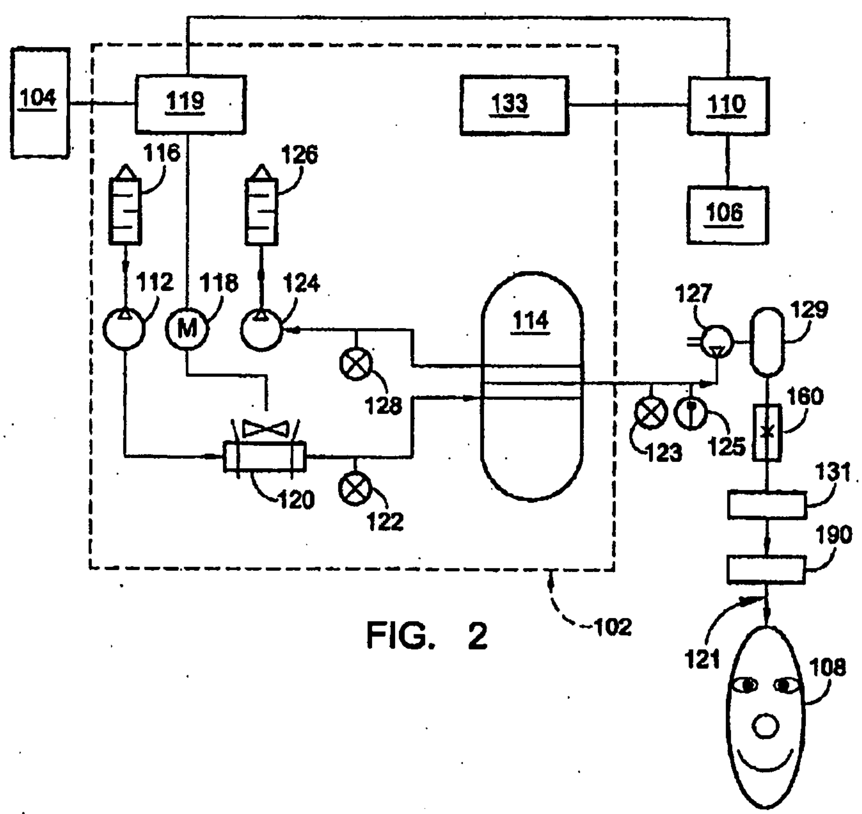
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FIG. 2

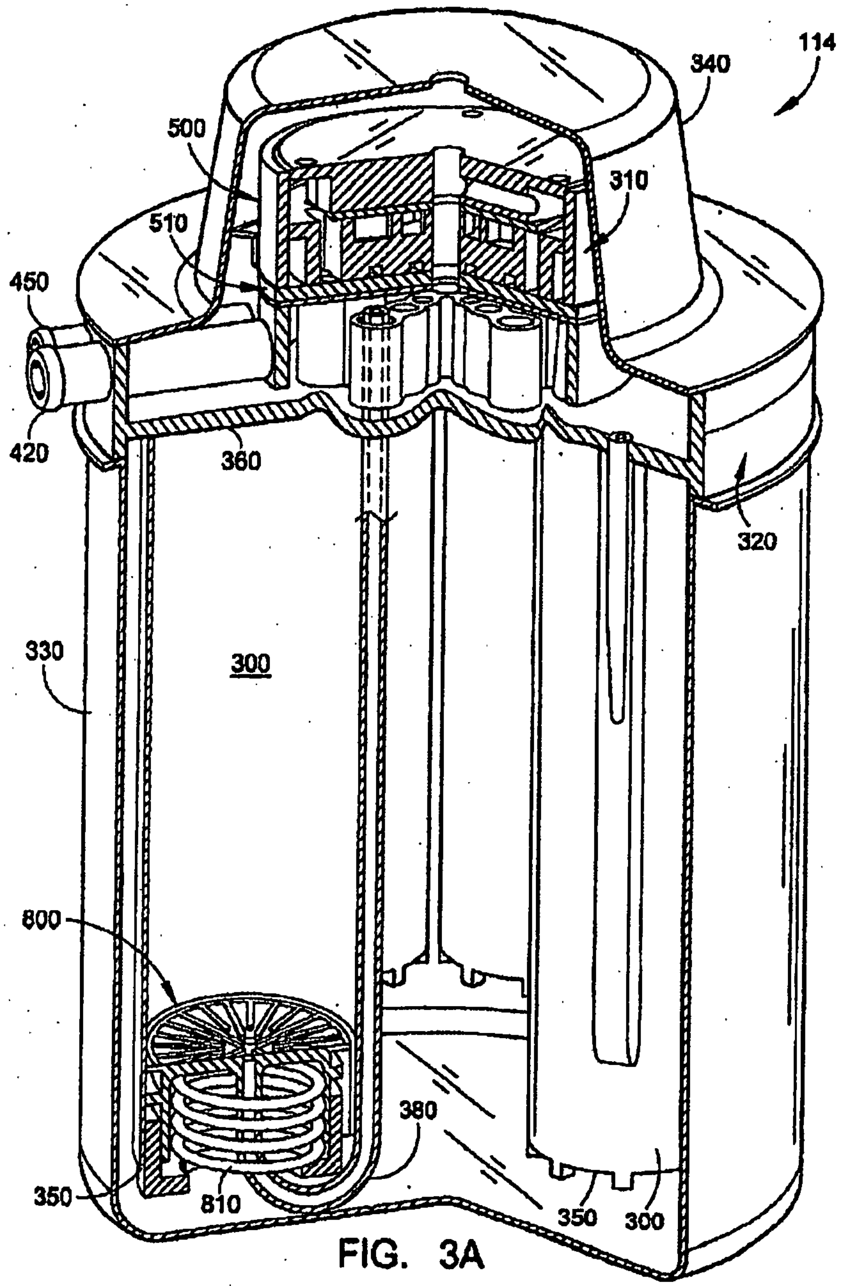
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FIG. 3A

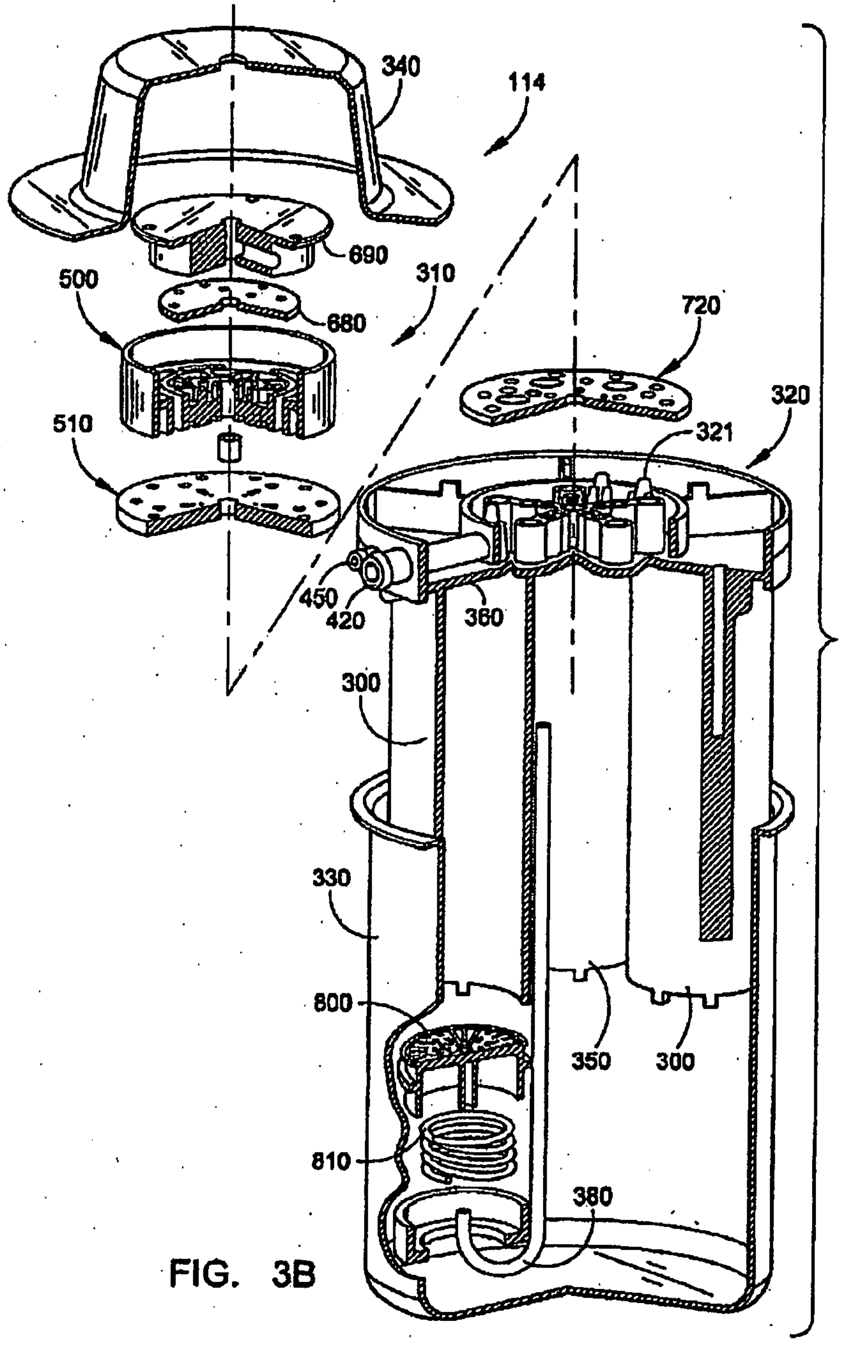
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FIG. 3B

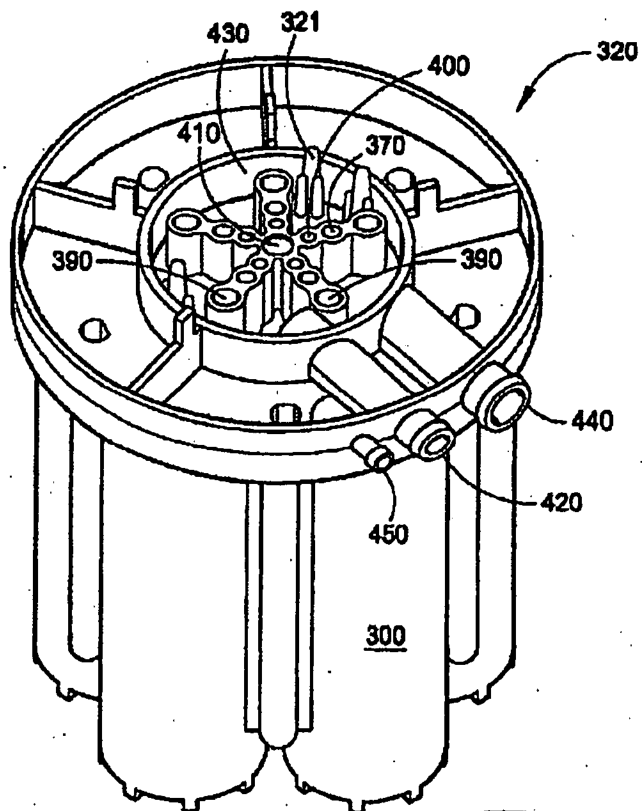
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FIG. 4

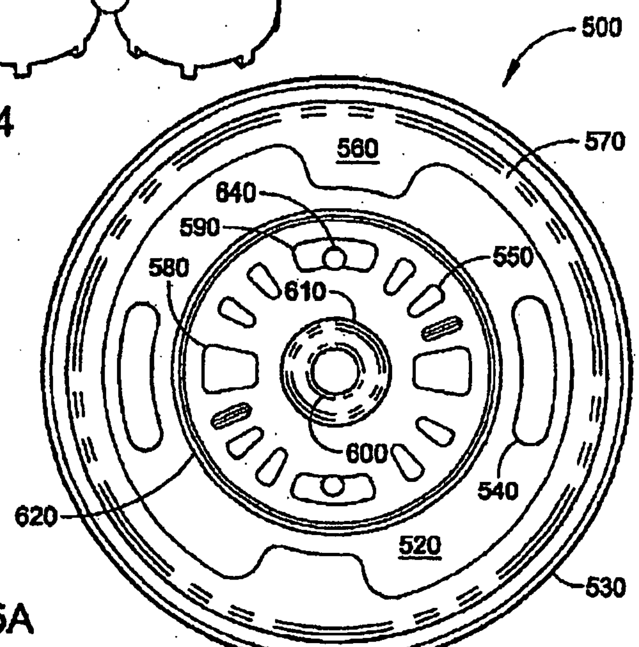
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FIG. 5A

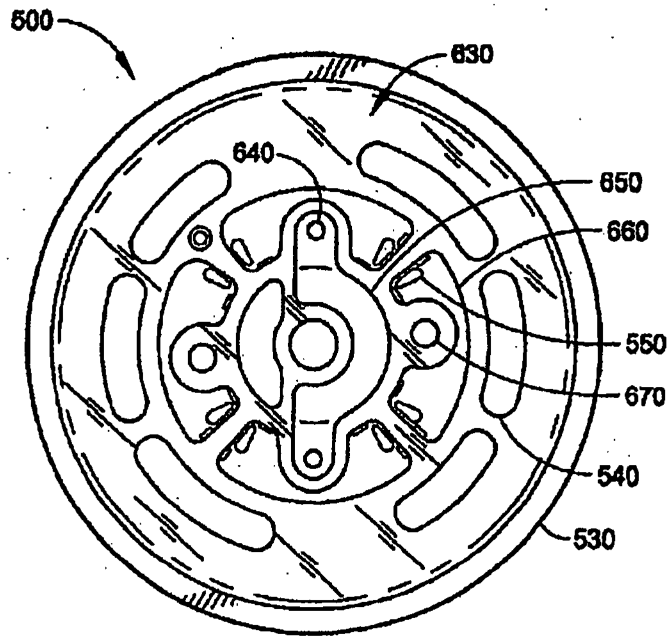
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FIG. 5B

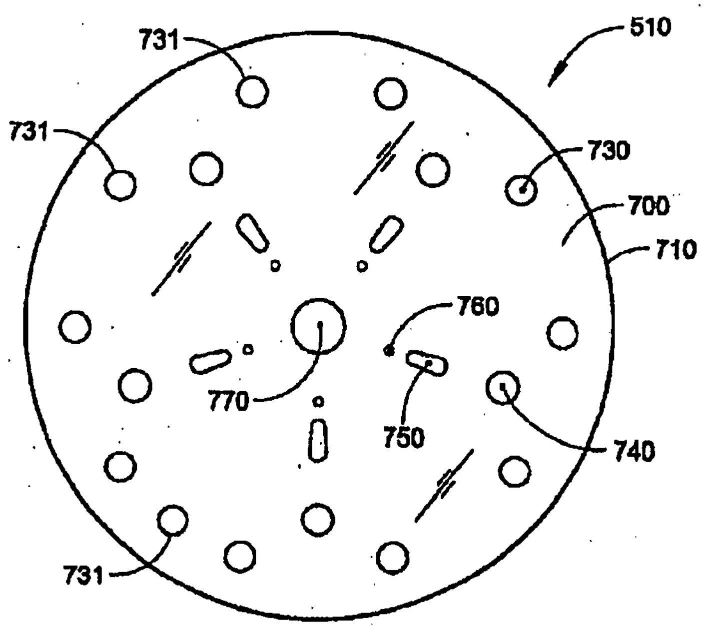
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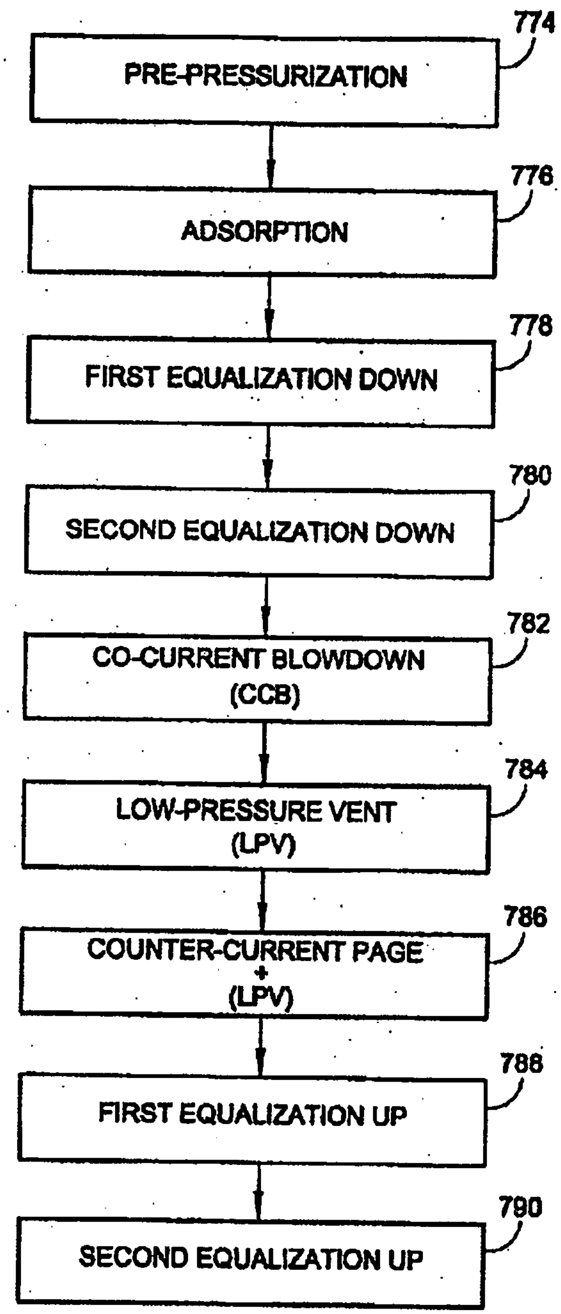
FIG. 6A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ADSORPTION
778
FIRST EQUALIZATION DOWN
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SECOND EQUALIZATION DOWN
782
CO-CURRENT BLOWDOWN (CCB)
784
LOW-PRESSURE VENT (LPV)
786
COUNTER-CURRENT PAGE + (LPV)
788
FIRST EQUALIZATION UP
790
SECOND EQUALIZATION UP

FIG. 6B

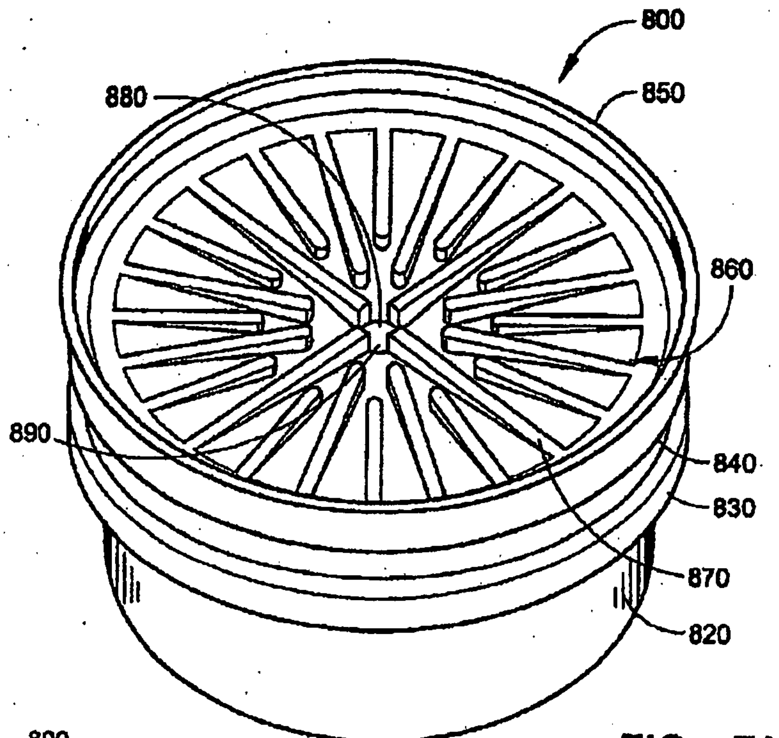

FIG. 7A

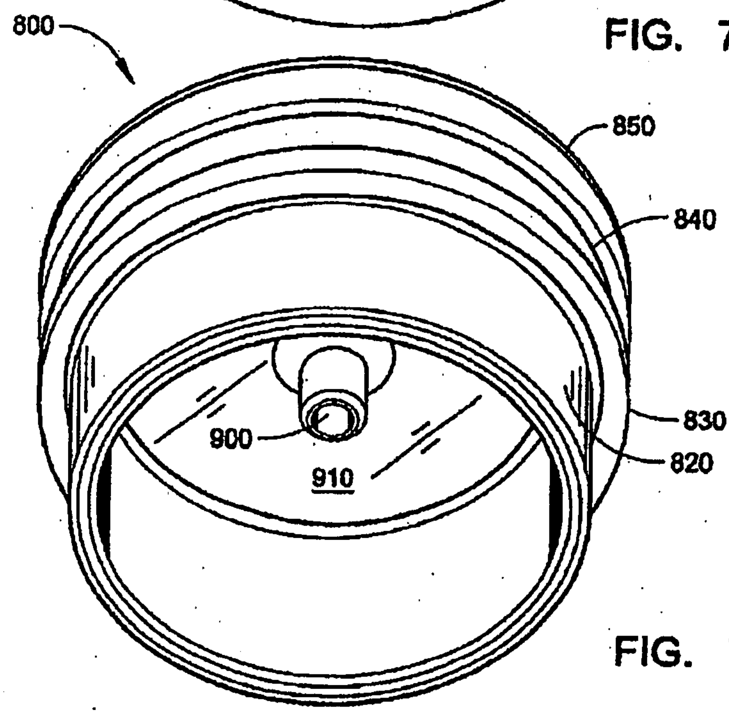

FIG. 7B

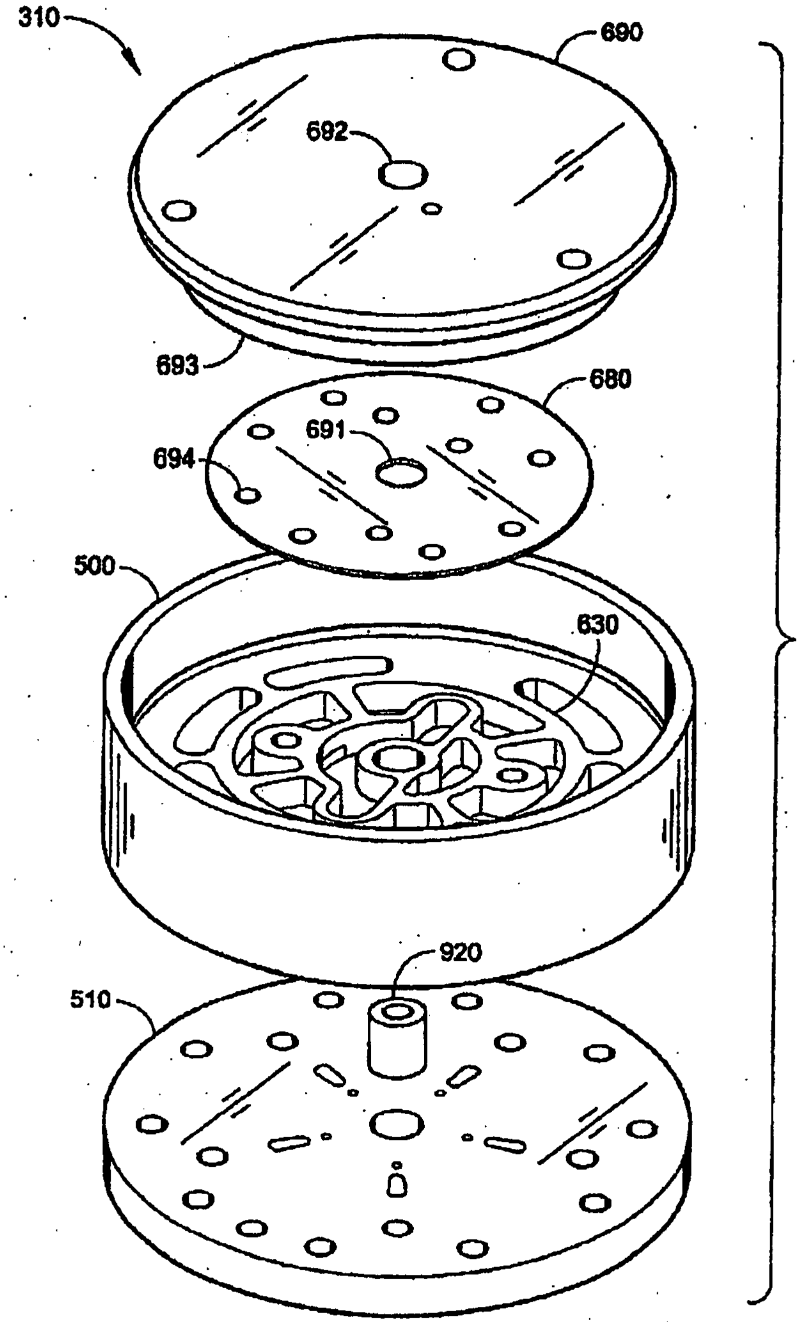

FIG. 8A

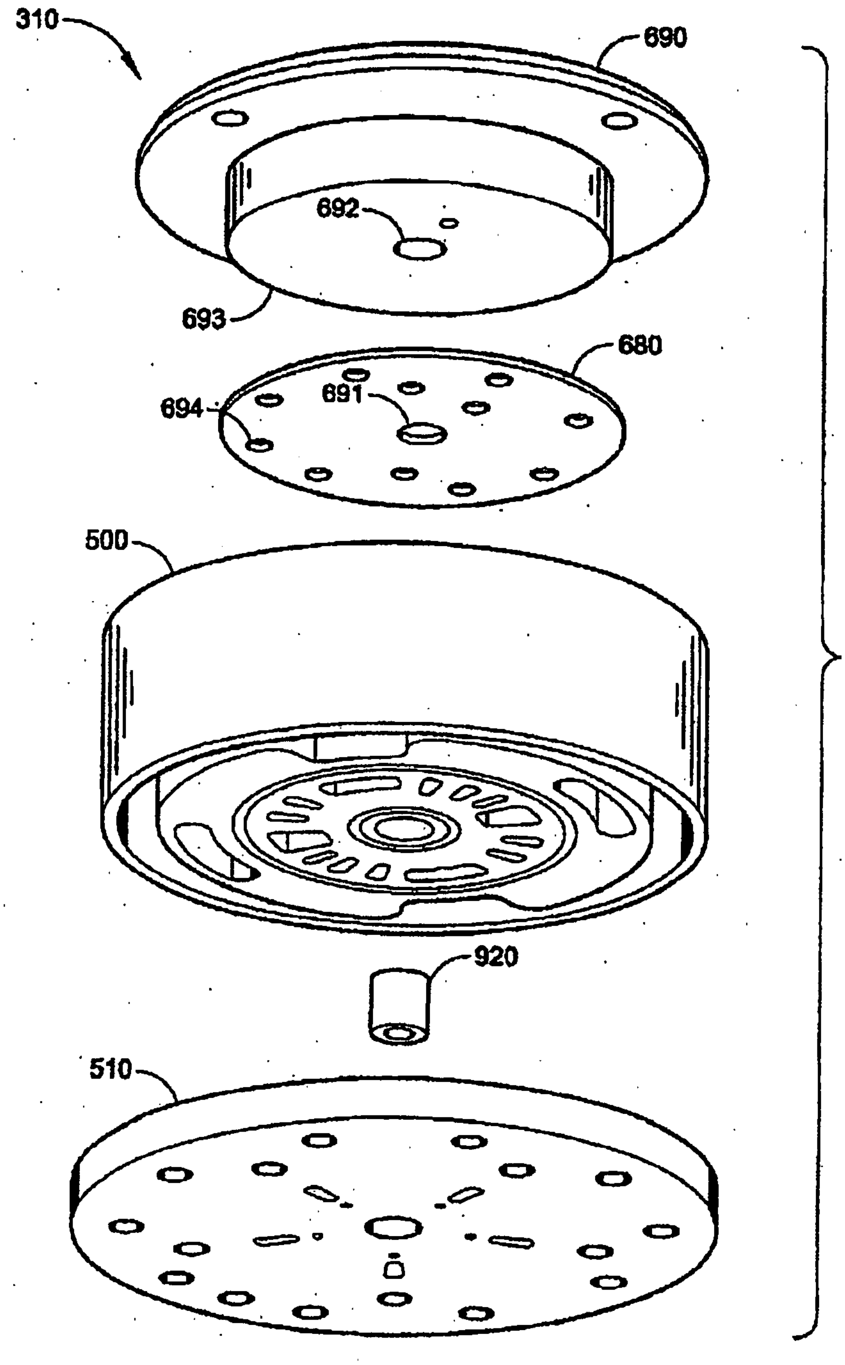

FIG. 8B

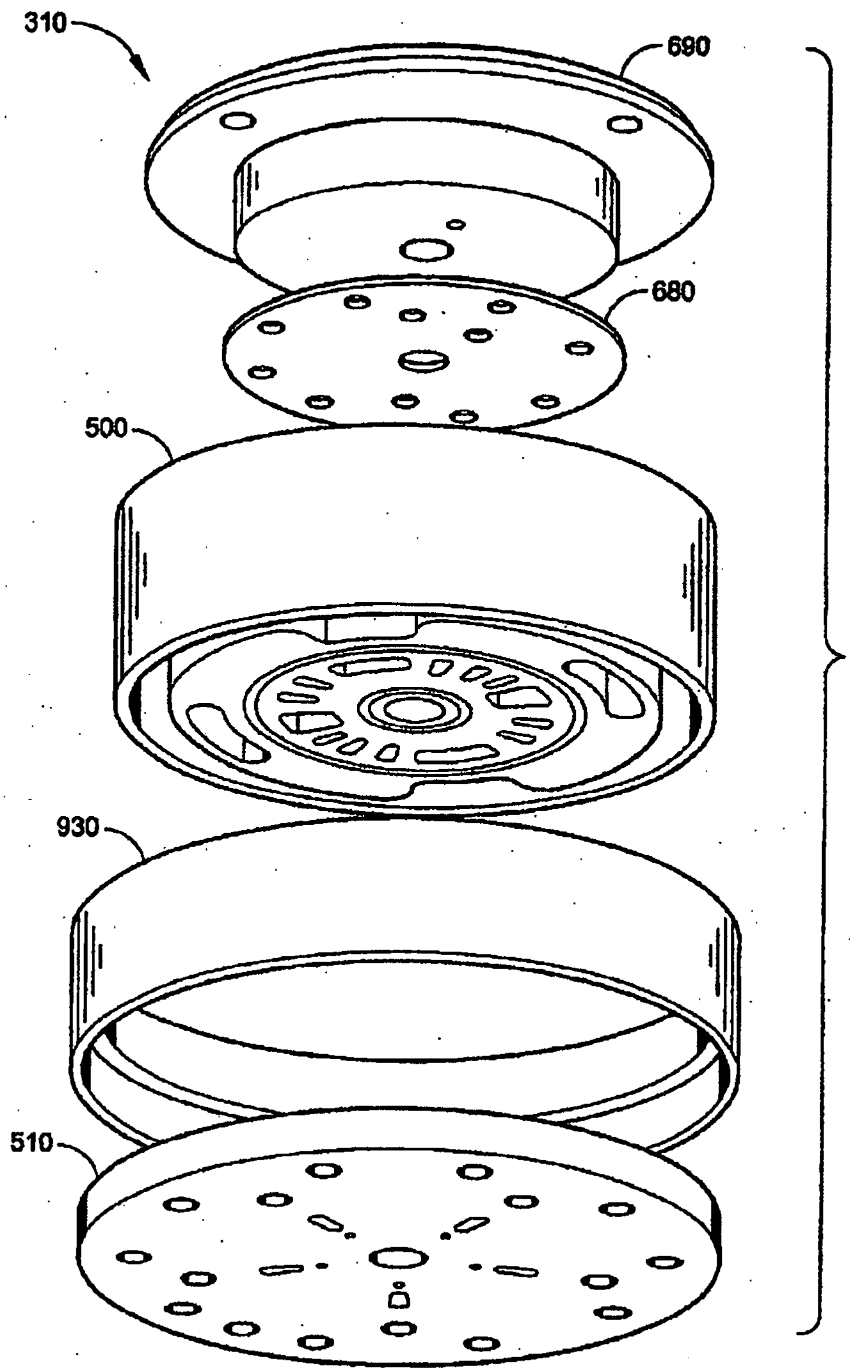

FIG. 9A

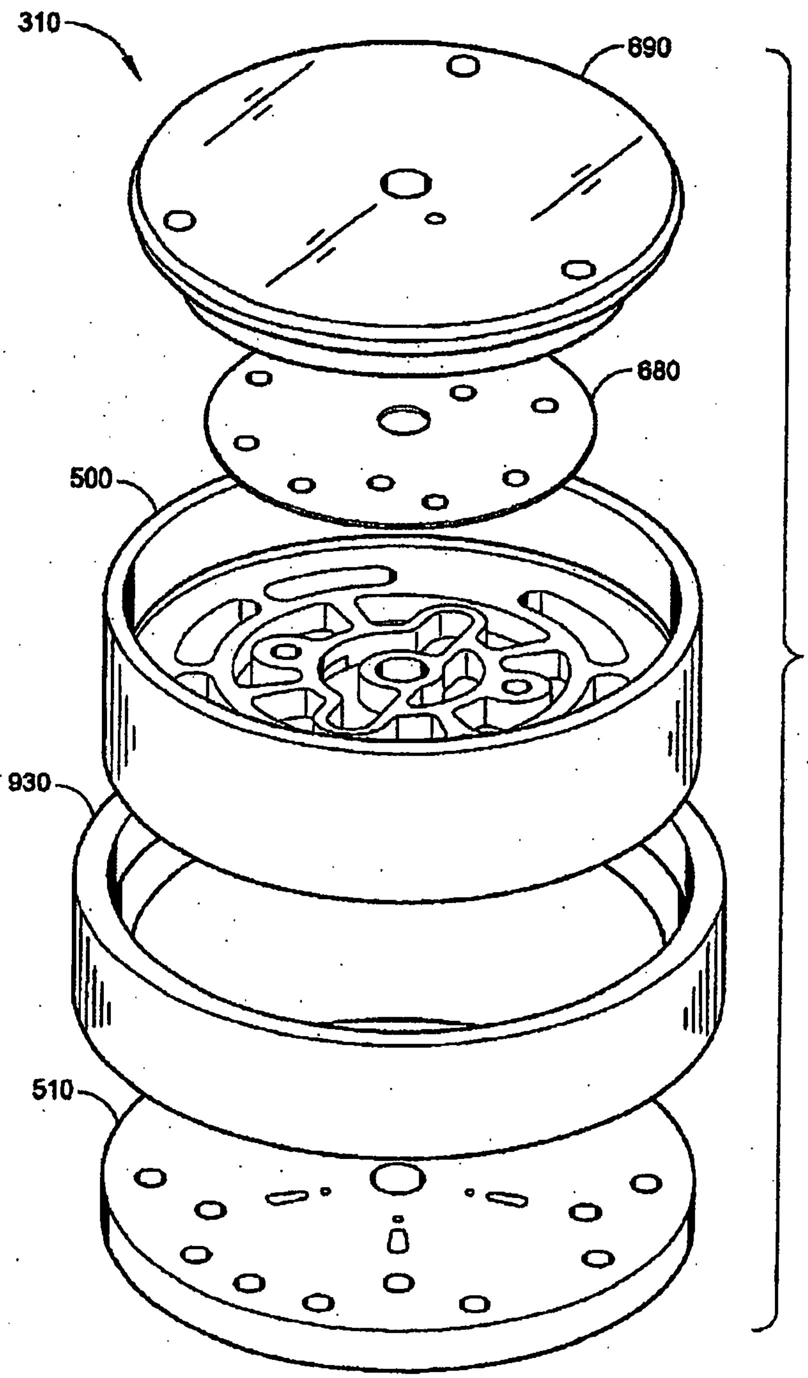

FIG. 9B

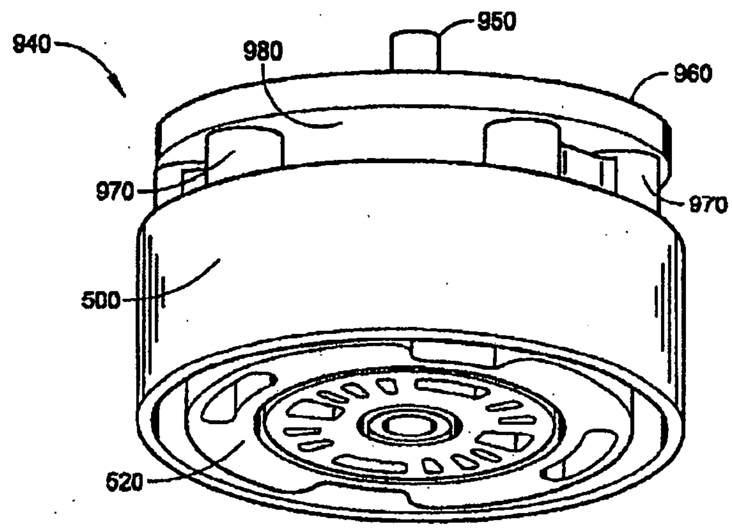

FIG. 10A

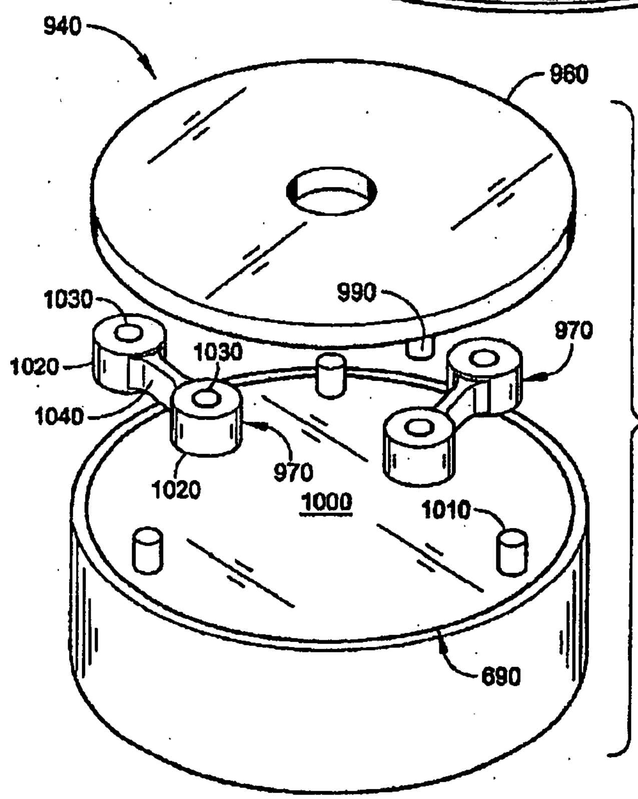

FIG. 10B

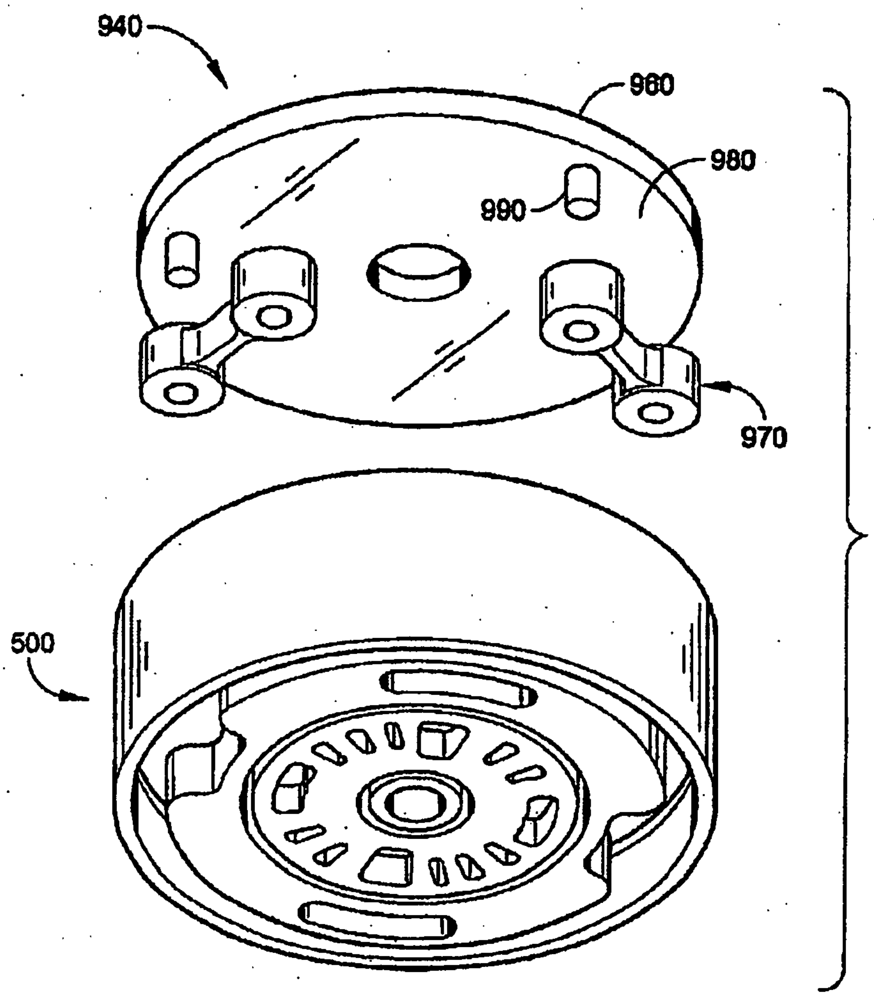

FIG. 10C

PRODUCT FLOW RATE (slpm)	RECOVERY (%)	PRODUCT PURITY (%)	FEED PRESSURE (psig)	VACUUM PRESSURE (psig)	FLOW RATE (slpm)		ADIABATIC WORK (W)*		
					COMP.	VACUUM	COMP.	VACUUM	TOTAL
3.0	55.1	91.7	7.7	-7.0	23.8	20.8	17.9	20.6	38.5
3.0	53.6	90.4	7.2	-7.0	24.1	21.1	17.1	21.2	38.3
3.0	53.6	90.9	7.2	-7.0	24.2	21.2	17.2	21.2	38.4
1.0	54.6	91.6	8.0	-7.0	8.0	7.0	6.9	7.0	13.9
2.0	57.2	92.0	10.6	-7.0	15.3	13.3	15.2	13.3	28.4
3.0	54.9	92.3	9.6	-7.5	24.0	21.0	21.8	22.9	44.7
2.8	51.7	93.6	10.1	-7.4	24.1	21.3	22.9	22.8	45.8
2.5	46.3	94.5	10.3	-7.5	24.3	21.8	23.5	23.8	47.2
3.2	56.3	90.7	9.9	-7.5	24.6	21.4	23.0	23.3	46.3
3.4	58.4	88.0	9.9	-7.0	24.4	21.0	22.8	20.9	43.7
2.0	46.9	94.7	12.1	-7.1	19.3	17.3	21.3	17.5	38.8
2.2	51.3	94.3	11.9	-7.2	19.3	17.1	21.0	17.6	38.6
2.4	55.6	93.6	11.7	-7.3	19.3	16.9	20.8	17.7	38.5
2.5	57.9	92.7	11.1	-7.3	19.1	16.6	19.7	17.4	37.1
2.8	61.8	89.0	11.3	-7.2	19.2	16.4	20.0	16.9	37.0
1.5	58.1	94.3	10.8	-7.2	11.2	9.8	11.3	10.1	21.4
1.5	59.9	94.0	10.8	-7.2	11.2	9.7	11.3	10.0	21.3
1.6	67.3	90.1	10.4	-7.3	11.2	9.4	10.9	9.9	20.8
1.0	64.0	94.1	9.0	-7.2	7.0	6.0	6.1	6.2	12.3
1.2	70.4	86.3	8.5	-7.4	7.0	5.8	5.8	6.2	12.0
1.1	68.1	90.3	8.7	-7.3	7.0	5.9	5.8	6.2	12.0
2.5	45.5	94.4	9.5	-6.1	24.7	22.2	22.3	18.8	41.1
2.8	50.5	93.7	9.7	-6.2	24.8	22.0	22.8	18.9	41.7
3.0	54.1	92.5	10.1	-6.3	24.4	21.4	23.2	18.6	41.8
3.2	56.3	90.7	9.9	-6.4	24.6	21.4	22.9	18.8	41.7
3.5	59.2	87.4	9.7	-6.4	24.6	21.1	22.7	18.8	41.5
1.0	46.0	90.9	5.8	-5.3	9.4	8.4	5.5	5.9	11.5
2.0	47.8	90.5	6.7	-5.4	18.0	16.0	12.0	11.6	23.6
3.0	48.2	90.7	10.1	-5.6	26.9	23.9	25.6	17.9	43.5
1.0	52.3	92.3	5.7	-6.1	8.4	7.4	4.9	6.1	11.0
1.0	51.3	91.1	5.3	-6.0	8.5	7.5	4.6	6.2	10.8
2.0	51.6	92.4	7.3	-5.9	17.1	15.1	12.2	12.2	24.4
2.0	52.4	91.5	7.1	-5.9	16.6	14.6	11.7	11.8	23.5
3.0	48.6	89.9	8.5	-5.8	26.4	23.4	21.8	18.3	40.1
3.0	48.9	90.7	8.8	-5.8	26.5	23.5	22.8	18.4	40.9

FIG. 11

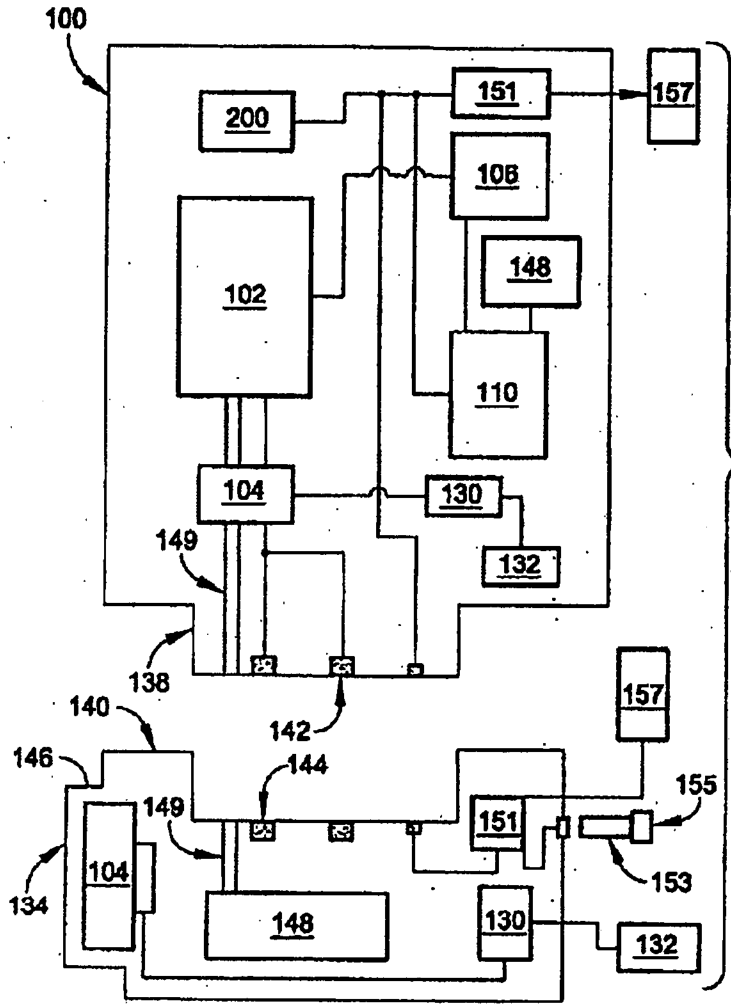
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FIG. 12

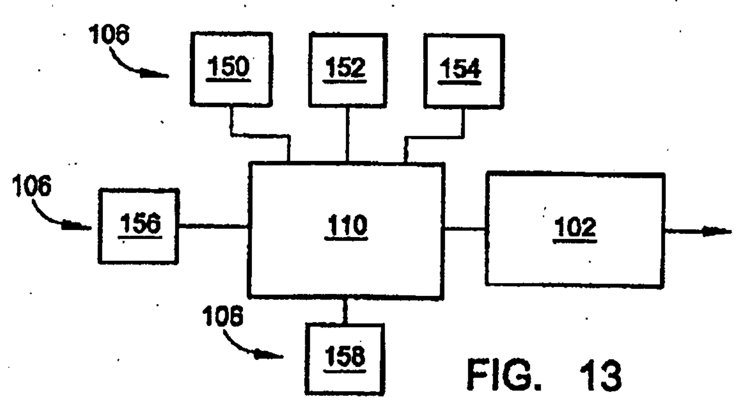
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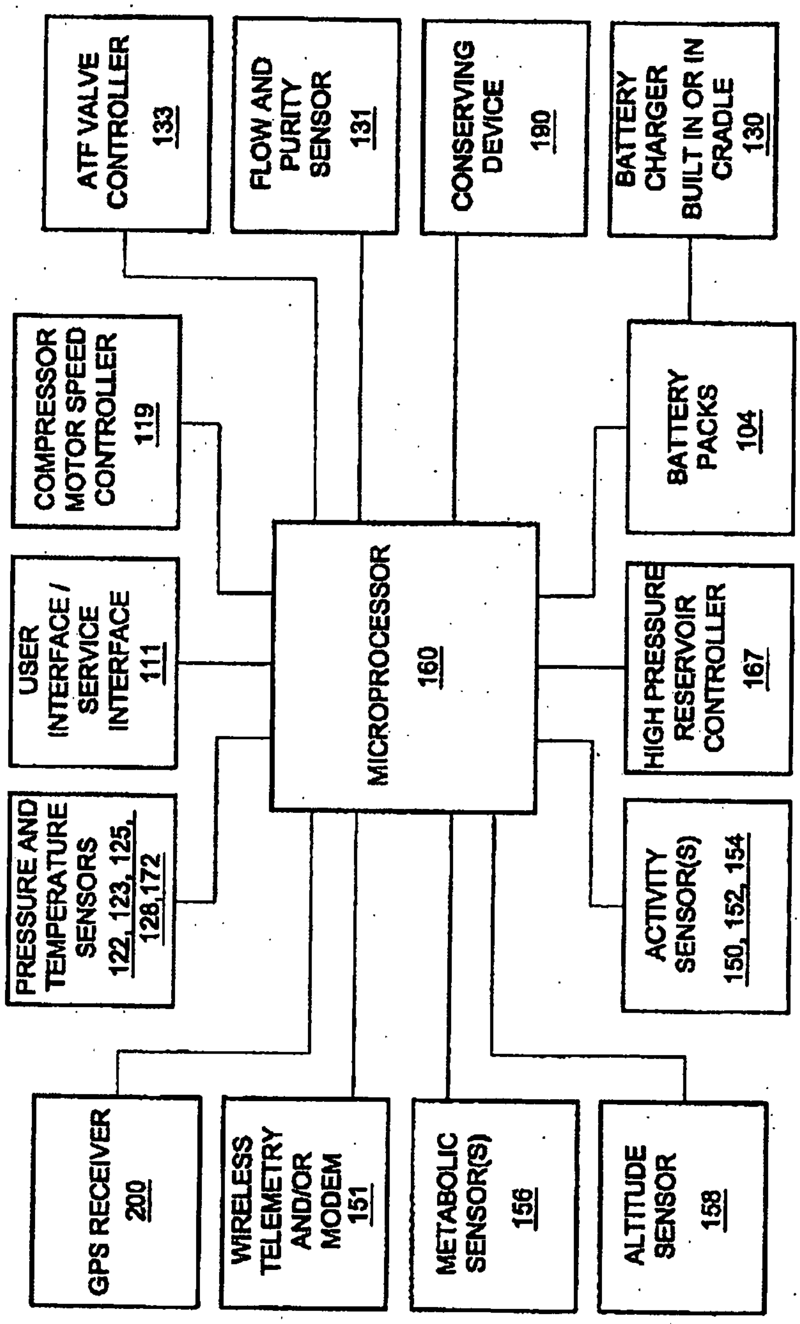
FIG. 13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CONSERVING DEVICE 190
BATTERY CHARGER BUILT IN OR IN CRADLE 130
COMPRESSOR MOTOR SPEED CONTROLLER 119
USER INTERFACE / SERVICE INTERFACE 111
PRESSURE AND TEMPERATURE SENSORS 122, 123, 125, 128,172
MICROPROCESSOR 160
BATTERY PACKS 104
HIGH PRESSURE RESERVOIR CONTROLLER 167
ACTIVITY SENSOR(S) 150, 152, 154
GPS RECEIVER 200
WIRELESS TELEMETRY AND/OR MODEM 151
METABOLIC SENSOR(S) 156
ALTITUDE SENSOR 158

FIG. 14

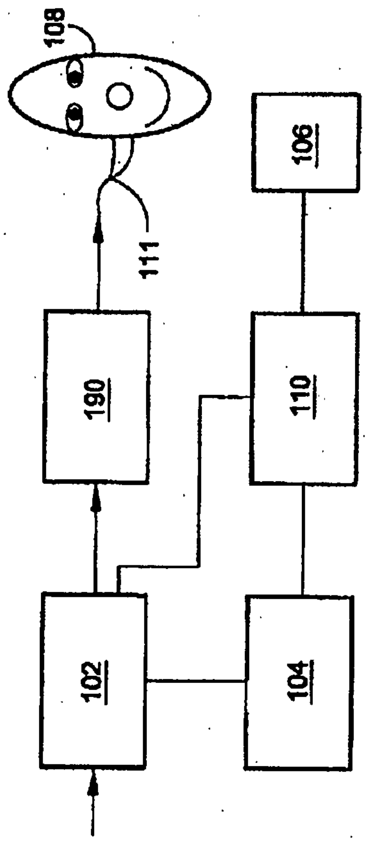
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FIG. 15

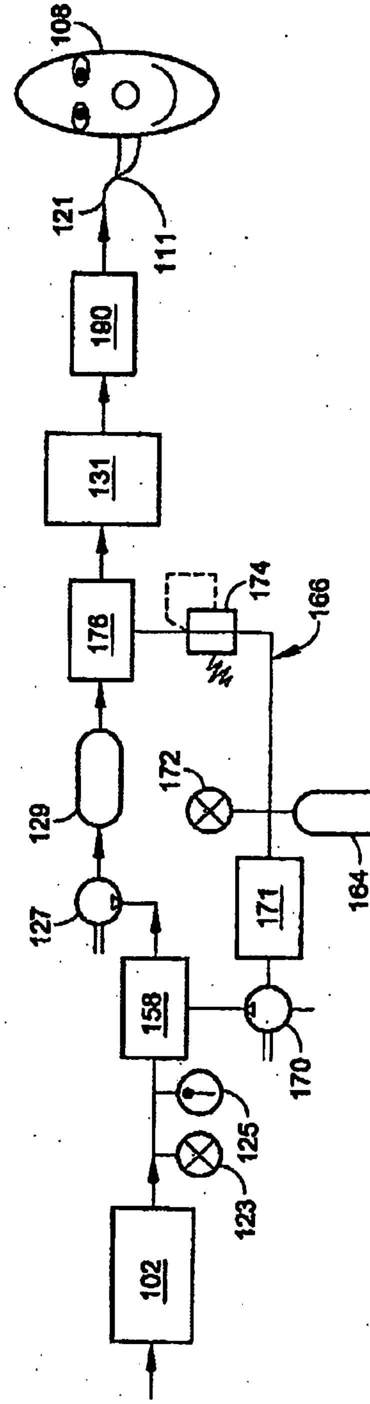
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FIG. 16

PORTABLE OXYGEN CONCENTRATION SYSTEM AND METHOD OF USING THE SAME

This application is a continuation-in-part of pending prior application Aer. No. 09/632,099, filed on Aug. 3, 2000.

BACKGROUND OF THE INVENTION

The field of this invention relates, in general, to oxygen concentrators and, in particular, to portable oxygen concentration systems for ambulatory respiratory patients that allow them to lead normal and productive lives.

There is a burgeoning need for home and ambulatory oxygen. Supplemental oxygen is necessary for patients suffering from lung disorders; for example, pulmonary fibrosis, sarcoidosis, or occupational lung disease. For such patients, oxygen therapy is an increasingly beneficial, life-giving development. While not a cure for lung disease, supplemental oxygen increases blood oxygenation, which reverses hypoxemia. This therapy prevents long-term effects of oxygen deficiency on organ systems—in particular, the heart, brain and kidneys.

Oxygen treatment is also prescribed for Chronic Obstructive Pulmonary Disease (COPD), which afflicts about six-hundred million people in the U.S., and for other ailments that weaken the respiratory system, such as heart disease and AIDS. Supplemental oxygen therapy is also prescribed for asthma and emphysema.

The normal prescription for COPD patients requires supplemental oxygen flow via nasal cannula or mask twenty four hours per day. The average patient prescription is two liters per minute of high concentration oxygen to increase the oxygen level of the total air inspired by the patient from the normal 21% to about 40%. While the average oxygen flow requirement is two liters per minute, the average oxygen concentrator has a capacity of four to six liters of oxygen per minute. This extra capacity is occasionally necessary for certain patients who have developed more severe problems, are not generally able to leave the home (as ambulatory patients) and do not require a portable oxygen supply.

There are currently three modalities for supplemental medical oxygen: high pressure gas cylinders, cryogenic liquid in vacuum insulated containers or thermos bottles commonly called "dewars," and oxygen concentrators. Some patients require in-home oxygen only while others require in-home as well as ambulatory oxygen depending on their prescription. All three modalities are used for in-home use, although oxygen concentrators are preferred because they do not require dewar refilling or exchange of empty cylinders with full ones. Home oxygen concentrators, however, do have their drawbacks. They consume relatively large amounts of electricity (350–400 Watts), are relatively large (about the size of a night-stand), are relatively heavy (weight about 50 lbs.), emit quite a bit of heat, and are relatively noisy.

Only small high pressure gas bottles and small liquid dewars are truly portable enough to be used for ambulatory needs (outside the home). Either modality may be used for both in-home and ambulatory use or may be combined with an oxygen concentrator which would provide in-home use.

As described below, the current oxygen-supplying methods and devices have proven cumbersome and unwieldy and there has been a long-felt need for an improved portable device for supplying oxygen to the user.

For people who need to have oxygen and operate away from an oxygen-generating or oxygen-storage source such as a stationary oxygen system (or even a portable system which cannot be readily transported), the two most prescribed options generally available to patients are: (a) to carry with them small cylinders typically in a wheeled stroller; and (b) to carry portable containers typically on a shoulder sling. Both these gaseous oxygen and liquid oxygen options have substantial drawbacks, but from a medical view, both have the ability to increase the productive life of a patient.

The major drawback of the gaseous oxygen option is that the small cylinders of gaseous oxygen can only provide gas for a short duration. Another drawback is that a patient's high-pressure gaseous oxygen cylinders are not allowed in some locations such as airplanes because of safety considerations. A further drawback of the gaseous oxygen option is the refill requirement for oxygen once the oxygen has been depleted from the cylinder. These small gas cylinders must be picked up and refilled by the home care provider at a specialized facility. This requires regular visits to a patient's home by a provider and a substantial investment in small cylinders by the provider because so many are left at the patient's home and refilling facility. Although it is technically possible to refill these cylinders in the patient's home using a commercial oxygen concentrator that extracts oxygen from the air, this task would typically require an on-site oxygen compressor to boost the output pressure of the concentrator to a high level in order to fill the cylinders. Some disadvantages of common on-site oxygen compressors are that they are expensive, loud and emit a lot of heat. Additionally, attempting to compress the oxygen in pressurized canisters in the home is potentially dangerous, especially for untrained people.

This approach of course presents several safety concerns for in-home use. For example, in order to put enough of this gas in a portable container, it must typically be compressed to high pressure (~2000 psi) Compressing oxygen from 5 psi (the typical output of an oxygen concentrator) to 2000 psi will produce a large amount of heat. (Enough to raise the temperature 165 degrees C. per stage based on three adiabatic compression stages with intercooling.) This heat, combined with the oxygen which becomes more reactive at higher pressures, sets up a potential combustion hazard in the compressor in the patient's home. Thus, operation of a high-pressure gas system in the patient's home is dangerous and not a practical solution.

The convenience and safety issues are not the only drawbacks of this compressed oxygen approach. Another drawback is that the compressors or pressure boosters needed are costly because they require special care and materials needed for high pressure oxygen compatibility.

Turning now to the liquid oxygen storage option, its main drawback is that it requires a base reservoir—a stationary reservoir base unit within the patient's home about the size of a standard beer keg—which may be refilled about once a week from an outside source. Liquid oxygen can then be transferred from the patient's base unit to a portable dewar, which can be used by the ambulatory patient. Also, with the liquid oxygen option, there is substantial waste, as a certain amount of oxygen is lost during the transfer to the portable containers and from evaporation. It is estimated that 20% of the entire contents of the base cylinder will be lost in the course of two weeks because of losses in transfer and normal evaporation. These units will typically boil dry over a period of 30 to 60 days even if no oxygen is withdrawn.

Home refilling systems that produce liquid oxygen and have the capability of refilling portable liquid oxygen dewars have been proposed. However, these devices require the user to perform the task of refilling bottles and add tens of dollars per month to the user's electric bill, which is not reimbursable.

There are other complications with these portable high-pressure cylinders and liquid dewars. Typically, supplemental oxygen is supplied to the patient by a home care provider, in exchange for which the provider receives a fixed monetary payment from insurance companies or Medicare regardless of the modality. Oxygen concentrators are preferred by the provider as the least expensive option for supplying the patient's at-home needs. For outside the home use, however, only small high-pressure gas bottles and small liquid dewars are portable enough to be used for ambulatory needs. Either one of these two modalities may be used for both in-home and ambulatory use or may be combined with an oxygen concentrator, which would provide in-home use. In either case, the home care provider must make costly weekly or biweekly trips to the patient's home to replenish the oxygen. One of the objects of this invention is to eliminate these costly milk runs."

So-called "portable" oxygen concentrators are commercially available for providing patients with gaseous oxygen by converting ambient air into concentrated gaseous oxygen. However, these devices are only "portable" in the sense that they are capable of being transported to another point of use via an automobile or an airplane. One of these devices is packaged in a suitcase and is billed as a transportable machine rather than a truly portable oxygen concentrator. The device weighs about 37 lbs. without battery and requires 135 Watts of power at a 2 LPM (liters per minute) oxygen flow rate. Operation from an automobile battery is possible when in route in a car, but operation from a separate battery is impractical. Another device is a 3 LPM concentrator mounted on its own cart. It weighs 22 lbs. without battery and also requires about 135 Watts of power. A further device weighs about 28 lbs. without battery and has a similar flow rate and power requirements to the above devices. Even without a battery, these devices are too heavy for the average ambulatory respiratory patient. With the weight of a battery, these prior art devices are not "portable" in the true sense of the word because they can not be readily transported from one point to another. Because these devices have relatively large power consumption requirements, they also require a sizable battery.

Further, in addition to the weight and power consumption problems with the above oxygen concentrators, none of these prior art concentrators are particularly quiet. They produce noise levels similar to those produced by a home concentrator. In fact, one of these devices specifie's noise production at 60 dBA (decibels), about twice the noise of a home concentrator. Consequently, none of these so-called "portable" oxygen concentrators are suitable for use in environments where low noise is especially important, e.g., restaurants, libraries, churches and theatres.

Thus, a long-felt need exists for a truly "portable" oxygen concentration system that eliminates the need for high-pressure gas cylinders and liquid dewars, the constant refilling/replacing requirements associated with high-pressure gas cylinders and liquid dewars, and the need for a separate home oxygen concentration system for ambulatory respiratory patients. A truly "portable" oxygen concentration system would be light enough so that, even with a battery, an average ambulatory respiratory patient could carry the device. Inherently the device would have to be designed to have relatively low power consumption requirements so that a light-weight battery pack or other energy source could be used. Further, the device should be small enough so that it can be conveniently carried by the user, emit a relatively low amount of noise and should only emit a small amount of heat.

SUMMARY OF INVENTION

An aspect of the present invention involves a portable oxygen concentrator system adapted to be readily transported by a user. The portable oxygen concentrator system includes a rechargeable energy source and a concentrator powered by the energy source. The concentrator converts ambient air into concentrated oxygen gas for the user and includes a plurality of adsorption beds and a rotary valve assembly. The rotary valve assembly is relatively rotatable with respect to the plurality of adsorption beds to provide valving action for selectively transferring fluids through the plurality of adsorption beds for converting ambient air into concentrated oxygen gas for the user. The ratio of adiabatic power to oxygen flow for the concentrator is in the range of 6.2 W/LPM to 23.0 W/LPM.

Another aspect of the invention involves a rotary valve assembly for a pressure swing adsorption system having a plurality of adsorption beds. The rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and are relatively rotatable about a common center of rotation to provide valving action for selectively transferring fluids therethrough. The valve port plate includes at least two ports interconnected with at least two adsorption beds. The rotary valve shoe includes a second valve surface opposite the engaged surface with at least one equalization passage to register with the at least two ports of the port plate to equalize pressure between the at least two adsorption beds.

Other and further objects, features, aspects, and advantages of the present inventions will become better understood with the following detailed description of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a portable oxygen concentration system constructed in accordance with an embodiment of the invention;

FIG. 2 is a block diagram of a portable oxygen concentration system constructed in accordance with another embodiment of the invention, and illustrates, in particular, an embodiment of an air separation device;

FIG. 3A is a perspective, cut-away view of an embodiment of a concentrator that may be used with the portable oxygen concentration system.

FIG. 3B is a perspective, exploded view of the concentrator illustrated in FIG. 3A.

FIG. 4 is a top perspective view of an embodiment of a top manifold and multiple adsorption beds that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIGS. 5A and 5B are a bottom plan view and a top plan view respectively of an embodiment of a rotary valve shoe that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIG. 6A is a top plan view of an embodiment of a valve port plate that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIG. 6B is a flow chart of an exemplary process cycle for the concentraotor illustrated in FIGS. 3A and 3B.

FIGS. 7A and 7B are a top plan view and a bottom plan view respectively of an embodiment of a media retention cap that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIGS. 8A and 8B are a top perspective, exploded view and a bottom perspective, exploded view respectively of an embodiment of a rotary valve assembly including a centering pin that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIGS. 9A and 9B are a bottom perspective, exploded view and a top perspective, exploded view respectively of an embodiment of a rotary valve assembly including a centering ring that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIG. 10A is a bottom perspective view of an embodiment of a rotary valve shoe, a motor drive, and a pair of elastic chain links that may be used with the concentrator illustrated in FIGS. 3A and 3B.

FIGS. 10B and 10C are a top perspective, exploded view and a bottom perspective, exploded view respectively of the rotary valve shoe, motor drive, and pair of elastic chain links illustrated in FIG. 10A.

FIG. 11 is a table of experimental data for a portable oxygen concentration system including the concentrator illustrated in FIGS. 3A and 3B.

FIG. 12 is a schematic illustration of a further embodiment of the portable oxygen concentration system and an embodiment of a cradle for use with the portable oxygen concentration system;

FIG. 13 is a block diagram of the one or more sensors that may be used with an embodiment of the portable oxygen concentration system;

FIG. 14 is a block diagram of the one or more components that may be controlled by the control unit of the portable oxygen concentration system;

FIG. 15 is a block diagram of a portable oxygen concentration system constructed in accordance with additional embodiment of the invention; and

FIG. 16 is a schematic illustration of another embodiment of a portable oxygen concentration system including a high-pressure reservoir.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

I. Portable Oxygen Concentration System

With reference to FIG. 1, a portable oxygen concentration system, indicated generally by the reference numeral 100, constructed in accordance with an embodiment of the invention will now be described. The oxygen concentration system 100 includes an air separation device such as an oxygen gas generator 102 that separates concentrated oxygen gas from ambient air, an energy source such as rechargeable battery, battery pack, or fuel cell 104 that powers at least a portion of the oxygen gas generator 102, one or more output sensors 106 used to sense one or more conditions of the user 108, environment, etc. to determine the oxygen output needed by the user or required from the system 100, and a control unit 110 linked to the output sensor 106, the air separation device 102, and the energy source 104 to control the operation of the air separation device 102 in response to the one or more conditions sensed by the one or more output sensors 106.

In an alternative embodiment, the system 100 may not include the one or more output sensors 106 coupled to the control unit 110. In this embodiment, conditions of the system 100 such as flow rate, oxygen concentration level, etc. may be constant for the system or may be manually controllable. For example, the system 100 may include a user interface 111 (FIG. 14) that allows the user, provider, doctor, etc. to enter information, e.g., prescription oxygen level, flow rate, etc. to control the oxygen output of the system 100.

Each element of the system 100 will now be described in more detail.

A. Air Separation Device

With reference to FIG. 2, the air separation device is preferably an oxygen generator 102 generally including a pump such as a compressor 112 and an oxygen concentrator 114 (OC), which may be integrated.

The oxygen generator 102 may also include one or more of the elements described below and shown within the segmented boundary line in FIG. 2. Ambient air may be drawn through an inlet muffler 116 by the compressor 112. The compressor 112 may be driven by one or more DC motors 118 (M) that run off of DC electrical current supplied by the rechargeable battery 104 (RB). The motor 118 also preferably drives the cooling fan part of the heat exchanger 120. A variable-speed controller (VSC) or compressor motor speed controller 119, which is described in more detail below, may be integral with or separate from the control unit 110 (CU) and is preferably coupled to the motor 118 for conserving electricity consumption. The compressor 112 delivers the air under pressure to the concentrator 114.

In a preferred embodiment, at a maximum speed air is delivered to the concentrator 114 at 7.3 psig nominal and may range from 5.3 to 12.1 psig. At maximum speed, the flow rate of feed is a minimum of 23.8 SLPM at inlet conditions of 14.696 psi absolute, 70 degrees F., 50% relative humidity.

A heat exchanger 120 may be located between the compressor 112 and the concentrator 114 to cool or heat the air to a desired temperature before entering the concentrator 114, a filter (not shown) may be located between the compressor 112 and the concentrator 114 to remove any impurities from the supply air, and a pressure transducer 122 may be located between the compressor 112 and the concentrator 114 to get a pressure reading of the air flow entering the concentrator 114.

The concentrator 114 separates oxygen gas from air for eventual delivery to the user 108 in a well-known manner. One or more of the following components may be located in a supply line 121 between the concentrator 114 and the user 108: a pressure sensor 123, a temperature sensor 125, a pump 127, a low-pressure reservoir 129, a supply valve 160, a flow and purity sensor 131, and a conservation device 190. As used herein, supply line 121 refers to the tubing, connectors, etc. used to connect the components in the line. The pump 127 may be driven by the motor 118. The oxygen gas may be stored in the low-pressure reservoir 129 and delivered therefrom via the supply line 121 to the user 108. The supply valve 160 may be used to control the delivery of oxygen gas from the low-pressure reservoir 129 to the user 108 at atmospheric pressure.

Exhaust gas may also be dispelled from the concentrator 114. In a preferred embodiment of the invention, a vacuum generator 124 (V), which may also be driven by the motor 118 and integrated with the compressor 112, draws exhaust gas from the concentrator 114 to improve the recovery and productivity of the concentrator 114. The exhaust gas may exit the system 100 through an exhaust muffler 126. A pressure transducer 128 may be located between the concentrator 114 and the vacuum generator 124 to get a pressure reading of the exhaust flow from the concentrator 114. At maximum rated speed and a flow rate of 20.8 SLPM, the pressure at the vacuum side is preferably −5.9 psig nominal and may range from −8.8 to −4.4 psig.

1. Compressor/Variable Speed Controller

Example of compressor technologies that may be used for the compressor 112 include, but not by way of limitation, rotary vane, linear piston with wrist pin, linear piston without wrist pin, nutating disc, scroll, rolling piston, diaphragm pumps, and acoustic. Preferably the compressor 112 and vacuum generator 124 are integrated with the motor 118 and are oil-less, preventing the possibility of oil or grease from entering the air flow path.

The compressor 112 preferably includes, at a minimum, a 3:1 speed ratio, with a low speed of at least 1,000 rpm and a 15,000 hour operating life when run at full speed. Operating temperature surrounding the compressor/motor system is preferably 32 to 122 degrees F. Storage temperature is preferably −4 to 140 degree F. Relative humidity is preferably 5 to 95% RH noncondensing. Voltage for the compressor 112 is preferably 12 V DC or 24V DC and the electrical power requirements are preferably less than 100 W at full speed and rated flow/nominal pressure and less than 40 W at ⅓ speed and ⅓ flow at rated pressure. A shaft mounted fan or blower may be incorporated with the compressor 112 for compressor cooling and possible complete system cooling. Preferably, the maximum sound pressure level of the compressor 112 may be 46 dBA at a maximum rated speed and flow/pressure and 36 dBA at ⅓ rated speed. Preferably the compressor 112 weighs less than 3.5 pounds.

It is desirable for the compressor 112 to run at a variety of speeds; provide the required vacuum/pressure levels and flow rates, emit little noise and vibration, emit little heat, be small, not be heavy, and consume little power.

The variable-speed controller 119 is important for reducing the power consumption requirements of the compressor 112 on the rechargeable battery 104 or other energy source. With a variable-speed controller, the speed of the compressor 112 may be varied with the activity level of the user, metabolic condition of the user, environmental condition, or other condition indicative of the oxygen needs of the user as determined through the one or more output sensors 106.

For example, the variable-speed controller may decrease the speed of the motor 118 when it is determined that the oxygen requirements of the user 108 are relatively low, e.g., when the user is sitting, sleeping, at lower elevations, etc., and increased when it is determined that the oxygen requirements of the user 108 are relatively high or higher, e.g., when the user stands, when the user is active, when the user is at higher elevations, etc. This helps to conserve the life of the battery 104, reduce the weight and size of the battery 104, and reduce the compressor wear rate, improving its reliability.

One of the inventors of the present invention was a co-inventor on a variable-speed controller in the past that regulated the compressor speed to operate the compressor only at the speed and power needed to deliver oxygen at the user's prescribed flow rate. This variable-speed controller is discussed in U.S. Pat. Nos. 5,593,478 and 5,730,778, which are hereby incorporated by reference as though set forth in full.

The variable-speed controller 119 allows the compressor 112 to operate at a low average rate, typically the average rate or speed will be between full speed and ⅙ full speed of the compressor 112, resulting in an increase in battery life, decrease in battery size and weight, and decrease in compressor noise and emitted heat.

2. Concentrator

In a preferred embodiment, the concentrator 114 is an Advanced Technology Fractionator (ATF) that may be used for medical and industrial applications. The ATF may implement a pressure swing adsorption (PSA) process, a vacuum pressure swing adsorption (VPSA) process, a rapid PSA process, a very rapid PSA process or other process. If a PSA process is implemented, the concentrator may include a rotating valve or a non-rotating valve mechanism to control air flow through multiple sieve beds therein. Examples of ATF concentrators are shown and described in U.S. Pat. Nos. 5,268,021, 5,366,541, Re. 35,099, which are hereby incorporated by reference as though set forth in full. The sieve beds may be tapered so that they have larger diameter where gaseous flow enters the beds and a smaller diameter where gaseous flow exits the beds. Tapering the sieve beds in this manner requires less sieve material and less flow to obtain the same output.

Although an ATF concentrator 114 is used in a preferred embodiment, it will be readily apparent to those skilled in the art that other types of concentrators or air-separation devices may be used such as, but not by way of limitation, membrane separation types and electrochemical cells (hot or cold). If other types of concentrators or air-separation devices are used, it will be readily apparent to those skilled in the art that some aspects described herein may change accordingly. For example, if the air-separation device is a membrane separation type, pumps other than a compressor may be used to move air through the system.

The ATF preferably used is significantly smaller that ATFs designed in the past. The inventors of the present invention recognized that reducing the size of the ATF concentrator 114 not only made the system 100 smaller and more portable, it also improved the recovery percentage, i.e., the percentage of oxygen gas in air that is recovered or produced by the concentrator 114 and the productivity (liters per minute/lb. of sieve material) of the concentrator 114. Reducing the size of the ATF decreases the cycle time for the device. As a result, productivity is increased.

Further, the inventors also determined that finer sieve materials increased recovery rates and productivity. The time constant to adsorb unwanted gases is smaller for finer particles because the fluid path is shorter for the gases than for larger particles. Thus, fine sieve materials having small time constants are preferred. An example of a sieve material that may be used in the ATF concentrator 114 is described in U.S. Pat. No. 5,413,625 to Chao, et al., which is incorporated by reference as though set forth in full. The sieve material may be a LithiumX Zeolite that allows for a high exchange of Lithium ions. The bead size may, for example, be 0.2–0.6 mm. In an alternative embodiment, the Zeolite may be in the form of a rigid structure such as an extruded monolith or in the form of rolled up paper. In this embodiment, the Zeolite structure would allow for rapid pressure cycling of the material without introducing significant pressure drop between the feed and product streams.

The size of the concentrator 114 may vary with the flow rate desired. For example, the concentrator 114 may come in a 1.5 Liter per minute (LPM) size, a 2 LPM size, a 2.5 LPM size, a 3 LPM size, etc.

The oxygen gas generator 102 may also include an oxygen source in addition to the concentrator 114 such as, but not by way of limitation, a high-pressure oxygen reservoir, as described in more detail below.

An ATF valve controller 133 may be integral with or separate from the control unit 110 and is coupled with valve electronics in the concentrator 114 for controlling the valve (s) of the concentrator 114.

The concentrator may have one or more of the following energy saving modes: a sleep mode, a conserving mode, and an active mode. Selection of these modes may be done manually by the user 108 or automatically such as through the described one or more sensors 106 and control unit 110.

With reference to FIGS. 3A and 3B, an embodiment of a concentrator 114 that may be used in the oxygen generator 102 will now be described in more detail. Although the concentrator 114 will be described as separating oxygen from air, it should be noted that the concentrator 114 may be used for other applications such as, but not by way of limitation, air separations for the production of nitrogen, hydrogen purification, water removal from air, and argon concentration from air. As used herein, the term "fluids" includes both gases and liquids.

The concentrator 114 described below includes numerous improvements over previous concentrators that result in increased recovery of the desired component and increased system productivity. Improved recovery is important since it is a measure of the efficiency of the concentrator. As a concentrator's recovery increases, the amount of feed gas required to produce a given amount of product decreases. Thus, a concentrator with higher recovery may require a smaller feed compressor (e.g., for oxygen concentration from air) or may be able to more effectively utilize feed gas to recover valuable species (e.g., for hydrogen purification from a reformate stream). Improved productivity is important since an increase in productivity relates directly to the size of the concentrator. Productivity is measured in units of product flow per mass or volume of the concentrator. Thus, a concentrator with higher productivity will be smaller and weigh less than a concentrator that is less productive, resulting in a more attractive product for many applications. Therefore, concentrator improvements in recovery, productivity, or both are advantageous. The specific improvements that lead to improved recovery and productivity are detailed below.

The concentrator 114 includes five adsorption beds 300, each containing a bed of adsorbent material which is selective for a particular molecular species of fluid or contaminant, a rotary valve assembly 310 for selectively transferring fluids through the adsorption beds 300, an integrated tube-assembly and mainifold "manifold" 320, a product tank cover 330, and a valve assembly enclosure 340.

The adsorption beds 300 are preferably straight, elongated, molded, plastic vessels surrounded by the product tank cover 330, which is made of metal, preferably aluminum. The molded, plastic adsorption beds 300 surrounded by the metal cover 330 make for a low-cost design without the detrimental effects of water influx that occur with prior-art plastic housings or covers. Plastic adsorption beds have the inherent problem of the plastic being permeable to water. This allows water to penetrate into the adsorbent material, decreasing the performance of the adsorbent material. Surrounding the plastic adsorption beds 300 with the aluminum cover 330, which also may serve as a product accumulation tank, maintains the low cost of the design and does not sacrifice performance.

Each adsorption bed 300 includes a product end 350 and a feed end 360. With reference additionally to FIG. 4, the product ends 350 of the beds 300 communicate with incoming product passages 370 of the manifold 320 through product lines 380 for communication with the rotary valve assembly 310. The feed ends 360 of the beds 300 communicate with outgoing feed passages 390 of the manifold 320 for communication with the rotary valve assembly 310.

The manifold 320 may also include outgoing product passages 400 that communicate the rotary valve assembly 310 with the interior of the product tank 330, an incoming feed passage 410 that communicates the rotary valve assembly 310 with a feed pressure line 420, and a vacuum chamber 430 that communicates the rotary valve assembly 310 with a vacuum pressure line 440. A product delivery line 450, which may be the same as the supply line 121 described above with respect to FIG. 2, communicates with the interior of the product tank 330. The vacuum pressure line 440 may communicate directly or indirectly with the vacuum generator 124 for drawing exhaust gas from the concentrator 114.

In use, air flows from the compressor 112 to the feed pressure line 420, through the incoming feed passage 410 of the manifold 320. From there, air flows to the rotary valve assembly 310 where it is distributed back through outgoing feed passages 390 of the manifold 320. From there, the feed air flows to the feed ends 360 of the adsorption beds 300. The adsorption beds 300 include adsorbent media that is appropriate for the species that will be adsorbed. For oxygen concentration, it is desirable to have a packed particulate adsorbent material that preferentially adsorbs nitrogen relative to oxygen in the feed air so that oxygen is produced as the non-adsorbed product gas. An adsorbent such as a highly Lithium exchanged X-type Zeolite may be used. A layered adsorbent bed that contains two or more distinct adsorbent materials may also be used. As an example, for oxygen concentration, a layer of activated alumina or silica gel used for water adsorption may be placed near the feed end 360 of the adsorbent beds 300 with a lithium exchanged X-type zeolite used as the majority of the bed toward the product end 350 to adsorb nitrogen. The combination of materials, used correctly, may be more effective than a single type of adsorbent. In an alternative embodiment, the adsorbent may be a structured material and may incorporate both the water adsorbing and nitrogen adsorbing materials.

The resulting product oxygen gas flows towards the products ends 350 of the adsorption beds 300, through the product lines 380, through incoming product passages 370 of the manifold 320, and to the rotary valve assembly 310, where it is distributed back through the manifold 320 via the outgoing product passage 400 and into the product tank 330. From the product tank 330, oxygen gas is supplied to the user 108 through the product delivery line 450 and the supply line 121.

With reference to FIGS. 3B, 5A, 5B, 6A, 8A, and 8B, an embodiment of the rotary valve assembly 310 will now be described. The rotary valve assembly 310 includes a rotary valve shoe or disk 500 and a valve port plate or disk 510. The rotary valve shoe 500 and valve port plate 510 are both preferably circular in construction and made from a durable material such as ceramic, which can be ground to a highly polished flat finish to enable the faces of the valve shoe 500 and port plate 510 to form a fluid-tight seal when pressed together.

With reference specifically to FIG. 5A, the rotary valve shoe 500 has a flat, bottom engagement surface 520 and a smooth cylindrical sidewall 530. The valve shoe 500 has several symmetrical arcuate passages or channels cut into the engagement surface 520, all of which have as their center the geometric center of the circular engagement surface 520. The passages or channels include opposite high-pressure feed channels 540, equalization channels 550, opposite low-pressure exhaust passages 560, circular low-pressure exhaust groove 570 which communicates with exhaust passages 560, opposite product delivery channels 580, opposite purge channels 590, a high-presure central feed passage 600, a first annular vent groove 610, and a second annular vent groove 620.

With reference additionally to FIG. 5B, a parallel, top, second valve surface 630 of the rotary valve shoe 500 will now be described. The purge channels 590 of the engagement surface 520 communicate with each other through vertical, cylindrical purge passages 640 and a rainbow-shaped purge groove 650 on the top surface 630. The equalization channels 550 of the engagement surface 520 extend vertically through the valve shoe 500. Pairs of equalization channels 550 communicate through equalization grooves 660 on the top surface 630. The equalization grooves 660 are generally U-shaped and extend around receiving holes 670. Equalization routing via the grooves 660 on the second valve surface 630, in a plane out of and parallel to a plane defined by the engagement surface 520, helps to maintain the relatively small size of the rotary valve shoe 500 while at the same time enabling more complex fluid routing through the valve shoe 500. The equalization grooves allow the secondary valve surface to be used to equalize pressures between adsorption beds 300.

With reference to FIGS. 3B, 8A, and 8B, a first valve shoe cover 680 is disposed over the second valve surface 630 to isolate the various grooves and passages on the second valve surface 630. Both the first valve shoe cover 680 and the second valve shoe cover 690 include aligned central holes 691, 692, respectively, for communicating the central feed passage 600 with a high-pressure feed fluid chamber formed around the periphery of a cylindrical base 693 of the second valve shoe cover 690. The first valve shoe cover 680 also includes a plurality of holes 694 near its periphery for the purpose of maintaining a balance of pressure during operation on either side of the first valve shoe cover 680 between the cylindrical base 693 and the second valve surface 630. Routing the high-pressure feed fluid into the high-pressure feed fluid chamber on the top or backside of the valve shoe 500 causes pressure balancing on the valve shoe 500 that counteracts the pressure force urging the valve shoe 500 away from the port plate 510. A spring or other type of passive sealing mechanism (not shown) may be used to hold the rotary valve shoe 500 against the port plate 510 when the concentrator 114 is not operating.

With reference to FIG. 5A, to additionally counteract the pressure force that works to unseat the rotary valve shoe 500 from the port plate 510, the exhaust goove 570 is sized such that, when the concentrator 114 is operated at nominal feed and purge (vacuum) pressures, the sealing force due to the vacuum in the exhaust groove 570 subtantially balances this unseating pressure force. This enables the use of relatively small passive sealing mechanisms, reducing the torque and power required to turn the rotary valve shoe 500 and also reduces the weight and size of the concentrator 114.

With reference to FIG. 6A, the valve port plate 510 will now be described in greater detail. The valve port plate 510 has a flat engagement surface 700 that engages the flat engagement surfce 520 of the rotary valve shoe 500 and a smooth cylindrical sidewall 710. With reference additionally to FIG. 3B, an underside of the valve port plate 510 is disposed on a manifold gasket 720. The valve port plate 510 includes multiple sets of generally symmetric concentrically disposed ports or openings aligned with openings in the manifold gasket 720 to communicate the ports in the plate 510 with the passages in the manifold 320. The ports extend vertically through the valve port plate 510 in a direction generally perpendicular to the engagement surface 700. In an alternative embodiment, the ports extend vertically through the valve port plate 510 in an angular direction toward the engagement surface 700. Preferably, all of the ports of each concentric set have the same configuration. Each concentric set of ports will now be described in turn.

A first set of eight circular vacuum ports 730 concentrically disposed at a first radius from the geometric center of the valve port plate 510 communicate with the vacuum chamber 430 of the manifold 320 and the exhaust gas grooves 570 of the valve shoe 500. In the prefered embodiment, eight ports are used as they allow sufficient gas flow through the valve without significant pressure drop. In an alternative embodiment, a number of ports different from eight could be used.

A second set of five round outgoing feed ports 740 concentrically disposed at a second radius from the geometric center of the valve port plate 510 communicate with outgoing feed passages 390 of the manifold 320, the feed channels 540 of the valve shoe 500, and the vacuum ports 730 via the exhaust passages 560 of the valve shoe 500.

A third set of five generally elliptical incoming product ports 750 concentrically disposed at a third radius from the geometric center of the valve port plate 510 communicate with the incoming product passages 370 of the manifold 320, the equalization channels 550 of the valve shoe 500, the purge channels 590 of the valve shoe 500, and the product delivery channels 580.

A fourth set of five circular outgoing product ports 760 concentrically disposed at a fourth radius from the geometric center of the valve port plate 510 communicate with the outgoing product passages 400 of the manifold 320 and the incoming product ports 750 via the product delivery channels 580.

A fifth set of three circular port plate alignment holes 731 concentrically disposed at a fifth radius from the geometric center of the valve port plate 510 align with alignment pins 321 (FIGS. 3B, 4) on the manifold 320. The alignment holes 731 ensure the port plate 510 will sit in proper alignment with the manifold 320. In an alternative embodiment, two or more alignment holes located at one or more radiuses from the geometric center of the valve port plate 510 may be aligned with an equal number of alignment pins located at set positions on the manifold 320.

A round central incoming feed port 770 disposed at the geometric center of the valve port plate 510 and the center of rotation of the valve assembly 310 communicates with the incoming feed passage 410 of the manifold 320 and the central feed pasage 600 of the rotary valve shoe 500.

In the rotary valve assembly 310 described above, a maximum of 1 PSI pressure drop occurs through any port of the valve asembly 310 when the system is producing 3 LPM of oxygen product. At lesser flows, the pressure drop is negligible.

With reference additionally to FIG. 6B, a single pressure swing adsorption cycle of the concentrator 114 will now be described. During use, the rotary valve shoe 500 rotates with respect to the valve port plate 510 so that the cycle described below is sequentially and continuously established for each adsorption bed 300. The speed of rotation of the rotary valve shoe 500 with respect to the valve port plate 510 may be varied alone, or in combination with a variable-speed compressor, in order to provide the optimal cycle timing and supply of ambient air for a given production of product. To help the reader gain a better understanding of the invention, the following is a description of what occurs in a single adsorption bed 300 and the rotary valve assembly 310 during a single cycle. It should be noted, with each revolution of the rotary valve shoe 500, the adsorption beds 300 undergo two complete cycles. For each cycle, the steps include: 1) pre-pressurization 774, 2) adsorption 776, 3) first equalization down 778, 4) second equalization down 780, 5) co-current blowdown 782, 6) low-pressure venting 784, 7) counter-current purge and low-pressure venting 786, 8) first equalization up 788, and 9) second equalization up 790.

Each of these steps will be described in turn below for an adsorption bed 300.

In the pre-pressurization step 774, air flows from the compressor 112 to the feed pressure line 420, through the incoming feed passage 410 of the manifold 320. From there, air flows through the central incoming feed port 770 of the port plate 510, through the central feed passage 600 and out the feed channels 540 of the valve shoe 500, through the outgoing feed ports 740, and through outgoing feed passages 390 of the manifold 320. From there, the feed air flows to the feed ends 360 of the adsorption beds 300. With reference to FIG. 5A, because the feed channel 540 is advanced with respect to the product delivery channel 580 (i.e., initially the feed channel 540 is in communication with outgoing feed port 740 and the product delivery channel 580 is blocked, not in communication with the incoming product port 750), the feed end 360 of the adsorption bed 300 is pressurized with feed gas, i.e., pressurized, prior to the commencement of product delivery. In alternative embodiments, the product end 350 may be pre-pressurized with product gas, or the product end 350 may be pre-pressurized with product gas and the feed end 360 may be pre-pressurized with feed gas.

In the adsorption step 776, because the product delivery channel 580 is in communication with the incoming product port 750, adsorption of Nitrogen occurs in the bed 300 and the resulting product oxygen gas flows towards the product ends 350 of the adsorption beds 300, through the product lines 380, and through incoming product passages 370 of the manifold 320. From there, oxygen gas flows through the incoming product port, into and out of the product delivery channel 580, through outgoing product port 760, through the outgoing product passage 400, and into the product tank 330. From the product tank 330, oxygen gas is supplied to the user 108 through the product delivery line 450 and the supply line 121.

In the first equalization-down step 778, the product end 350 of the bed 300, which is at a high pressure, is equalized with the product end of another bed, which is at a low pressure, to bring the product end 350 of the bed 300 to a lower, intermediate pressure. The product ends 350 communicate through the product lines 380, the incoming product passages 370, the incoming product ports 750, the equalization channels 550, and the equalization groove 660. As indicated above, equalization routing via the grooves 660 on the second valve surface 630, in a plane out of and parallel to a plane defined by the engagement surface 520, helps to maintain the relatively small size of the rotary valve shoe 500, in order to keep the torque required to turn the valve shoe 500 as low as possible, while at the same time enabling more complex fluid routing through the valve shoe 500. In this step 778 and the equalization steps 780, 788, 790 to be discussed below, the adsorption beds 300 may be equalized at either the feed end 360, the product end 350, or a combination of the feed end 360 and the product end 350.

In the second equalization-down step 780, the product end 350 of the bed 300, which is at an intermediate pressure, is equalized with the product end of another bed, which is at a lower pressure, to bring the product end 350 of the bed 300 further down to an even lower pressure than in step 778. Similiar to the first equalization-down step 778, the product ends 350 communicate through the product lines 380, the incoming product passages 370, the incoming product ports 750, the equalization channels 550, and the equalization groove 660.

In the co-current blowdown ("CCB") step 782, oxygen enriched gas produced from the product end 350 of the adsorption bed 300 is used to purge a second adsorption bed 300. Gas flows from the product side of the adsorption bed 300, through product line 380, incoming product passage 370, and incoming product port 750. The gas further flows through purge channel 590, purge passage 640, through the purge groove 650, out the purge passage 640 on the opposite side of the valve shoe 500, through the purge channel 590, through the incoming product port 750, through the incoming product pasasge 370, through the product line 380, and into the product end 350 of adsorption bed 300 to serve as a purge stream. In an alternative embodiment, in this step 782 and the following step 784, co-current blowdown may be replaced with counter-current blowdown.

In the low-pressure venting ("LPV") step 784, the adsorption bed 300 is vented to low pressure through the feed end 360 of the adsorption bed 300. The vacuum in the exhaust groove 570 of the rotary valve shoe 500 communicates with the exhaust passage 560 and the feed end 360 of the adsorption bed 300 (via the outgoing feed port 740 and outgoing feed passage 390) to draw the regeneration exhaust gas out of the adsorption bed 300. The low pressure venting step 784 occurs without introduction of oxygen enriched gas because the exhaust passage 560 is in communication with the outgoing feed port 740 and the purge channel 590 is not in communication with the incoming product port 750.

In the counter-current purge and low-pressure venting ("LPV") step 786, oxygen enriched gas is introduced into the product end 350 of the adsorption bed 300 in the manner described above in step 782 concurrently with the feed end 360 of the adsorption bed 300 being vented to low pressure as was described in the above step 784. Counter-current purge is introduced into the product end 350 of the adsorbent bed 300 through fluid communication with the product end 350 of a second adsorption bed 300. Oxygen enriched gas flows from the product end 350 of the second adsorption bed 300 through the product line 380, incoming product passage 370, incoming product port 750, through purge channel 590, purge passage 640, through the purge groove 650, out the purge passage 640 on the opposite side of the valve shoe 500, through the purge channel 590, through the incoming product port 750, through the incoming product passage 370, through the product line 380, and into the product end 350 of adsorption bed 300. Because the exhaust passage 560 is also in communication with the outgoing feed port 740 during this step 786, oxygen enriched gas flows from the product end 350 to the feed end 360, regenerating the adsorption bed 300. The vacuum in the exhaust groove 570 of the rotary valve shoe 500 communicates with the exhaust passage 560 and the feed end 360 of the adsorption bed 300 (via the outgoing feed port 740 and outgoing feed passage 390) to draw the regeneration exhaust gas out of the adsorption bed 300. From the exhaust passage 560, the exhaust gas flows through the vacuum ports 730, into the vacuum chamber 430, and out the vacuum presure line 440. In an alternative embodiment, the vacuum may be replaced with a low-pressure vent that is near atmospheric pressure or another pressure that is low relative to the feed pressure. In another embodiment, product gas from the product tank 330 is used to purge the product end 350 of the adsorbent bed 300.

In the first equalization-up step 788, the product end 350 of the bed 300, which is at a very low pressure, is equalized with the product end of another bed, which is at a high pressure, to bring the adsorption bed 300 to a higher, intermediate pressure. The product ends 350 communicate through the product lines 380, the incoming product passages 370, the incoming product ports 750, the equalization channels 550, and the equalization groove 660.

In the second equalization-up step 790, the product end 350 of the bed 300, which is at an intermediate pressure, is equalized with the product end of another bed, which is at a higher pressure, to bring the product end 350 of the bed 300 further up to an even higher pressure than in step 788. Similiar to the first equalization-down step 778, the product ends 350 communicate through the product lines 380, the incoming product passages 370, the incoming product ports 750, the equalization channels 550, and the equalization groove 660.

It should be noted, in a preferred embodiment, the combined duration of feed steps 774, 776 may be substantially the same as the combined duration of purge steps 782, 784, 786, which may be substantially three times the duration of each equalization step 778, 780, 788, 790. In an alternative embodiment, the relative duration of the feed steps 774, 776, the purge steps 782, 784, 786, and the each equalization step 778, 780, 788, 790 may vary.

After the second equalization-up step 790, a new cycle begins in the adsorption bed 300 starting with the pre-pressurization step 774.

The five-bed concentrator 114 and cycle described above has a number of advantages over other-numbered concentrators and cycles used in the past, some of which are described below. The multiple equalization steps 788, 790 at the product ends 350 and the pre-pressurization step 774 contribute to the pre-pressurization of the adsorption beds 300 prior to product delivery. As a result, the beds 300 reach their ultimate pressure (substantially equal to the feed pressure) quickly and thereby allow for maximum utilization of the adsorbent media. Additionally, pre-pressurizing the adsorbent beds 300 allows product to be delivered at substantially the same pressure as the feed, thereby retaining the energy of compression in the stream, which makes the product stream more valuable for use in downstream processes. In an alternative embodiment, pre-pressurizing the beds 300 with product before exposing the feed end 360 of the bed 300 to the feed stream eliminates any pressure drop experienced due to the fluid interaction or fluid communication between two or more adsorbent beds 300 on the feed end 360. Additionally, compared to systems with greater numbers of beds, the use of a 5-bed system, reduces the duration and number of beds that are in fluid communication with the feed chanels 540 at the same time, thereby reducing the propensity for fluid flow between adsorption beds. Since fluid flow between adsorption beds is associated with a reversal of the flow direction in the higher pressure bed (resulting in decreased performance), reduction in this effect is advantageous.

A further advantage of a 5-bed system over many systems is that it includes a small number of adsorption beds 300, allowing the concentrator to be relative small, compact, and light-weight, while delivering sufficient flow and purity and maintaining high oxygen recovery. Other PSA systems, typically those with a small number of adsorption beds, result in deadheading the compressor (resulting in high power use) during a portion of the cycle. Deadheading the compressor eliminates detrimental flow between the feed side 360 of the two or more adsorption beds 300 (as discussed above) but increases system power. The 5-bed system eliminates compressor deadheading and minimizes performance-limiting feed side 360 flow between adsorbent beds 300.

Use of the multiple pressure equalization steps 778, 780, 788, 790 reduces the amount of energy of compression required to operate the concentrator 114. Equalizing the beds 300 conserves high-pressure gas by moving it to another bed 300 rather than venting it to the atmosphere or to a vacuum pump. Because there is a cost associated with pressurizing a gas, conserving the gas provides a savings and improves recovery. Also, because a bed 300 may contain gas enriched with product, usually at the product end 350 of the bed 300, allowing this gas to move into another bed 300, rather than venting it, conserves product and improves recovery. The number of equalizations are preferably between one and four. It should be noted, each equalization represents two equalization steps, an equalization-down step and an equalization-up step. Thus, two equalizations means two down equalizations and two up equalizations, or four total equalizations. The same is true for other-number equalizations. In a preferred embodiment, one to four equalizations (two to eight equalization steps) are used in each cycle. In a more preferred embodiment, one to three equalizations (two to six equalization steps) are used in each cycle. In a most preferred embodiment, two equalizations (four equalization steps) are used in each cycle.

In alternative embodiments, the concentrator 114 may have other numbers of adsorption beds 300 based on the concentration of the feed stream, the specific gases to be separated, the pressure swing adsorption cycle, and the operating conditions. For example, but not by way of limitation, there also are advantages to four-bed concentrators and six-bed concentrators. When operating a cycle similar to that described above with a four-bed concentrator, the problem of fluid communication between the feed chanels 540 and more than one adsorption bed (at one instant) is completely eliminated. When the feed-end fluid communication is eliminated, the feed steps 774, 776 occur in a more desirable fashion resulting in improved recovery of the desired product. The advantages of a six-bed system, compared to a five-bed system, are realized when the pressure-swing cycle described above is modified so that there are three equalization up stages and three equalization down stages instead of two equalization up stages and two equalization down stages. A third equalization is advantageous when the feed gas is available at high pressure. The third equalization conserves compressor energy because it allows the equalized beds to obtain substantially 75% of the feed pressure compared to substantially 67% of the feed pressure when two equalization stages are used. In any PSA cycle, whenever an equalization up occurs, there is a corresponding equalization down. The requirement of matching equalization stages inparts some restrictions on the relative timing of the cycle steps. If, for example, the duration of the feed step is substantially the same as the duration of each equalization step, then a six-bed cycle would provide the required matching of equalization stages.

A number of additional inventive aspects related to the concentrator 114 that increase recovery of a desired component and system productivity will now be described. With reference to FIGS. 3A, 3B, 7A, and 7B, an embodiment of a media retention cap 800 that reduces dead volume in the adsorption beds 300 will now be described. Each media retention cap 800 is located at the product end 350 of the adsorption bed 300 and supports the adsorbent material above the media retention cap 800. A spring 810 located within and below the media retention cap 800 urges the media retention cap 800 upwards to hold the packed bed of adsorbent material firmly in place. The media retention cap 800 has a cylindrical base 820 with first and second annular flanges 830, 840. The second annular flange 840 terminates at its top in a circular rim 850. A top surface 860 of the media retention cap 800 includes a plurality of ribs 870 radiating in a generally sunburst pattern from a central port 880. Adjacent the central port 880, gaps 890 create diffusion zones for purge fluid coming out of the central port 880. The gaps 890 and the radiating ribs 870 cause the purge fluid to be distributed outward from the central port 880, causing a more uniform, improved regeneration of the adsorbent material during a purging step. The radiating ribs 870 also help to channel product gas towards the central port 880 during a product delivery step. In an alternative embodiment, the media retention cap 800 may have a generally non-cylindrical surface to retain media in a generally non-cylindrical adsorbtion bed 300. In a further alternative embodiment, the central port 880 may be located away from the geometric center of the either cylindrical or non-cylindrical media retention cap 800.

With reference to FIG. 7B, on the underside of the media retention cap 800, the cydrical base 820 forms an interior chamber in which the spring 810 is disposed. A central port nipple 900 extends from a bottom surface 910 of the media retention cap 800. An end of the product line 380 connects to the central port nipple 900 for communicating the product end 350 of the adsorption bed 300 with the incoming product passage 370 of the manifold 320.

In the past, media retention caps may be held in place with a spring that fits inside and above the cap so that the spring is in the fluid flow path between the bottom of the adsorbent material and any exit port, at the product end 350 of the bed 300. The volume in which the spring is housed represents dead volume in the system. As used herein, "dead volume" is system volume that is compressed and purged, but does not contain adsorbent media. The process of filling this volume with compressed feed and then venting that volume represents wasted feed. The improved media retention cap 800 does not add dead volume to the system because the spring 810 is housed outside of the fluid flow path. Elimination of any extra volume within the system results directly in more effective utilization of the feed, and, thus, higher recovery of the desired product.

With reference to FIGS. 8A and 8B, an embodiment of a centering mechanism for maintaining the rotary valve shoe 500 laterally fixed and centered with respect to the valve port plate 510 will now be described. The centering mechanism may include a centering pin 920 having a hollow cylindrical shape and made of a rigid material. When the engagement surface 520 of the rotary valve shoe 500 is engaged with the engagement surface 700 of the valve port plate 510, the centering pin 920 is partially disposed in the central feed pasage 600 of the rotary valve shoe 500 and the central incoming feed port 770 of the valve port plate 510. In use, the rotary valve shoe 500 rotates around the centering pin 920 and the hollow interior of the centering pin 920 allows high-pressure feed fluid to flow therethrough. The pin 920 maintains the rotating valve shoe in a fixed position relative to the valve port plate 510. In the past, the rotary valve shoe was roughly centered with respect to the valve port plate by the motor that drives the rotary valve shoe. If the rotary valve shoe 500 and the valve port plate 510 are off center with respect to each other, the concentrator 114 will not cycle as intended, inhibiting the productivity, recovery, and efficiency of the concentrator. The precision offered by the centering pin 920 is important when the valve assembly 310 is controlling complex cycles or maintaining very small pressure drops.

With reference to FIGS. 9A and 9B, a rotary valve assembly constructed in accordance with another embodiment of the invention includes an alternative centering mechanism to maintain the rotating valve shoe 500 in a fixed position relative to the valve port plate 510. A circular centering ring 930 fits snugly over the smooth cylindrical sidewall 530 of the rotary valve shoe 500 and the smooth cylindrical sidewall 710 of the stationary valve port plate 510. The circular ring 930 centers the rotary valve shoe 500 relative to the valve port plate 510 by holding the rotary shoe 500 in a fixed position relative to the port plate 510 while at the same time allowing the rotary valve shoe 500 to rotate.

With reference to FIGS. 10A–10C, an embodiment of an elastic link for coupling the motor 118 to the valve shoe 500 will now be described. A drive mechanism 940 includes a drive shaft 950, a drive wheel 960, and three (two shown) elastic chain links 970. The drive shaft 950 may be connected to the motor 118 for rotating the drive wheel 960. With reference to FIG. 10C, a lower side 980 of the drive wheel 960 may include downwardly protruding cylindrical support posts 990. Similarly, with reference to FIG. 10B, an upper side 1000 of the second valve shoe cover 690 may include upwardly protruding cylindrical support posts 1010. The elastic chain links 970 are preferably made of semi-rigid, elastic material (such as silicon rubber) and have a generally wrench-shaped configuration. Each elastic chain link 970 includes cylindrical receiving members 1020 with central cylindrical bores 1030. The cylindrical receiving members 1020 are joined by a narrow connecting member 1040. The drive wheel 960 is coupled to the second valve shoe cover 690 through the elastic chain links 970. One receiving member 1020 of each elastic chain link receives the support post 990 of the drive wheel 960 and the other receiving member 1020 receives the support post 1010 of the second valve shoe cover 690. In the past, rigid connections were made between the motor and the rotating valve shoe. These rigid connections caused the rotating valve shoe to be affected by vibration or other non-rotational movement of the motor. The elastic chain links 970 absorb the vibration and non-rotational movement of the motor, preventing this detrimental energy from being imparted to the rotating valve shoe 500.

FIG. 11 is a table of experimental data from a concentrator similar to the concentrator 114 shown and described above with respect to FIGS. 3–10. As shown by this table, the recovery of oxygen from air with the concentrator 114 is 45–71% at about 90% purity. The ratio of adiabatic power (Watts) to oxygen flow (Liters Per Minute) is in the range of 6.2 W/LPM to 23.0 W/LPM. As defined in Marks' Standard Handbook for Mechanical Engineers, Ninth Edition, by Eugene A. Avallone and Theodore Baumeister, the equation for adiabatic power, tanken from the equation from adiabatic work, is as follows:

$$\text{Power} = \frac{W}{t} = P_1 V_1 \left(\frac{k}{1-k}\right)\left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right]C$$

Power = Adiabatic Power (Watts)
W = Adiabatic Work (Joule)
t = time (Second)
P_1 = Atomspheric Pressure (psia)
P_2 = Compressor/Vacuum pressure (psia)
k = Ratio of Specific Heats = constant = 1.4 (for air)
V_1 = Volumetric flow rate at atmospheric pressure (SLPM)
C = Conversion Factor, added by authors for clarity = 0.114871 Watts/psi/LPM

B. Energy Source

With reference additionally to FIG. 12, in order to properly function as a lightweight, portable system 100, the system 100 must be energized by a suitable rechargeable energy source. The energy source preferably includes a rechargeable battery 104 of the lithium-ion type. It will be readily apparent to those skilled in the art that'. the system 100 may be powered by a portable energy source other than a lithium-ion battery. For example, a rechargeable or renewable fuel cell may be used. Although the system is generally described as being powered by a rechargeable battery 104, the system 100 may be powered by multiple batteries. Thus, as used herein, the word "battery" includes one or more batteries. Further, the rechargeable battery 104 may be comprised of one or more internal and/or external batteries. The battery 104 or a battery module including the battery 104 is preferably removable from the system 100. The system 100 may use a standard internal battery, a low-cost battery, an extended-operation internal battery, and an external secondary battery in a clip-on module.

The system 100 may have a built-in adapter including battery charging circuitry 130 and one or more plugs 132 configured to allow the system 100 to be powered from a DC power source (e.g., car cigarette lighter adapter) and/or an AC power source (e.g., home or office 110 VAC wall socket) while the battery 104 is simultaneously being charged from the DC or AC power source. The adapter or charger could also be separate accessories. For example, the adapter may be a separate cigarette lighter adapter used to power the system 100 and/or charge the battery 104 in an automobile. A separate AC adapter may be used to convert the AC from an outlet to DC for use by the system 100 and/or charging the battery 104. Another example of an adapter may be an adapter used with wheel chair batteries or other carts.

Alternatively, or in addition, a battery-charging cradle 134 adapted to receive and support the system 100 may have an adapter including battery charging circuitry 130 and a plug 132 that also allow the system 100 to be powered while the battery 104 is simultaneously being charged from a DC and/or AC power source.

The system 100 and cradle 134 preferably include corresponding mating sections 138, 140 that allow the system 100 to be easily dropped into and onto the cradle 134 for docking the system 100 with the cradle 134. The mating sections 138,140 may include corresponding electrical contacts 142, 144 for electrically connecting the system 100 to the cradle 134.

The cradle 134 may be used to recharge and/or power the system 100 in the home, office, automobile, etc. The cradle 134 may be considered part of the system 100 or as a separate accessory for the system 100. The cradle 134 may include one or more additional charging receptacles 146 coupled to the charging circuitry 130 for charging spare battery packs 104. With a charging receptacle 146 and one or more additional battery packs 104, the user can always have a supply of additional fresh, charged batteries 104.

In alternative embodiments, the cradle 134 may come in one or more different sizes to accommodate one or more different types of systems 100.

The cradle 134 and/or system 100 may also include a humidifying mechanism 148 for adding moisture to the air flow in the system 100 through appropriate connections 149. In an alternative embodiment of the invention, the humidifying mechanism 148 may be separate from the system 100 and the cradle 134. If separate from the system 100 and cradle 134, the cradle 134 and/or system 100 may include appropriate communication ports for communicating with the separate humidifying mechanism 148. The cradle 134 may also include a receptacle adapted to receive a separate humidifying mechanism 148 for use with the system 100 when the system 100 is docked at the cradle 134.

The cradle 134 and/or system 100 may also include a telemetry mechanism or modem 151 such as a telephone modem, high-speed cable modem, RF wireless modem or the like for communicating the control unit 110 of the system 100 with one or more remote computers. To this end, the cradle 135 may include a line 153 with a cable adapter or telephone jack plug 155, or a RF antenna 157. In an alternative embodiment of the invention, the telemetry mechanism or modem 151 may be separate from the cradle 134 and to this end, the cradle 134 or system 100 may include one or more appropriate communication ports, e.g., a PC port, for directly communicating the telemetry mechanism or modem 151 with the cradle 134 or system 100. For example, the cradle 134 may be adapted to communicate with a computer (at the location of the cradle) that includes the telemetry mechanism or modem 151. The computer may include appropriate software for communicating information described below using the telemetry mechanism or modem 151 with the one or more remote computers.

The telemetry mechanism or modem 151 may be used to communicate physiological information of the user such as, but not by way of limitation, heart rate, oxygen saturation, respiratory rate, blood pressure, EKG, body temperature, inspiratory/expiratory time ratio (I to E ratio) with one or more remote computers. The telemetry mechanism or modem 151 may be used to communicate other types of information such as, but not by way of limitation, oxygen usage, maintenance schedules on the system 100, and battery usage with one or more remote computers.

A user ideally uses the system 100 in its cradle 134 at home, at the office, in the automobile, etc. A user may decide to have more than one cradle, e.g., one at home, one at the office, one in the automobile, or multiple cradles at home, one in each room of choice. For example, if the user has multiple cradles 134 at home, when the user goes from room to room, e.g., from the family room to the bedroom, the user simply lifts the system 100 out of its cradle 134 in one room, and walks to the other room under battery operation. Dropping the system 100 in a different cradle 134 in th destination room restores the electrical connection between the system 100 and the AC power source. Since the system's batteries 104 are constantly charging or charged when located in the cradle 134, excursions outside the home, office, etc. are as simple as going from room to room in the user's home.

Because the system 100 is small and light (2–15 pounds), the system 100 may simply be lifted from the cradle 134 and readily carried, e.g., with a shoulder strap, by an average user to the destination. If the user is unable to carry the system 100, the system 100 may be readily transported to the destination using a cart or other transporting apparatus. For an extended time away from home, office, etc., the user may bring one or more cradles 134 for use at the destination. Alternatively, in the embodiment of the system 100 including the built-in adapter, power may be drawn from power sources such as a car cigarette lighter adapter and/or an AC power outlet available at the destination. Further, spare battery Packs 104 may be used for extended periods away from standard power sources.

If the battery pack 104 includes multiple batteries, the system 100 may include a battery sequencing mechanism to conserve battery life as is well known in the cellphone and laptop computer arts.

C. Output Sensor

With reference to FIGS. 1, 2 and 13, one or more output sensors 106 are used to sense one or more conditions of the user 108, environment, etc. to determine the oxygen flow rate needs of the user and, hence, the oxygen flow rate output requirements for the system 100. A control unit 110 is linked to the one or more output sensors 106 and the oxygen gas generator 102 to control the oxygen generator 102 in response to the condition(s) sensed by the one or more output sensors 106. For example, but not by way of limitation, the output sensor(s) 106 may include any or all of the activity sensors shown and described in U.S. Pat. No. 5,928,189, which is incorporated by reference as though set forth in full. These output sensors include a pressure sensor 150, a position sensor 152, an acceleration sensor 154, as well as a physiological condition or metabolic sensor 156 and an altitude sensor 158.

The first three sensors 150, 152, 154 (and, in certain circumstances, the physiological condition sensor 156) are activity sensors because these sensors provide a signal representing activity of the user 108. In the delivery of oxygen with a portable oxygen concentration system, it is important to deliver an amount of oxygen gas proportional to the activity level of the user 108 without delivering too much oxygen. Too much oxygen may be harmful for the user 108 and reduces the life of the battery 104. The control unit 110 regulates the oxygen gas generator 102 to control the flow rate of oxygen gas to the user 108 based on the oneor more signals representative of the activity level of the user produced by the one or more sensors 106. For example, if the output sensor(s) 106 indicates that the user 108 has gone from an inactive state to an active state, the control unit 110 may cause the oxygen gas generator 102 to increase the flow rate of oxygen gas to the user 108 and/or may provide a burst of oxygen gas to the user 108 from a high-pressure oxygen reservoir to be described. If the output sensor(s) 106 indicates that the user 108 has gone from an active state to an inactive state, the control unit 110 may cause the oxygen gas generator 102 to reduce the flow rate of oxygen gas to the user.

In an embodiment of the invention, the amount of oxygen gas supplied is controlled by controlling the speed of the compressor motor 118 via the variable-speed controller 119.

Alternatively, or in addition to the variable-speed controller, the supply of oxygen gas may be controlled by the supply valve 160 located in the supply line 121 between the oxygen gas (generator 102 and the user 108. For example, the supply valve 160 may be movable between at least a first position and a second position, the second position allowing a greater flow of concentrated gaseous oxygen through than the first position. The control unit 110 may cause the supply valve 160 to move from the first position to the second position when one or more of the activity level sensors 152, 154,156 senses an active level of activity of the user 108. For example, the control unit 110 may include a timer, and when an active level is sensed for a time period exceeding a predetermined timed period, the control unit 110 causes the valve 160 to move from the first position to the second position.

Examples of pressure sensors 150 include, without limitation, a foot switch that indicates when a user is in a standing position compared to a sedentary position, and a seat switch that indicates when a user is in a seated position compared to a standing position.

A pendulum switch is an example of a position sensor 152. For example, a pendulum switch may include a thigh switch positioned pendulously to indicate one mode when the user is standing, i.e., the switch hangs vertically, and another mode when the user seated, i.e., the thigh switch raised to a more horizontal position. A mercury switch may be used as a position sensor.

An acceleration sensor 158 such as an accelerometer is another example of an activity sensor that provides a signal representing activity of the user.

The physiological condition or metabolic sensor 156 may also function as an activity sensor. The physiological condition sensor 156 may be used to monitor one or more physiological conditions of the user for controlling the oxygen gas generator 102 or for other purposes. Examples of physiological conditions that may be monitored with the sensor 156 include, but without limitation, blood oxygen level, heart rate, respiration rate, blood pressure, EKG, body temperature, and I to E ratio. An oximeter is an example of a sensor that is preferably used in the system 100. The oximeter measures the blood oxygen level of the user, upon which oxygen production may be at least partially based.

An altitude sensor 158 is an example of an environmental or ambient condition sensor that may sense an environmental or ambient condition upon which control of the supply of oxygen gas to the user may be at least partially based. The altitude sensor 158 may be used alone or in conjunction with any or all of the above sensors, the control unit 110 and the oxygen gas generator 102 to control the supply of oxygen gas to the user in accordance with the sensed altitude or elevation. For example, at higher sensed elevations, where air is less concentrated, the control unit may increase the flow rate of oxygen gas to the user 108 and at lower sensed elevations, where air is more concentrated, the control unit may decrease the flow rate of oxygen gas to the user 108 or maintain it at a control level.

It will be readily apparent to those skilled in the art that one or more additional or different sensors may be used to sense a condition upon which control of the supply of oxygen gas to the user may be at least partially based. Further, any or all of the embodiments described above for regulating the amount of oxygen gas supplied to the user 108, i.e., variable-speed controller 119, supply valve 160, (or alternative embodiments) may be used with the one or more sensors and the control unit 110 to control of the supply of oxygen gas to the user 108.

D. Control Unit

With reference to FIG. 14, the control unit 110 may take any well-known form in the art and includes a central microprocessor or CPU 160 in communication with the components of the system described herein via one or more interfaces, controllers, or other electrical circuit elements for controlling and managing the system. The system 100 may include a user interface (FIG. 14) as part of the control unit 110 or coupled to the control unit 110 for allowing the user, provider, doctor, etc. to enter information, e.g., prescription oxygen level, flow rate, activity level, etc., to control the system 100.

The main elements of an embodiment of the system 100 have been described above. The following sections describe a number of additional features, one or more of which may be incorporated into the embodiments of the invention described above as one or more separate embodiments of the invention.

II. Conserving Device

With reference to FIG. 15, a conserving device or demand device 190 may be incorporated into the system 100 to more efficiently utilize the oxygen produced by the oxygen gas generator 102. During normal respiration, a user 108 inhales for about one-third of the time of the inhale/exhale cycle and exhales the other two-thirds of the time. Any oxygen flow provided to the user 108 during exhalation is of no use to the user 108 and, consequently, the additional battery power used to effectively provide this extra oxygen flow is wasted. A conserving device 190 may include a sensor that senses the inhale/exhale cycle by sensing pressure changes in the cannula 111 or another part of the system 100, and supply oxygen only during the inhale portion or a fraction of the inhale portion of the breathing cycle. For example, because the last bit of air inhaled is of no particular use because it is trapped between the nose and the top of the lungs, the conserving device 190 may be configured to stop oxygen flow prior to the end of inhalation, improving the efficiency of the system 100. Improved efficiency translates into a reduction in the 20 size, weight, cost and power requirements of the system 100.

The conserving device 190 may be a stand-alone device in the output line of the system 100, similar to a regulator for scuba diving, or may be coupled to the control unit 110 for controlling the oxygen generator 102 to supply oxygen only during inhalation by the user 108.

The conserving device 190 may include one or more of the sensors described above. For example, the conserving device may include a sensor for monitoring the respiration rate of the user.

The system 100 may also include a special cannula retraction device for retracting the cannula 111 when not in use. Further, the cannula 111 may come in different lengths and sizes.

III. High-Pressure Reservoir

With reference to FIG. 16, a high-pressure reservoir 164 may be located in a secondary line 166 for delivering an additional supply of oxygen gas to the user 108 when the oxygen gas generator 102 can not meet the oxygen gas demands of the user 108. Any of the components described below in the secondary line 166 may be coupled to the control unit 110 or a high-pressure reservoir controller 167 (FIG. 14) for control thereby. Exemplary situations where this additional oxygen gas need may occur are when a user suddenly goes from an inactive state to an active state, e.g., when getting out of a chair, when the system 100 is turned on, or when the system 100 goes from a conserving mode or sleep mode to an active mode. As used herein, secondary line 166 refers to the tubing, connectors, etc. used to connect the components in the line. A valve 168 may be controlled by the control unit 110 to allow gaseous oxygen to flow into the secondary line 166. The valve 168 may be configured to allow simultaneous flow to both the supply line 121 and the secondary line 166, flow to only the supply line 121, or flow to only the secondary line 166.

A pump or compressor 168, which is preferably powered by the motor 118, delivers the oxygen gas at a relatively high pressure, e.g., at least approximately 100 psi, to the high-pressure reservoir 164.

An oxygen-producing electrochemical cell 171 may be used in conjunction with or instead of the elements described in the secondary line 166 to supply additional oxygen gas to the user 108. U.S. Pat. No. 6,010,317 to Maget, et al., which is incorporated by reference as though set forth in full, describes an electrochemical cell that may be used for this purpose. For example the electrochemical cell 171 may be used to deliver oxygen gas at a relatively high pressure to the highpressure reservoir 164.

A pressure sensor 172 is in communication with the high-pressure reservoir 164 and the control unit 110 so that when the pressure in the high-pressure reservoir 164 reaches a certain limit, the control unit 110 causes the valve 168 to direct oxygen to the secondary line 166.

A regulator 174 may be used to control flow and reduce pressure of the oxygen gas to the user 108.

A valve 176 may also be controlled by the control unit 110 to allow gaseous oxygen from the high-pressure reservoir 164 to flow into the supply line 121 when the user 108 requires an amount of oxygen gas that cannot be met by the oxygen gas generator 102. The valve 176 may be configured to allow simultaneous flow from the oxygen gas generator 102 and the high-pressure reservoir 164, from only the oxygen gas generator 102, or from only the high-pressure reservoir 164.

The one or more sensors 106 are interrelated with the control unit 110 and the oxygen gas generator 102 so as to supply an amount of oxygen gas equivalent to the oxygen gas needs of the user 108 based at least in part upon one or more conditions sensed by the one or more sensors 106. When the oxygen gas generator 102 cannot meet the oxygen gas demands of the user 108, the control unit 110, based at least in part upon sensing one or more conditions indicative of the oxygen needs of the user, may cause the high-pressure reservoir 164 (via the valve 176) to supply the additional oxygen gas needed.

In the scenario where the oxygen gas generator 102 is capable of supplying the full oxygen gas needs of the user 108, but is simply turned off or is in a conserving or sleep mode, the period of time that the high-pressure reservoir 164 supplies the oxygen gas, i.e., the period of time that the valve 176 connects the high-pressure reservoir 164 with the supply line 121, is at least as long as the time required for the oxygen gas generator 102 to go from an off or inactive condition to an on or active condition. In another scenario, the control unit 110 may cause oxygen gas to be supplied to the user from the high-pressure reservoir 164 when the demand for gaseous oxygen by the user exceeds the maximum oxygen gas output of the oxygen gas generator 102. Although the high-pressure reservoir 164 is shown and described as being filled by the oxygen gas generator 102, in an alternative embodiment, the high-pressure reservoir 164 may be filled by a source outside or external to the system.

IV. Global Positioning System

With reference back to FIG. 12, in an alternative embodiment of the invention, the system 100 may include a global positioning system (GPS) receiver 200 for determining the location of the system 100. The location of the receiver 200 and, hence, the user 108 can be transmitted to a remote computer via the telemetry mechanism or modem 151. This may be desirable for locating the user 108 in the event the user has a health problem, e.g., heart attack, hits a panic button on the system, an alarm is actuated on the system, or for some other reason.

V. Additional Options and Accessories

In addition to the cradle 134, the portable oxygen concentration system 100 may include additional options and accessories. A number of different types of bags and carrying cases such as, but not by way of limitation, a shoulder bag, a backpack, a fanny pack, a front pack, and a split pack in different colors and patterns may be used to transport the system 100 or other system accessories. A cover may be used to shield the system from inclement weather or other environmental damage. The system 100 may also be transported with a rolling trolley/cart, a suit case, or a travel case. The travel case may be designed to carry the system 100 and include enough room to carry the cannulae 111, extra batteries, an adapter, etc. Examples of hooks, straps, holders for holding the system 100 include, but not by way of limitation, hooks for seatbelts in cars, hooks/straps for walkers, hooks/straps, for wheel chairs, hooks/straps for hospital beds, hooks for other medical devices such as ventilators, hooks/straps for a golf bag or golf cart, hooks/straps for a bicycle, and a hanging hook. The system 100 may also include one or more alarm options. An alarm of the system 100 may be actuated if, for example, a sensed physiological condition of the user 108 falls outside a pre-defined range. Further, the alarm may include a panic alarm that may be manually actuated by the user 108. The alarm may actuate a buzzer or other sounding device on the system 100 and/or cause a communication to be sent via the telemetry mechanism or modem 151 to another entity, e.g., a doctor, a 911 dispatcher, a caregiver, a family member, etc.

Although this invention has been described in terms of certain preferred embodiments, other embodiments apparent to those of ordinary skill in the art are also within the scope of this invention. Accordingly, the scope of this invention is intended to be defined only by the claims that follow.

We claim:

1. A portable oxygen concentrator system adapted to be readily transported by a user, comprising:

a rechargeable energy source;

a concentrator powered by said energy source and adapted to convert ambient air into concentrated oxygen gas for said user, the concentrator including a plurality of adsorption beds and a rotary valve assembly, the rotary valve assembly relatively rotatable with respect to the plurality of adsorption beds to provide valving action for selectively transferring fluids through the plurality of adsorption beds for converting ambient air into concentrated oxygen gas for said user,

wherein the ratio of adiabatic power to oxygen flow for the concentrator is in the range of 6.2 W/LPM to 23.0 W/LPM.

2. The portable oxygen concentrator system of claim 1, wherein the concentrator includes exactly five adsorption beds.

3. The portable oxygen concentrator system of claim 1, wherein the rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and relatively rotatable about a common center of rotation to provide valving action for selectively transferring fluids therethrough, and a centering mechanism other than a motor to center the rotary valve shoe relative to the valve port plate.

4. The portable oxygen concentrator system of claim 3, wherein the valve port plate and the rotary valve shoe include respective central holes, and the centering mechanism includes a centering pin disposed in the central holes of the valve port plate and rotary valve shoe to center the rotary valve shoe relative to the valve port plate.

5. The portable oxygen concentrator system of claim 3, wherein the valve port plate and rotary valve shoe include cylindrical sidewalls, and the centering mechanism includes a centering ring disposed around the sidewalls of the valve port plate and the rotary valve shoe to center the rotary valve shoe relative to the valve port plate.

6. The portable oxygen concentrator system of claim 1, wherein the adsorption beds carry adsorbent material, and include a first end, a second end, an adsorbent media disposed in the adsorption beds between the first end and the second end, a media retention cap disposed between the adsorbent media and the second end, a spring to urge the media retention cap against the adsorbent material to hold the adsorbent media in place, and the spring not located in a flow path of the adsorption beds.

7. The portable oxygen concentrator system of claim 6, wherein the media retention cap includes a surface that contacts the adsorbent media, the surface including a central hole and a plurality of ribs radiating from the central hole.

8. The portable oxygen concentrator system of claim 6, wherein the media retention cap includes a bottom base with an interior, and the spring is disposed in the interior of the bottom base.

9. The portable oxygen concentrator system of claim 1, wherein the rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and relatively rotatable about a common center of rotation to provide valving action for selectively transferring fluids therethrough, and the portable oxygen concentrator system further includes a motor to rotate the rotary valve shoe, and one or more elastic links to couple the motor to the rotary valve shoe.

10. The portable oxygen concentrator system of claim 9, wherein the motor includes a drive shaft and a drive wheel with one or more protruding support members, the rotary valve shoe includes one or more protruding support members, and the elastic link connects the one or more protruding support members of the drive wheel with the one or more protruding support members of the rotary valve shoe.

11. The portable oxygen concentrator system of claim 1, wherein the concentrator includes plastic adsorption beds and a metal cover surrounding the plastic adsorption beds.

12. The portable oxygen concentrator system of claim 11, wherein the adsorption beds are, elongated, molded, plastic vessels.

13. The portable oxygen concentrator system of claim 12, wherein the metal cover is made of aluminum and surrounds the adsorption beds to form a product tank.

14. The portable oxygen concentrator system of claim 1, wherein the rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and relatively rotatable about a common center of rotation to provide valving action to put the adsorption beds in a pressure swing adsorption cycle, and the pressure swing adsorption cyle includes a number of equalization steps in each adsorption bed ranging from two to eight.

15. The portable oxygen concentrator system of claim 14, wherein the pressure swing adsorption cyle includes a number of equalization steps in each adsorption bed ranging from two to six.

16. The portable oxygen concentrator system of claim 14, wherein the pressure swing adsorption cyle includes four equalization steps in each adsorption bed.

17. The portable oxygen concentrator system of claim 14, wherein the equalization steps include a first equalization down step, a second equalization down step, a first equalization up step, and a second equalization up step.

18. The portable oxygen concentrator system of claim 14, wherein adsorption beds include a feed end and a product end, and equalization occurs between product ends of adsorption beds.

19. The portable oxygen concentrator system of claim 1, further including a variable-speed compressor to supply ambient air to the concentrator.

20. The portable oxygen concentrator system of claim 1, wherein recovery of oxygen from air from the concentrator is 45–71% at about 90% purity.

21. The portable oxygen concentrator system of claim 1, wherein the rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and relatively rotatable about a common center of rotation to provide valving action for selectively transferring fluids therethrough, said valve port plate having at least two ports interconnected with at least two adsorption beds, and said rotary valve shoe having a second valve surface opposite said engaged surface with at least one equalization passage to register with said at least two ports of the port plate to equalize pressure in said at least two adsorption beds.

22. The portable oxygen concentrator system of claim 1, wherein a pressure drop through the rotary valve assembly is no more than 1 PSI when the concentrator is producing 3 LPM of oxygen gas.

23. The portable oxygen concentrator system of claim 1, wherein the rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and relatively rotatable about a common center of rotation to provide valving action for selectively transferring fluids therethrough, the rotation speed of the rotary valve shoe with respect to the valve port plate is varied in order to provide desired cycle timing for a given production of product.

24. The portable oxygen concentrator system of claim 23, further including a variable-speed compressor to supply compressed ambient air to the concentrator, and the rotation speed of the rotary valve shoe with respect to the valve port plate is varied in combination with variation in the speed of the variable-speed compressor in order to provide desired cycle timing and desired supply rate of ambient air to the concentrator for a given production of product.

25. The portable oxygen concentrator system of claim 1, wherein the rotary valve assembly includes a valve port plate and a rotary valve shoe having respective engaged surfaces and relatively rotatable about a common center of rotation to provide valving action for selectively transferring fluids therethrough, and the rotary valve shoe includes a vacuum sealing mechanism that counteracts a pressure force working to unseat the rotary valve shoe from the valve port plate.

26. A portable oxygen concentrator system adapted to be readily transported by a user, comprising:

an internal rechargeable energy source;

an air separation device powered by said energy source and adapted to convert ambient air into concentrated oxygen gas for said user, the air separation device including a plurality of adsorber columns and a rotating valve, the rotating valve relatively rotatable with respect to the plurality of adsorber columns to provide valving action for selectively transferring fluids through the plurality of adsorber columns for converting ambient air into concentrated oxygen gas for said user,

wherein the portable oxygen concentrator system weighs 2–15 pounds and the adsorber columns each including a layered adsorbent bed having two or more distinct adsorbent material layers.

27. The portable oxygen concentrator system of claim 26, wherein the adsorber columns each include a feed end and a product end, and the two or more distinct adsorbent material layers include at least a water adsorption layer and a nitrogen adsorption layer, the water adsorption layer located closer to the feed end than the nitrogen adsorption layer.

28. The portable oxygen concentrator system of claim 27, wherein the water adsorption layer is an activated alumina.

29. The portable oxygen concentrator system of claim 27, wherein the water adsorption layer is a silica gel.

30. The portable oxygen concentrator system of claim 27, wherein the nitrogen adsorption layer is a lithium exchanged X-type zeolite.

31. A portable oxygen concentrator system adapted to be readily transported by a user, comprising:

an internal rechargeable energy source;

an air separation device powered by said energy source and adapted to convert ambient air into concentrated oxygen gas for said user, the air separation device including a plurality of adsorber columns each including a feed end and a product end and at least one valve operable with respect to the plurality of adsorber columns to provide valving action for selectively transferring fluids through the plurality of adsorber columns for convening ambient air into concentrated oxygen gas for said user,

wherein the portable oxygen concentrator system weighs 2–15 pounds and tie adsorber columns each including a layered adsorbent bed having two or more distinct adsorbent material layers, the two or more distinct adsorbent material layers including at least a water adsorption layer and a nitrogen adsorption layer, the water adsorption layer located closer to the feed end than the nitrogen adsorption layer.

32. The portable oxygen concentrator system of claim 31, wherein the water adsorption layer is an activated alumina.

33. The portable oxygen concentrator system of claim 31, wherein the water adsorption layer is a silica gel.

34. The portable oxygen concentrator system of claim 31, wherein the nitrogen adsorption layer is a lithium exchanged X-type zeolite.

* * * * *

JS 44 (Rev. 12/07)

CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM.)

2010 FEB 22 PM 3:54

CLERK US DISTRICT COURT
SOUTHERN DISTRICT OF CALIFORNIA

I. (a) PLAINTIFFS

SEQUAL TECHNOLOGIES, INC., a Delaware corporation

(b) County of Residence of First Listed Plaintiff: San Diego, CA
(EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorney's (Firm Name, Address, and Telephone Number)
Andrew D. Skale, Mintz Levin Cohn Ferris Glovsky & Popeo
3580 Carmel Mountain Road, Ste. 300, SD, CA 92130 (858) 314-1500

DEFENDANTS

INOGEN, INC., a Delaware corporation

County of Residence of First Listed Defendant: Goleta, CA
(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE LAND INVOLVED.

'10 CV 0410 WQH RBB

Attorneys (If Known) F.T. Alexandra Mahaney, Wilson Sonsini Goodrich & Rosati
12235 El Camino Real, SD, CA 92130

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

- ☐ 1 U.S. Government Plaintiff
- ☒ 3 Federal Question (U.S. Government Not a Party)
- ☐ 2 U.S. Government Defendant
- ☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant) (For Diversity Cases Only)

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated or Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated and Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT (Place an "X" in One Box Only)

CONTRACT
- ☐ 110 Insurance
- ☐ 120 Marine
- ☐ 130 Miller Act
- ☐ 140 Negotiable Instrument
- ☐ 150 Recovery of Overpayment & Enforcement of Judgment
- ☐ 151 Medicare Act
- ☐ 152 Recovery of Defaulted Student Loans (Excl. Veterans)
- ☐ 153 Recovery of Overpayment of Veteran's Benefits
- ☐ 160 Stockholders' Suits
- ☐ 190 Other Contract
- ☐ 195 Contract Product Liability
- ☐ 196 Franchise

REAL PROPERTY
- ☐ 210 Land Condemnation
- ☐ 220 Foreclosure
- ☐ 230 Rent Lease & Ejectment
- ☐ 240 Torts to Land
- ☐ 245 Tort Product Liability
- ☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
- ☐ 310 Airplane
- ☐ 315 Airplane Product Liability
- ☐ 320 Assault, Libel & Slander
- ☐ 330 Federal Employers' Liability
- ☐ 340 Marine
- ☐ 345 Marine Product Liability
- ☐ 350 Motor Vehicle
- ☐ 355 Motor Vehicle Product Liability
- ☐ 360 Other Personal Injury

PERSONAL INJURY
- ☐ 362 Personal Injury - Med. Malpractice
- ☐ 365 Personal Injury - Product Liability
- ☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- ☐ 370 Other Fraud
- ☐ 371 Truth in Lending
- ☐ 380 Other Personal Property Damage
- ☐ 385 Property Damage Product Liability

CIVIL RIGHTS
- ☐ 441 Voting
- ☐ 442 Employment
- ☐ 443 Housing/ Accommodations
- ☐ 444 Welfare
- ☐ 445 Amer. w/Disabilities - Employment
- ☐ 446 Amer. w/Disabilities - Other
- ☐ 440 Other Civil Rights

PRISONER PETITIONS
- ☐ 510 Motions to Vacate Sentence

Habeas Corpus:
- ☐ 530 General
- ☐ 535 Death Penalty
- ☐ 540 Mandamus & Other
- ☐ 550 Civil Rights
- ☐ 555 Prison Condition

FORFEITURE/PENALTY
- ☐ 610 Agriculture
- ☐ 620 Other Food & Drug
- ☐ 625 Drug Related Seizure of Property 21 USC 881
- ☐ 630 Liquor Laws
- ☐ 640 R.R. & Truck
- ☐ 650 Airline Regs.
- ☐ 660 Occupational Safety/Health
- ☐ 690 Other

LABOR
- ☐ 710 Fair Labor Standards Act
- ☐ 720 Labor/Mgmt. Relations
- ☐ 730 Labor/Mgmt.Reporting & Disclosure Act
- ☐ 740 Railway Labor Act
- ☐ 790 Other Labor Litigation
- ☐ 791 Empl. Ret. Inc. Security Act

IMMIGRATION
- ☐ 462 Naturalization Application
- ☐ 463 Habeas Corpus - Alien Detainee
- ☐ 465 Other Immigration Actions

BANKRUPTCY
- ☐ 422 Appeal 28 USC 158
- ☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- ☐ 820 Copyrights
- ☒ 830 Patent
- ☐ 840 Trademark

SOCIAL SECURITY
- ☐ 861 HIA (1395ff)
- ☐ 862 Black Lung (923)
- ☐ 863 DIWC/DIWW (405(g))
- ☐ 864 SSID Title XVI
- ☐ 865 RSI (405(g))

FEDERAL TAX SUITS
- ☐ 870 Taxes (U.S. Plaintiff or Defendant)
- ☐ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
- ☐ 400 State Reapportionment
- ☐ 410 Antitrust
- ☐ 430 Banks and Banking
- ☐ 450 Commerce
- ☐ 460 Deportation
- ☐ 470 Racketeer Influenced and Corrupt Organizations
- ☐ 480 Consumer Credit
- ☐ 490 Cable/Sat TV
- ☐ 810 Selective Service
- ☐ 850 Securities/Commodities/ Exchange
- ☐ 875 Customer Challenge 12 USC 3410
- ☐ 890 Other Statutory Actions
- ☐ 891 Agricultural Acts
- ☐ 892 Economic Stabilization Act
- ☐ 893 Environmental Matters
- ☐ 894 Energy Allocation Act
- ☐ 895 Freedom of Information Act
- ☐ 900 Appeal of Fee Determination Under Equal Access to Justice
- ☐ 950 Constitutionality of State Statutes

V. ORIGIN (Place an "X" in One Box Only)

☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from another district (specify) ☐ 6 Multidistrict Litigation ☐ 7 Appeal to District Judge from Magistrate Judgment

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing (Do not cite jurisdictional statutes unless diversity): 35 U.S.C. 271

Brief description of cause: Patent Infringement

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23 DEMAND $

CHECK YES only if demanded in complaint: JURY DEMAND: ☑ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

(See instructions): JUDGE Hon. Marilyn L. Huff DOCKET NUMBER 09CV2391 H (JMA)

DATE 02/22/2010 SIGNATURE OF ATTORNEY OF RECORD [signature]

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Court Name: USDC California Southern
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Transaction Date: 02/22/2010
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For: SEQUAL TECH V INOGEN
Case/Party: D-CAS-3-10-CV-000410-001
Amount: $350.00

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Check/Money Order Num: 4855
Amt Tendered: $350.00

Total Due: $350.00
Total Tendered: $350.00
Change Amt: $0.00

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charged for any returned check.