Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2293503 C 2006/09/05

(11)(21) 2 293 503

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1998/06/11
(87) Date publication PCT/PCT Publication Date: 1998/12/23
(45) Date de délivrance/Issue Date: 2006/09/05
(85) Entrée phase nationale/National Entry: 1999/12/03
(86) N° demande PCT/PCT Application No.: US 1998/012246
(87) N° publication PCT/PCT Publication No.: 1998/057728
(30) Priorité/Priority: 1997/06/16 (US08/876,749)

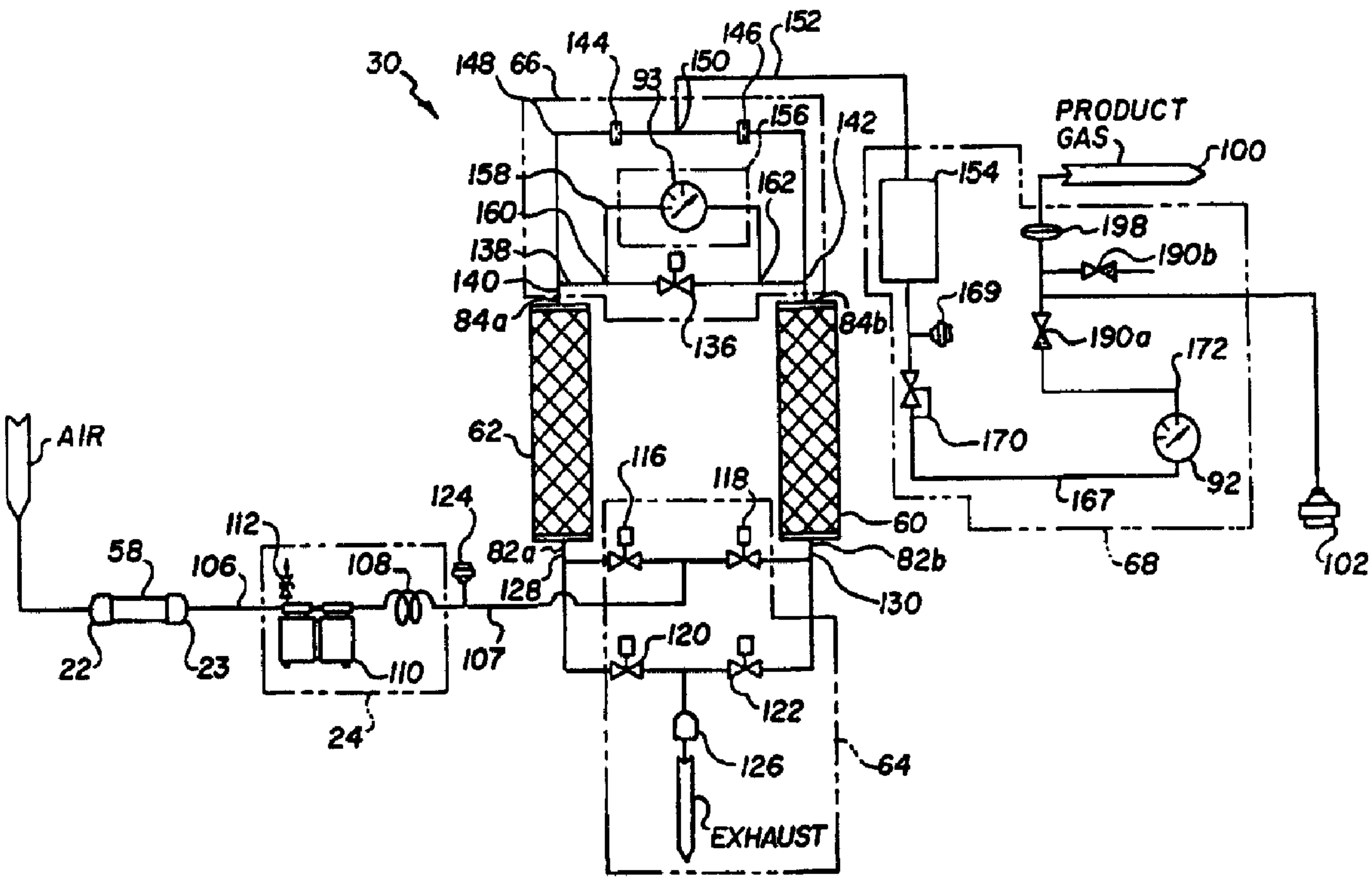
(51) Cl.Int./Int.Cl. *B01D 53/047* (2006.01), *A62B 18/00* (2006.01), *A61M 16/06* (2006.01), *B01D 53/053* (2006.01)

(72) Inventeur/Inventor:
MCCOMBS, NORMAN RICHARD, US

(73) Propriétaire/Owner:
AIRSEP CORPORATION, US

(74) Agent: SHAPIRO COHEN

(54) Titre : APPAREIL ET PROCEDE D'ADSORPTION MODULEE EN PRESSION
(54) Title: PRESSURE SWING ADSORPTION APPARATUS AND METHOD



(57) Abrégé/Abstract:
A pressure swing adsorption apparatus (30) to vary selectively the concentration of at least one constituent of a gaseous mixture by sending a gaseous mixture into an adsorber (62) to generate a particular product gas while delivering to another adsorber (60) both a predetermined portion of the product gas to purge the other adsorber and a selected amount of the product gas, independent of the flow rate and in addition to the predetermined portion, to produce a desired relative concentration of the constituents of the product gas selectable from a range of available relative concentrations.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : **B01D 53/047, 53/053** — **A1**

(11) International Publication Number: **WO 98/57728**

(43) International Publication Date: 23 December 1998 (23.12.98)

(21) International Application Number: PCT/US98/12246

(22) International Filing Date: 11 June 1998 (11.06.98)

(30) Priority Data:
08/876,749 16 June 1997 (16.06.97) US

(71) Applicant: AIRSEP CORPORATION [US/US]; 290 Creekside Drive, Buffalo, NY 14228-2070 (US).

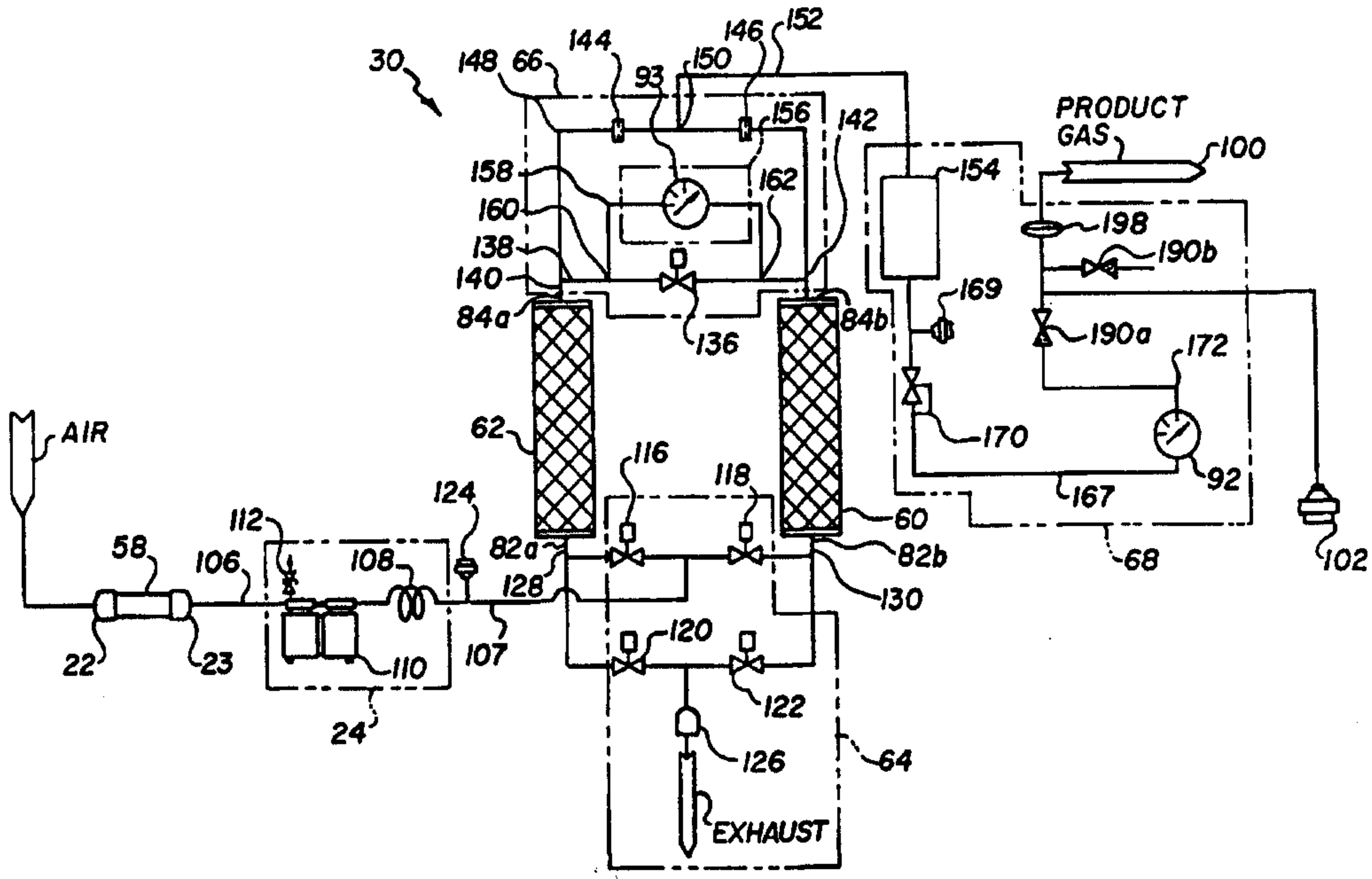
(72) Inventor: MCCOMBS, Norman, Richard; 109 Millwood Drive, Tonawanda, NY 14150 (US).

(74) Agent: KAREKEN, Ronald, S.; Jaeckle, Fleischmann & Mugel, LLP, 39 State Street, Rochester, NY 14614-1310 (US).

(81) Designated States: AL, AU, BA, BB, BG, BR, CA, CN, CU, CZ, EE, GE, GW, HU, ID, IL, IS, JP, KP, KR, LC, LK, LR, LS, LV, MG, MK, MN, MX, NO, NZ, PL, RO, SG, SI, SK, SL, TR, TT, UA, UZ, VN, YU, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: PRESSURE SWING ADSORPTION APPARATUS AND METHOD



(57) Abstract

A pressure swing adsorption apparatus (30) to vary selectively the concentration of at least one constituent of a gaseous mixture by sending a gaseous mixture into an adsorber (62) to generate a particular product gas while delivering to another adsorber (60) both a predetermined portion of the product gas to purge the other adsorber and a selected amount of the product gas, independent of the flow rate and in addition to the predetermined portion, to produce a desired relative concentration of the constituents of the product gas selectable from a range of available relative concentrations.

PRESSURE SWING ADSORPTION APPARATUS AND METHOD

This invention relates generally to a gas concentrator apparatus for separating gas mixtures by pressure swing adsorption and more particularly to the production of a product gas in which the concentrations of the constituent gases can be selectively varied.

BACKGROUND OF THE INVENTION

The general type of pressure swing adsorption apparatus with which this invention is concerned is set forth in U.S. Patents 4,802,899 and 5,531,807. Generically, a pressure swing adsorption apparatus includes at least a pair of adsorbers each having a fixed bed of adsorbent material to fractionate at least one constituent gas from a gaseous mixture when the gaseous mixture from a feed stream is sequentially directed through the adsorbers in a co-current direction. While one adsorber performs adsorption, the other adsorber is simultaneously purged of its adsorbed constituent gas by product gas that is withdrawn from the one adsorber and directed through the other adsorber in a counter-current direction. Once the other adsorber is purged, the gaseous mixture is then directed to the other adsorber in the co-current direction, so that the other adsorber performs adsorption while the one adsorber is simultaneously purged.

Highly concentrated product gas is attained by controlling the gas transfer zones of the adsorbers. A conventional adsorber contains four zones as illustrated in Figure 1A. When, for example, compressed air enters the adsorber 2 through an input 4, the air contains about 78% nitrogen, 21% oxygen, 0.9% argon, and a variable amount of water. The first zone or water zone 6, captures the water. The second zone 8 adsorbs the fractionated nitrogen and a lesser degree oxygen. The third zone or mass transfer zone ("MTZ") 10 comprises a varied concentration of product oxygen gas that increases in concentration in relation to the distance from the second zone 8 by capturing more fractionated nitrogen. The fourth zone 12 comprises the highly concentrated product oxygen gas and extends to the terminal end 14 of the adsorber 2.

A highly concentrated product oxygen gas is achieved by stabilizing the water zone 6 near the input 4 of the adsorber 2 and maintaining the MTZ 10 as a sharp demarcation between the second and fourth zones 8, 12. These zones 6, 10 are stabilized and maintained by directing certain quantities of product oxygen gas counter-currently through the adsorber 2.

Some applications, however, require a lower concentration of product oxygen gas. Controlling the apparatus to produce a product oxygen gas having a desired and specific concentration and flow rate in which these characteristics are independent of each other is an object of this present invention.

One prior proposal to change the desired concentration of oxygen in the product gas is to blend ambient air from the feed stream with the highly concentrated oxygen product. Such a proposal has numerous adverse effects. One adverse effect is that the concentration of product oxygen gas is dependent upon the flow of the gaseous mixture. Thus, when the flow of gaseous mixture is disturbed, the concentration of product gas is also affected. Another adverse effect is that the blended air is potentially "wet" and can cause undesirable condensation in the product oxygen gas.

Another earlier proposal is to overdraw the pressure swing adsorption apparatus by drawing the product oxygen gas at a high flow rate. However, a high flow rate moves and extends first zone 6, second zone 8, and MTZ 10. In particular, the MTZ 10 moves and extends through and beyond the terminal end 14 of the adsorber 2 as illustrated in Figure 1B. When this occurs, the product oxygen gas is withdrawn at an unknown and uncontrollable lower concentration. Overdrawing also has a number of adverse effects. First, the efficiency of the apparatus is compromised because it is difficult to stabilize the water zone 6 and the MTZ Zone 10. Second, it is difficult to control the MTZ 10 when the MTZ 10 is at the terminal end 14, which in turn makes it difficult to control the concentration range of the product oxygen gas generated, as illustrated in Figure 1C. Third, it is difficult to duplicate particular concentrations. Lastly, the flow rate and the concentration of the product gas are intrinsically dependent upon each other since the flow rate controls the concentration level of product gas.

SUMMARY OF THE INVENTION

The present invention eliminates the described adverse effects by providing a new and improved pressure swing adsorption apparatus (oxygen concentrator) that can be set to attain various desired concentrations and flow rates of product oxygen gas wherein the flow rate and concentration are controlled independently of each other. This is accomplished by providing a variable control means in the apparatus that controls, independently of the flow rate, a variable amount of product gas to be passed through the adsorbers in the counter-current direction to produce a desired concentration of the product gas from a range of available concentrations. Once the desired concentration of product gas is independently attained, the apparatus is capable of controlling the flow rate of the product gas independently of the concentration of the product gas.

In a first broad aspect of the present invention there is disclosed a pressure swing adsorption apparatus for selectively changing the relative concentrations of constituent gases in a gaseous mixture of two or more constituent gases and having:

(a) at least two adsorbers, each adsorber having two ends and comprising (i) means for receiving the gaseous mixture at one end of the adsorber, (ii) means for moving the gaseous mixture through the adsorber in a co-current direction, (iii) means defining a plurality of gas transfer zones including a mass transfer zone for adsorbing at least a substantial portion of one of the constituent gases in the gaseous mixture to produce a product gas, and (iv) means for discharging the product gas from the other end of the adsorber;

(b) means for directing the gaseous mixture in the co-current direction alternatively to each of the adsorber receiving means;

(c) means fluidly coupled to both discharge means for receiving a usable portion of the product gas discharged in the co-current direction from each of the other ends of the adsorbers; and

(d) purge means fluidly connecting the other ends of both adsorbers for directing a predetermined portion of the product gas flowing in the co-current direction from one adsorber to flow through the other adsorber, in a counter-current direction, from the other end to the one end of the other adsorber, to purge and expel through the one end of the other adsorber, the one constituent gas adsorbed by the other adsorber;

the improvement characterized by

(e) adjustable zone controlling means fluidly connected to the adsorbers for selectively changing the concentrations of the constituent gases in the product gas delivered to the receiving means by selectively diverting variable portions of product gas, in addition to the predetermined portion, discharged from the one adsorber to flow through the other adsorber in the counter-current direction to control the location of at least the mass transfer zone in the one adsorber and to produce a selected one of a number of concentrations of the other constituent gas in the product gas received by the receiving means.

In a second broad aspect of the invention, there is disclosed a pressure swing adsorption apparatus having at least two multi-zone adsorbers, each adsorber having a mass transfer zone to adsorb a substantial portion of at least one constituent gas in a gaseous mixture of at least two gaseous constituents, a method for selectively changing the relative concentrations of the constituent gases to produce a usable product gas selected from one of a number of different concentrations of the constituent gases in the product gas, said method comprising:

alternately moving, at a predetermined flow rate, the gaseous mixture in a co-current direction through each one of the adsorbers to produce the product gas by adsorbing at least at substantial portion of the one constituent gas; and moving a predetermined portion of the product gas produced by each one of the adsorbers in a counter-current direction through the other adsorber to purge adsorbed constituent gas from said other adsorber;

the improvement characterized by:

diverting a variable portion of the product gas from said one adsorber, in addition to the predetermined portion, to said other adsorber to control, independently of the flow rate, the location of the mass transfer zone and the amount of adsorption of the one constituent gas in said one adsorber to produce the product gas at the selected concentration of constituent gases; and

delivering to a receiving station the balance of the product gas having the selected concentration and comprising the usable product gas.

These and other objects, features and advantages of the invention will become more apparent from a reading of the following description in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1A is a graph of the concentration of N_2 in air as it proceeds through an adsorber designed to generate a high concentrated product gas. (Prior Art)

FIG. 1B is a graph of the concentration of N_2 in air as it proceeds through an adsorber designed to generate a lower concentrated product gas. (Prior Art)

FIG. 1C is a graph of the concentration range of product gas produced from an adsorber illustrated in Figure 1b. (Prior Art)

FIG 2 is a schematic diagram illustrating the flow connections and working components of an oxygen concentrator according to this invention.

FIG. 2 is a schematic diagram illustrating the flow connections and working components of an oxygen concentrator according to this invention.

FIG. 3 is a front view of an oxygen concentrator incorporating the connections and components of Figure 2.

FIG. 4 is a graph of the concentration of N_2 in the gaseous mixture as it proceeds through an adsorber designed to generate different desired concentrations of product gas.

FIG. 5 is a graph of the resulting product gas concentration range produced from an adsorber as illustrated in Figure 2 in relation to the graph illustrated in FIG. 1C.

FIG. 6 is a schematic of the electrical system of the oxygen concentrator of Figure 2.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

Turning now to the drawing and considering first Figures 2 and 3, there is shown an embodiment, generally indicated 20, of a pressure swing adsorption apparatus in accordance with the present invention for fractionating at least one component or constituent from a gaseous mixture by pressure swing adsorption.

With reference to Figure 2, the gaseous air mixture is supplied to the apparatus 20 through an assembly of working components 30. The components 30 initially receive a feed gas stream in an input 22 of an intake resonator 58 to decrease the noise for the intake of the feed stream. The feed stream continues through resonator outlet 23 and is moved through piping 106 by means of a pump or compressor assembly 24. Compressor assembly 24 containing compressor 110 and heat exchanger 108 moves the feed stream through assembly piping 107 to a valve block 64, in particular a first feed valve 116.

From feed valve 116 and through piping 128, the feed stream enters an inlet 82a of a first adsorber 62 in a co-current direction. While in adsorber 62, the feed stream fractionates into the desired concentration of product gas. The product gas then proceeds through outlet 84a of first adsorber 62 into the product manifold assembly 66.

While in the product manifold 66, the product gas is controllably directed in three directions. The first direction is through T-connection 140 and piping 138 to product equalization valve 136. The second direction is through

T-connection 140 and piping **148** to purge orifice **144**. The last direction is through T-connections 140 and **160** and piping 138 and **158** to second purge loop **156**, in particular a conventional concentration valve **93**. If purge orifice 144 is open and concentration valve 93 is closed the concentration of the product gas will be high as shown in Fig. 1A. In the present invention purge orifice 144 and concentration valve 93 are open and together independently control the concentration of the product gas. In particular, orifice 144 and valve 93 control the position of MTZ 10 (possible positions include lines **10a, 10b** and **10c** and variations in-between as illustrated by arrows **164**) and water zone 6 of second adsorber **60**, as shown in Figure 4, and the concentration range of the product gas, as shown in Figure 5.

Returning to Figure 2, a small portion of the product gas proceeds through purge orifices 144, **146**, and T-connections **150**, **142**, and the product gas proceeding through valve 93 and T-connections **162**, 142 are counter-currently directed through an outlet **84b** and an inlet **82b** of second adsorber **60**. The counter-current product gas purges adsorber 60 and with the purged nitrogen then proceeds through piping **130** to valve block 64, in particular waste valve **122** and waste silencer **126** and then exhausted as shown. The other or usable portion of the product gas proceeding through purge orifice 144 is directed through T-connection 150 to flow control assembly **68**.

Within the flow control assembly 68 are a mixing tank **154**, a test block component **169**, a pressure regulator **170**, a conventional flow controller valve **92**, check valves **190a**, b, a conventional bacteria filter **198** and outlet connector **100**. Mixing tank 154 receives the product gas through piping **152** and T-connection 150 to average the product gas to the desired concentration. Once through mixing tank 154, the product gas is pushed through piping **167** and monitored by pressure regulator 170 until it reaches the flow controller valve 92. The product gas flow rate is independently controlled by the flow controller valve 92 to proceed through piping **172** and check valve **190a** to outlet connector 100.

When adsorber 62 is saturated and adsorber 60 purged, the above-process is reversed, and adsorber 60 is used to produce oxygen concentrated product gas. The reverse process is the same as the above-process except for three differences. The first difference is that the feed stream from pump 24 is directed to feed valve **118** for adsorber 60. The second difference is that purge orifice 144 is replaced by purge orifice **146**. The last difference is that waste valve 122 is replaced by waste valve **120**. Thus a portion of product gas flows from adsorber 60 through purge orifice 146 to assembly 68 and the balance flows in a counter-current direction through valve 136 and second loop 156 to purge nitrogen through valve 120 and silencer 126. The feed valves 116, 118 and waste valves 120, 122 are solenoid valve pairs. In each pair, one is open and the other is closed depending upon the direction of the gas through the respective adsorber 60, 62.

As will be apparent hereinafter, the apparatus 20 and components 30 are specifically described and illustrated in relation to the application of pressure swing adsorption to the fractionation of air to produce an oxygen-rich stream. Hence, the feed stream supplied to the apparatus 20 is compressed atmospheric air. Although the present description is limited to the production of desired concentration of oxygen product gas, it is apparent that skilled practitioners could use this pressure swing adsorption apparatus to produce other gases as well.

The oxygen concentrator 20 as shown in Figure 3 includes a base **26** that supports a protective housing 28, defining a cabinet assembly **34** with a removable back panel (not shown), a removable front panel **38**, a removable left side panel **40**, and a removable right side panel **42**. The base 26 includes a fixed central support structure that forms a back board for attaching components 30 to the support structure. A fixed upper front panel **48** holds a control panel **50**. The working components 30 on the front side of the concentrator 20 include intake resonator 58, compressor assembly 24, control panel 50, pair of adsorbers 60, 62, and product flow control assembly 68. The working components 30 of the back side of the concentrator includes pair of adsorbers 60, 62, valve block 64, product manifold assembly 66, product flow control assembly 68 and a circuit board **70**. The functions of these components 30 are described hereinafter.

Each adsorber 60, 62 includes a substantially elongated vessel attached to the support structure and has an interior cavity which is substantially filled with a bed of adsorption material adapted to adsorb nitrogen from air routed therethrough. Furthermore, each adsorber 62 or 60 includes an inlet 82*a* or 82*b* and an outlet 84*a* or 84*b* adjacent the lower end and upper end, respectively, of the corresponding adsorber vessel 80*a* or 80*b*. The inlet and outlet of each adsorber 60 or 62 are in flow communication with one another through the bed of adsorption material. Hence, air directed into each adsorber inlet 82*a* or 82*b* is exposed to the adsorption material, by which nitrogen in the air is adsorbed, and the resulting oxygen concentrated product gas then exits the corresponding adsorber through outlet 84a or 84b.

The adsorption beds of the adsorbers 60, 62 may be comprised of any of a number of adsorbent materials such as a molecular sieve material known as sodium alumina silicate. Characteristically, the adsorbent material adsorbs nitrogen from air routed through the corresponding adsorber 60 or 62 from the inlet 82b or 82a to the outlet 84b or 84a thereof so that the product oxygen gas exiting the adsorber outlet 84*b* or 84*a* is a desired concentration of oxygen gas. Furthermore, the adsorbent material releases its adsorbed nitrogen when a purge gas passes counter-currently through adsorber 60 or 62, for purposes of regenerating the adsorbent material. Only one of the adsorbers 60 or 62 performs adsorption at any one time while the other adsorber 60 or 62 undergoes regeneration. For increasing the efficiency of regeneration, an amount of product gas produced by the adsorber 60 or 62 performing adsorption is used to purge the other adsorber undergoing regeneration.

A conventional fan 63, shown schematically in Figure 6, is located immediately behind the compressor assembly 24 to draw air into the apparatus 20 through a ventilation orifice (not shown) located on the back panel (not shown). The air circulates through the apparatus 20 to cool the components 30 and a portion of this air is drawn into intake 22 of intake resonator 58.

The control panel 50, as illustrated in Figure 3, comprises panel instruments **90**, such as a conventional flow controller valve 92 and a conventional concentration valve 93 [such as an Essex valve Model No.

FM023-1 with variations in the orifice size], an hour-meter 94, a circuit breaker 96, an on/off switch 98, an outlet connector 100, and a supplemental oxygen connector 102. These panel instruments will be described hereinafter.

Many of these panel instruments 90 and working components 30 are electrically connected to circuit board 70. The circuit board 70, shown in Figure 6 and described hereinafter, is mounted to the support structure by insulated standoffs.

The product manifold assembly 66, illustrated in Figure 2, includes equalization valve 136, piping 138, 148, 158, purge orifices 144, 146, T-connections 140, 142, 150, 160, 162, and concentration valve 93.

The product flow control assembly 68 includes piping 152, 167, 172, mixing tank 154, test block component 169, pressure regulator 170, flow controller valve 92, check valves 190a and 190b, and outlet connector 100.

As referenced above, the operation of the apparatus 20 initiates when the intake resonator 58 receives air through inlet 22. The resonator 58 is connected to the compressor assembly 24 by means of assembly piping 106.

As shown in Figure 2, compressor assembly 24 includes conventional components such as heat exchanger 108, compressor 110, a relief valve 112 and a high pressure switch 124. Valve 112 is operatively connected to compressor 110 through piping 106. In operation, valve 112 limits the pressure of the air supplied to the compressor 110 at a predetermined pressure. Similarly, high pressure switch 124 is operatively connected to heat exchanger 108 to limit the feed stream pressure to a predetermined limit. The high pressure switch 124 is a conventional switch that indicates high pressure within the valve block 64. The indicator can be either audio or visual or even both. The visual indicator is normally seen through conventional LED devices 132 found on the circuit board 70 (Figure 6).

The valve block 64 is an integrated valving and porting system that ensures proper operation of various instruments. The instruments include the pair of feed valves 116, 118, the pair of waste valves 120, 122, and waste silencer 126. The feed valves 116, 118 are connected between the heat exchanger 108 and the adsorber inlets 82*a*, 82*b*. In this connection, two sections of piping 128, 130 appropriately extend from the valve block 64 to the adsorber inlets 82*a* and 82*b*.

The waste valves 120 and 122 are interconnected with the adsorber inlets 82*a*, 82*b* and direct purged gas and purged nitrogen in a counter-current direction through piping 128, 130 to silencer 126 and then to be discharged to the atmosphere through the silencer 126. Sounds normally associated with the discharging of a pressurized stream of gas to the atmosphere are muffled by the silencer 126.

The product manifold assembly 66 receives the product gas from the outlets 84b, 84a of the adsorbers 60 and 62 and includes a product and equalization valve 136 for equalizing the internal pressure of the adsorbers 60 and 62 between product-producing and regeneration cycles. The product equalization valve 136 is operatively connected to the adsorber outlets 84*a* and 84*b* by means of piping 138 and T-connections 140 and 142. By opening the valve 136, the adsorber vessels 80*a*, 80*b* communicate with one another through the adsorber outlets 84*a*, 84*b* in a manner permitting the internal pressure of the adsorbers 60 and 62 to equalize. By closing the valve 136, flow of gaseous product between the adsorber outlets 84*a* and 84*b* through the valve 136 is prevented.

Furthermore, and with reference to Figure 2, a pair of purge orifices 144, 146 are connected in parallel flow relation to the product equalization valve 136 by way of piping section 148 between T-connections 140 and 142 and a third T-connection 150. In operation, the orifices 144, 146 limit the purge flow of product oxygen gas that goes through adsorbers 60, 62 counter-currently to obtain the optimal high concentration product oxygen gas. The orifices 144, 146 also dampen, only in correlation with concentration valve 93, the product oxygen gas pressure excursions, as illustrated in Figure 5, that proceed through T-connection 150 to piping 152 which is connected to a mixing tank 154.

Along with equalizing the internal pressure of the adsorbers 60 and 62, there is illustrated according to the invention a second purge loop 156 including a section of purging piping 158 that is connected in parallel flow relation to the product equalization valve 136 and purge orifices 144, 146 by means of T-connections 160, 162 on piping 138. Interconnected to the purge piping 158 is the concentration valve 93. Valve 93 comprises multiple orifices ranging from a minimal flow rate to a maximum flow rate which can be altered to attain different desired concentrations of product gas. In table 1, below, symbols A-G represent the various orifice sizes that provide different quantities of product gas within the purge loop 156 with A being the minimum and G being the maximum.

During a regeneration operation of one of the adsorbers 60, 62, concentration valve 93 is manually, or if so desired automatically, set to allow a certain quantity of product oxygen gas to move between the outlets 84*a*, 84*b* of the adsorbers 62, 60. As the quantity of product oxygen gas flowing through the concentration valve 93 increases, the MTZ 10 of the adsorber spreads through the bed of adsorbent 2, as illustrated in Figure 4 up to line 10c, in a controllable manner while simultaneously stabilizing the water zone 6. In other words, if the quantity of product gas flowing through valve 93 is decreased, the MTZ 10 of the adsorber becomes sharper (as shown in line 10a) similar but not equal to the 95% oxygen stream illustrated in Figure 1A. Thereby, the MTZ 10 of the adsorber 60 is controllable, as shown by arrows 164, to produce a resulting product oxygen gas of desired concentration from a range of available concentrations. The resulting product oxygen gas has a manageable and controllable concentration range by reducing the pressure excursions of the gas, as illustrated in Figure 5 that can be further controlled through the product flow control assembly 68 described hereinafter.

When the product oxygen gas exits the product manifold assembly 66 as shown in Figure 2, the product gas enters the flow control assembly 68 through mixing tank 154 to average the concentration of the product gas. Moreover, mixing tank 154 can contain an adsorbent material, for example those used in adsorber 60, 62, to ensure the nitrogen is averaged in the product gas.

The remainder of the product flow control assembly 68 is connected to the mixing tank 154 through piping 167 for receiving the product oxygen gas flowing therethrough. The product flow control assembly 68 comprises the flow controller valve 92, pressure regulator 170 that maintains a desired concentration range, and test block component 169 as shown in Figure 6. The test block component 169 includes a low pressure switch 168 and high pressure switch 124 for sensing pressure of the product oxygen gas at preselected locations in piping 167. Switches 168 and 124 are interconnected with control panel 50.

Valves 92 and 93 each comprise many various orifice sizes. These orifice sizes can be manually set (or automatically if so desired) to control the flow of the product oxygen gas or to achieve the desired concentration of product oxygen gas ranging in relation with the concentration valve 93 from about ninety-five point five (95.5) percent oxygen to about twenty-one (21) percent oxygen, preferably in the ranges as illustrated in Table 1.

Table 1

Concentration Valve Position	Percent O_2 Concentration (Flow Controller Valve) Liters per Minute									
	06	07	08	09	10	11	12	13	14	15
A	77	72	67	62	56	53	50	48	46	45
B	57	55	54	53	51	50	48	47	45	44
C	51	50	49	47	47	46	45	44	44	43
D	46	45	45	44	44	43	42	42	42	41
E	43	43	42	42	42	41	40	40	39	39
F	41	41	41	40	40	39	39	39	39	39
G	40	40	39	39	39	38	38	37	37	37

Attached to the discharge or downstream side of the flow controller valve 92 is a section of piping 172 which is connected to outlet connector 100 on panel 50 through which product oxygen gas exits the concentrator 20.

Operation of the oxygen concentrator 20 can be described briefly through a description of the sequencing of the valving means of the concentrator 20 as illustrated in Figures 2 and 6 At start-up of the concentrator 20, valves 116, 118, 120, 122, and 136 are open to eliminate the back pressure and then closed through a timing mechanism of conventional switches and relay switches printed on the circuit board 70. The source air entering the concentrator 20 through inlet 22 is thereby directed through the adsorber 62 from its inlet 82*a* to its outlet 84*a* in a co-current direction. An amount, dependent upon the orifice size of the concentrator valve 93 selected, of oxygen emitted from the adsorber outlet 84*a* is directed in parallel through valve 93 and in part through orifices 144, 146 in a counter current direction, through adsorber 60 from outlet 84*b* to inlet 82*b* thereof, and through waste valve 122 which opens by the timing mechanism. The balance of the resulting product gas of the desired oxygen concentration is delivered to the mixing tank 154.

The operation continues until the adsorber 62 becomes about saturated with nitrogen. The determination of when the adsorber is about saturated has been predetermined and is controlled through the timing mechanism which controls the various valves 116, 118, 120 122 and 136. When this occurs to the adsorber 62, feed valve 116 and waste valve 122 are closed and equalization valve 136 is opened to permit the internal pressures of adsorbers 60, 62 to equalize. Once the adsorber pressures are equalized, the equalization valve 136 is closed, and the feed valve 118 for adsorber 60 and waste valve 120 for adsorber 62 are opened. The source air entering the concentrator 20 through the inlet 22 is thereby directed through the adsorber 60 from its inlet 82*b* to its outlet 84*b* in a co-current direction. Similarly, an amount, dependent upon the orifice size of the concentrator valve 93 selected, of product gas emitted from the adsorber outlet 84*b* is directed through valve 93 and orifices 144, 146 in a counter current direction, through adsorber 62 from outlet 84*a* to inlet 82*a* thereof, and through waste valve 120. The resulting product oxygen gas has a desired concentration in accordance with the setting of valve 93.

When the adsorber 60 becomes about saturated and purged the feed valve 118 and waste valve 120 are closed and equalization valve 136 is opened to thereby permit the internal pressures of the adsorbers 60, 62 to equalize. At that point, the cycles of operation are repeated with the closing of equalization valve 136 and reopening of feed valve 116 and waste valve 122. It follows that while one adsorber produces oxygen-rich product gas in a product-producing cycle, the other adsorber is being purged of the adsorbed gases in a regeneration operation, and vice-versa.

Each of the aforementioned feed, waste, and equalization valves is preferably a solenoid-type valve responsive to a turning on or shutting off of power to the valve. Control of the various product-producing and regeneration operations is conducted by appropriately sequencing the opening and closing of the feed, waste, and equalization valves. In the concentrator 20, control of those valves is achieved by timing mechanisms of conventional switches and relays printed on circuit board 70. The timing mechanism is operatively connected to the valves for turning the valves ON and OFF at the end of a predetermined period of time. Hence, product-producing and regeneration operations are automatically controlled in the concentrator 20 by automatically controlling the amount of time that each of the feed, waste, and equalization valves are opened and closed.

As illustrated in Figure 6 , the timing mechanism printed on the circuit board 70 controls these numerous valves through conventional circuitry, and switches known to skilled practitioners. The board 70 is also connected to a battery unit 173 and buzzer 174, as are LED indicator devices 132. The buzzer 174 is connected to switches 124, 168. Power is generally received through an electrical connection, such as an electrical plug 176 and a secondary external power source 177. Plug 176 and source 177 are interconnected by connector 179 as shown. The power is supplied through a circuit breaker 96 and master power switch 98 to the circuit board 70. The circuit board 70 then directs and controls the valves 116, 118, 120, 122, and 136, panel instruments 90, compressor assembly 24 with a high temperature cutoff switch 111 in series, and the air circulating fan. In case of an emergency, the apparatus 20 has the battery unit 173 that is electrically connected to the circuit board 70. When the battery unit 173 is operating, the buzzer 174 warns the user.

In other embodiments of the present invention, the electrical circuitry can be connected to a conventional modem system (not shown) which determines the operation times and settings and allows an administrator to control the settings of the valves 116, 118, 120, 122 and, optionally, the settings of valves 92 and 93 if these valves are connected to circuit board 70.

The housing means 28 can be made of conventional soundproof materials, and for portability, the base 26 can have wheels **178, 180** as shown in Figure 3.

It will be understood that numerous modifications and substitutions may be made to the described embodiment without departing from the spirit of the invention. Accordingly, the described embodiment is intended for purposes of illustration and not as a limitation.

What is claimed is:

1. In a pressure swing adsorption apparatus for selectively changing the relative concentrations of constituent gases in a gaseous mixture of two or more constituent gases and having:

(a) at least two adsorbers, each adsorber having two ends and comprising (i) means for receiving the gaseous mixture at one end of the adsorber, (ii) means for moving the gaseous mixture through the adsorber in a co-current direction, (iii) means defining a plurality of gas transfer zones including a mass transfer zone for adsorbing at least a substantial portion of one of the constituent gases in the gaseous mixture to produce a product gas, and (iv) means for discharging the product gas from the other end of the adsorber;

(b) means for directing the gaseous mixture in the co-current direction alternately to each of the adsorber receiving means;

(c) means fluidly coupled to both discharge means for receiving a usable portion of the product gas discharged in the co-current direction from each of the other ends of the adsorbers; and

(d) purge means fluidly connecting the other ends of both adsorbers for directing a predetermined portion of the product gas flowing in the co-current direction from one adsorber to flow through the other adsorber, in a counter-current direction, from the other end to the one end of the other adsorber, to purge and expel through the one end of the other adsorber, the one constituent gas adsorbed by the other adsorber;

the improvement characterized by

(e) adjustable zone controlling means fluidly connected to the adsorbers for selectively changing the concentrations of the constituent gases in the product gas delivered to the receiving means by selectively diverting variable portions of product gas, in addition to the predetermined portion, discharged from the one adsorber to flow through the other adsorber in the counter-current direction to control the location of at least the mass transfer zone in the one adsorber and to produce a selected one of a number of concentrations of the other constituent gas in the product gas received by the receiving means.

2. The pressure swing adsorption apparatus of claim 1 wherein the adjustable zone controlling means comprises valve means defining an orifice of a size to divert the selected amount of additional product gas, and means for selecting the orifice size from a variation of orifice sizes.

3. The pressure swing adsorption apparatus of claim 1 and further comprising means for controlling the rate of flow of the product gas.

4. The pressure swing adsorption apparatus of claim 3 wherein the adjustable zone controlling means comprises valve means defining an orifice of a size to divert the selected amount of additional product gas, and means for selecting the orifice size from a variation of orifice sizes.

5. The pressure swing adsorption apparatus of claim 3 wherein the adjustable zone controlling means and the flow rate controlling means selectively change, in a range from about ninety-five point five to about twenty-one percent, the concentration of the other constituent gas in the portion of product gas received by the receiving means.

6. The pressure swing apparatus of claim 5 wherein the range of concentration is from about seventy-seven to about thirty-seven percent.

7. The pressure swing adsorption apparatus of claim 3 wherein the flow rate controlling means produces a selected flow rate of the product gas in a range from about 6 to about 15 liters per minute.

8. The pressure swing adsorption apparatus of claim 1 wherein one of the gas transfer zones of each adsorber comprises a water adsorption zone to substantially adsorb any water in the gaseous mixture, and the adjustable zone controlling means further stabilizes the water adsorption zone.

9. The pressure swing adsorption apparatus of claim 1 wherein the one constituent gas comprises nitrogen and the other constituent gas comprises oxygen.

10. In a pressure swing adsorption apparatus having at least two multi-zone adsorbers, each adsorber having a mass transfer zone to adsorb a substantial portion of at least one constituent gas in a gaseous mixture of at least two gaseous constituents, a method for selectively changing the relative concentrations of the constituent gases to produce a usable product gas selected

from one of a number of different concentrations of the constituent gases in the product gas, said method comprising:

alternately moving, at a predetermined flow rate, the gaseous mixture in a co-current direction through each one of the adsorbers to produce the product gas by adsorbing at least a substantial portion of the one constituent gas; and

moving a predetermined portion of the product gas produced by each one of the adsorbers in a counter-current direction through the other adsorber to purge adsorbed constituent gas from said other adsorber;

the improvement characterized by:

diverting a variable portion of the product gas from said one adsorber, in addition to the predetermined portion, to said other adsorber to control, independently of the flow rate, the location of the mass transfer zone and the amount of adsorption of the one constituent gas in said one adsorber to produce the product gas at the selected concentration of constituent gases; and

delivering to a receiving station the balance of the product gas having the selected concentration and comprising the usable product gas.

11. The method as claimed in claim 10 further comprising the step of controlling, independently of the step of diverting the variable portion of the product gas, the flow rate of the delivered product gas within a predetermined range of flow rates.

12. The method as claimed in claim 10 wherein the step of controlling the mass transfer zones comprises the step of passing the diverted product gas through an orifice and selecting the orifice size to divert the desired amount of product gas.

13. The method as claimed in claim 11 wherein the step of controlling the mass transfer zones comprises the step of passing the diverted product gas through an orifice and selecting the orifice size to divert the desired amount of product gas.

14. The method as claimed in claim 10 wherein the step of diverting the variable portion of product gas produces, in a range from about ninety-five

point five to about twenty-one percent, the concentration of the other constituent gas in the usable product gas.

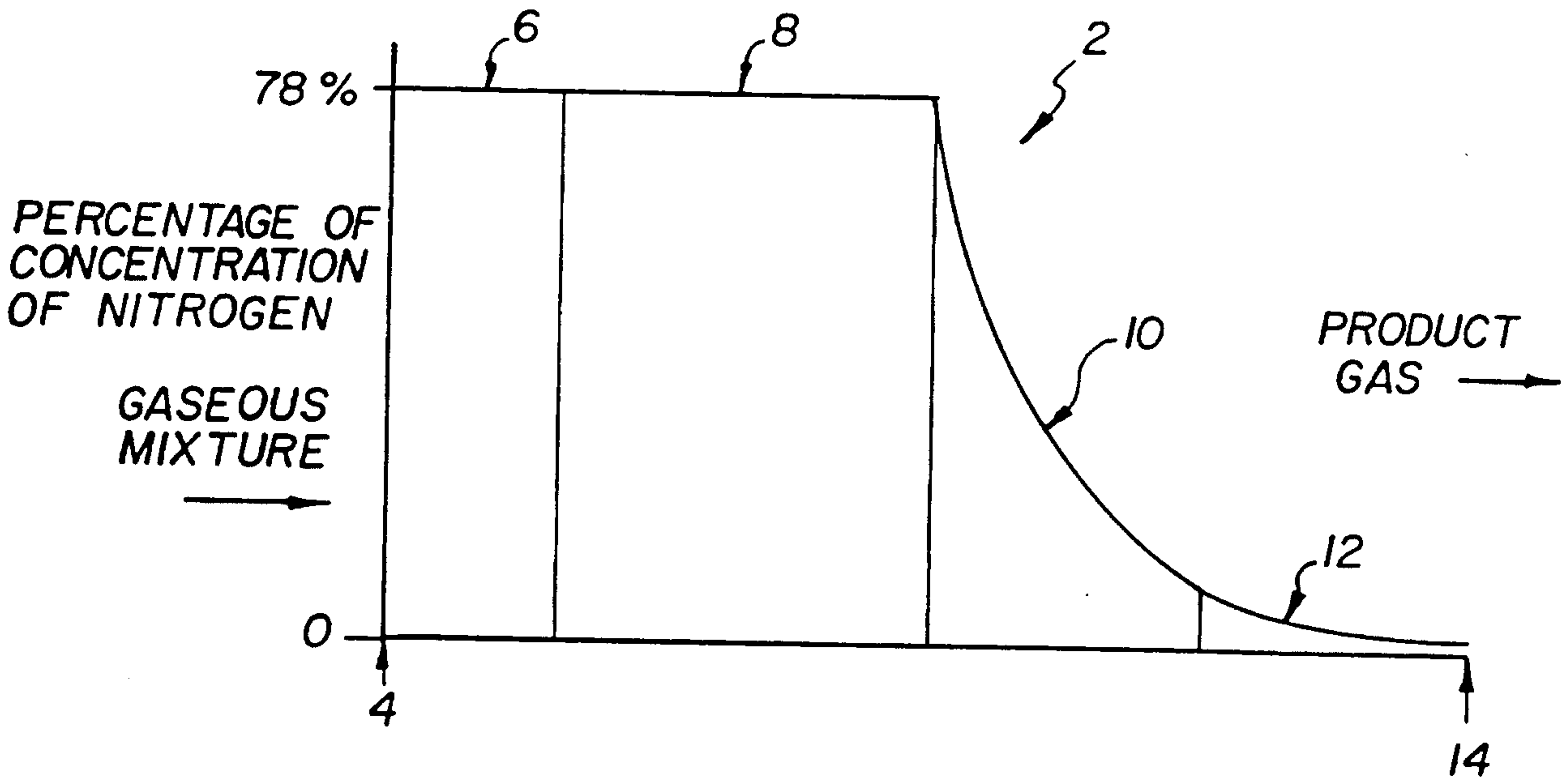
15. The method as claimed in claim 14 wherein the range of concentration of the other constituent gas in the usable product gas is from about seventy-seven to about thirty-seven percent.

16. The method as claimed in claim 11 wherein the predetermined range of flow rates is from about 6 to about 15 liters per minute.

17. The method as claimed in claim 10, in which each adsorber includes a zone to substantially adsorb any water in the gaseous mixture, and further comprising the step of controlling and stabilizing the water adsorption zone of said adsorber.

FIG. 1A

(PRIOR ART)



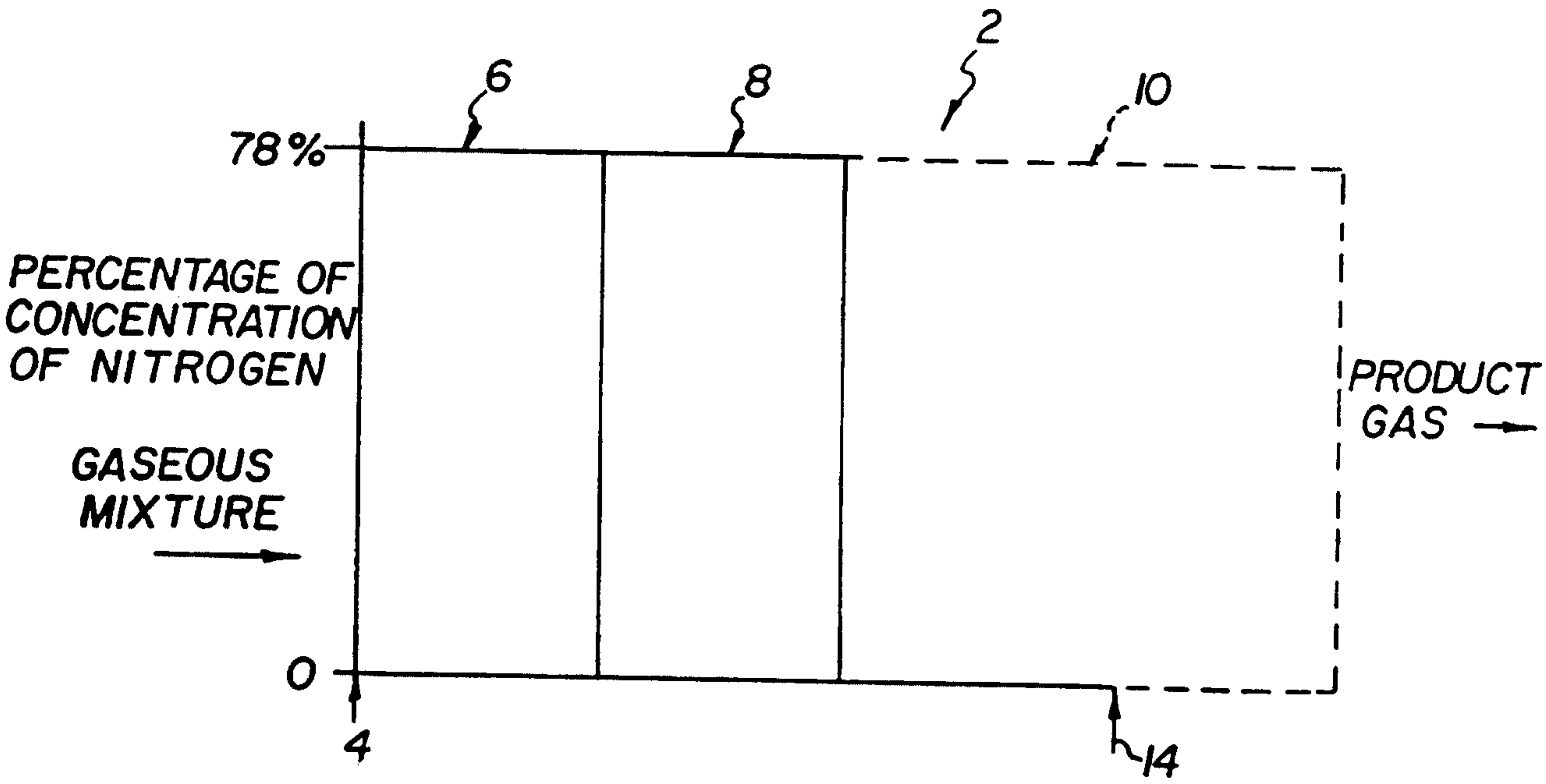


FIG. 1B

(PRIOR ART)

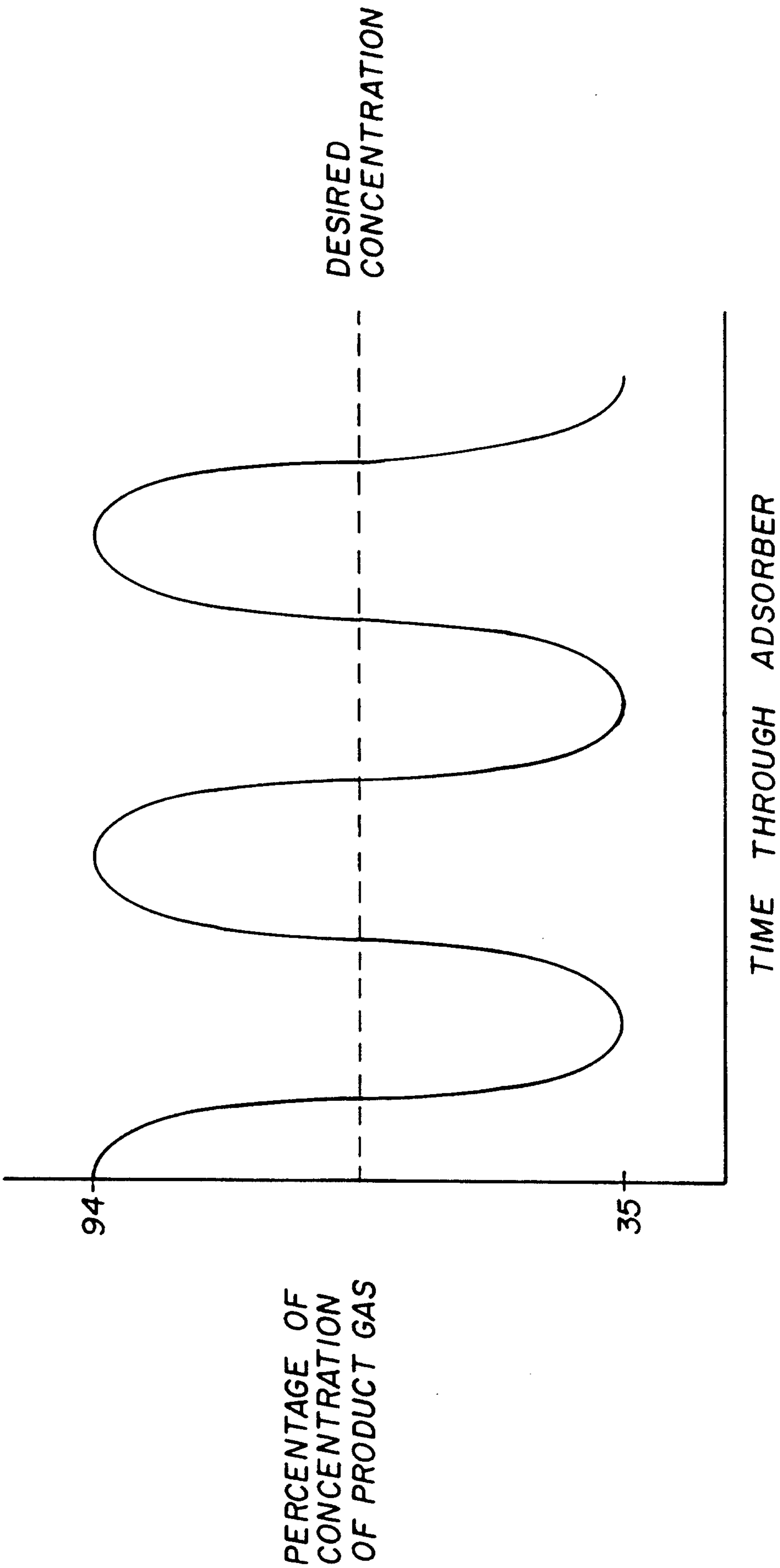


FIG. 1C
(PRIOR ART)

PCT/US 98/12246
IPEA/US 24 MAR 1999

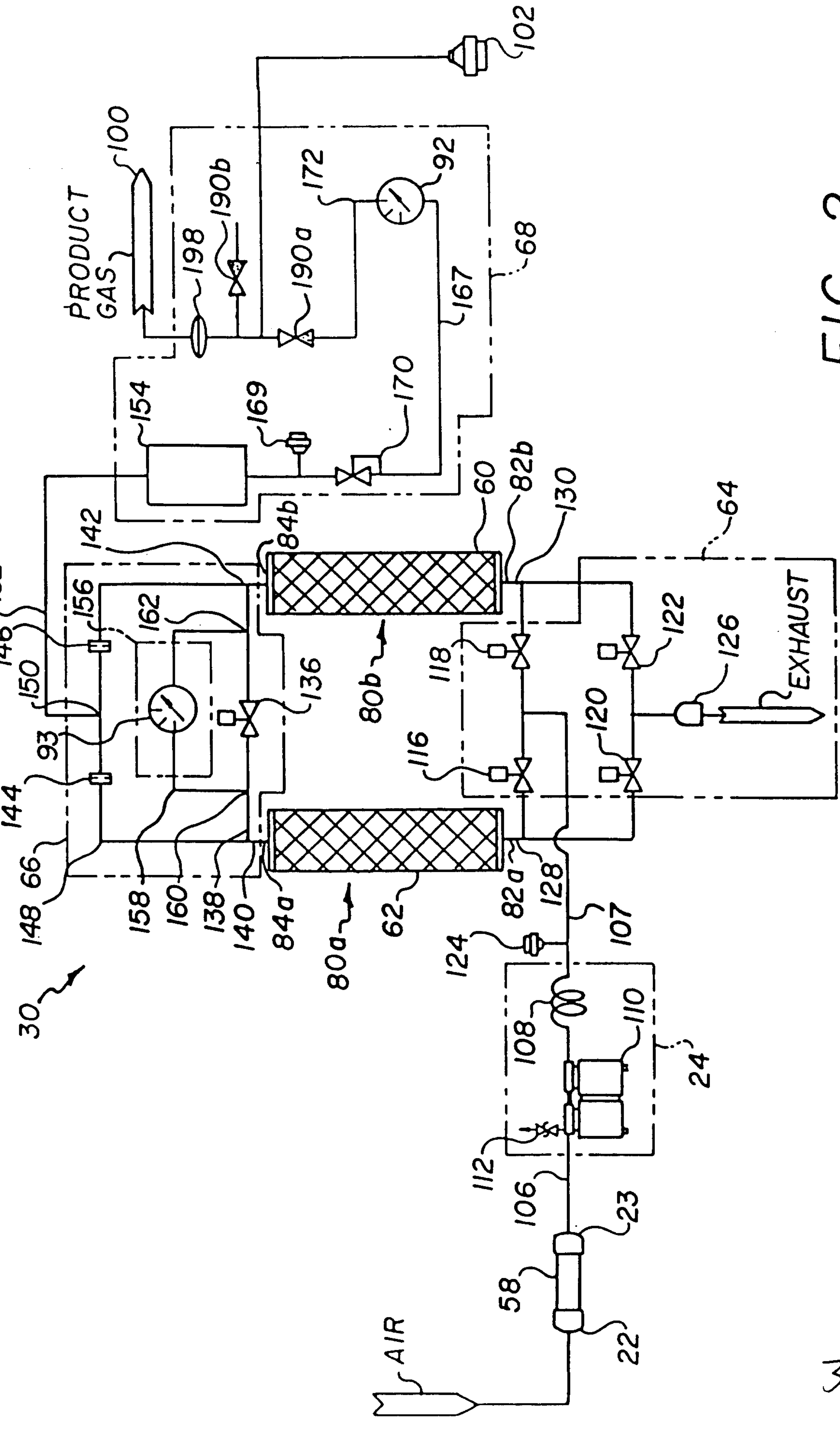


FIG. 2

3/6

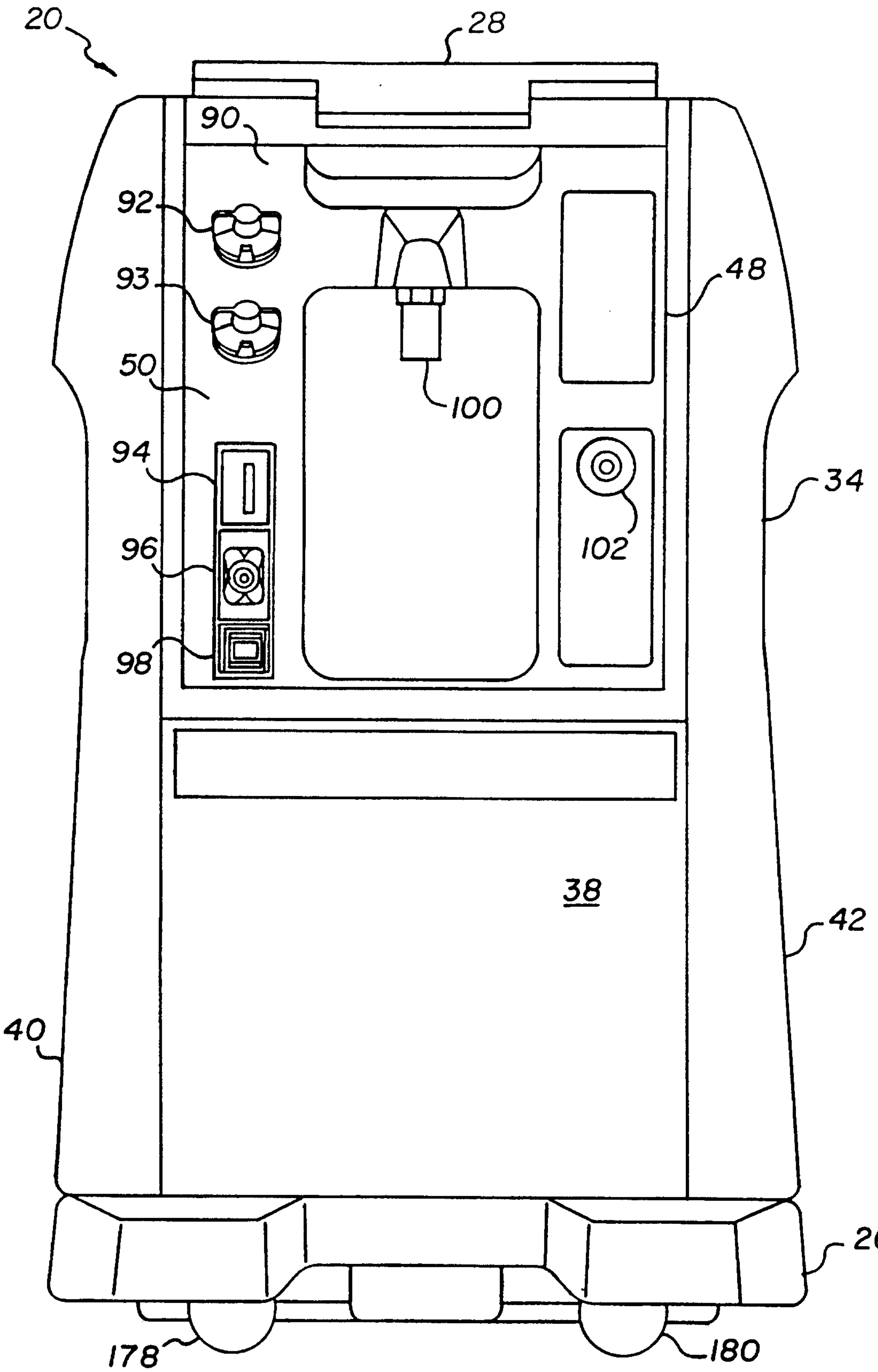


FIG. 3

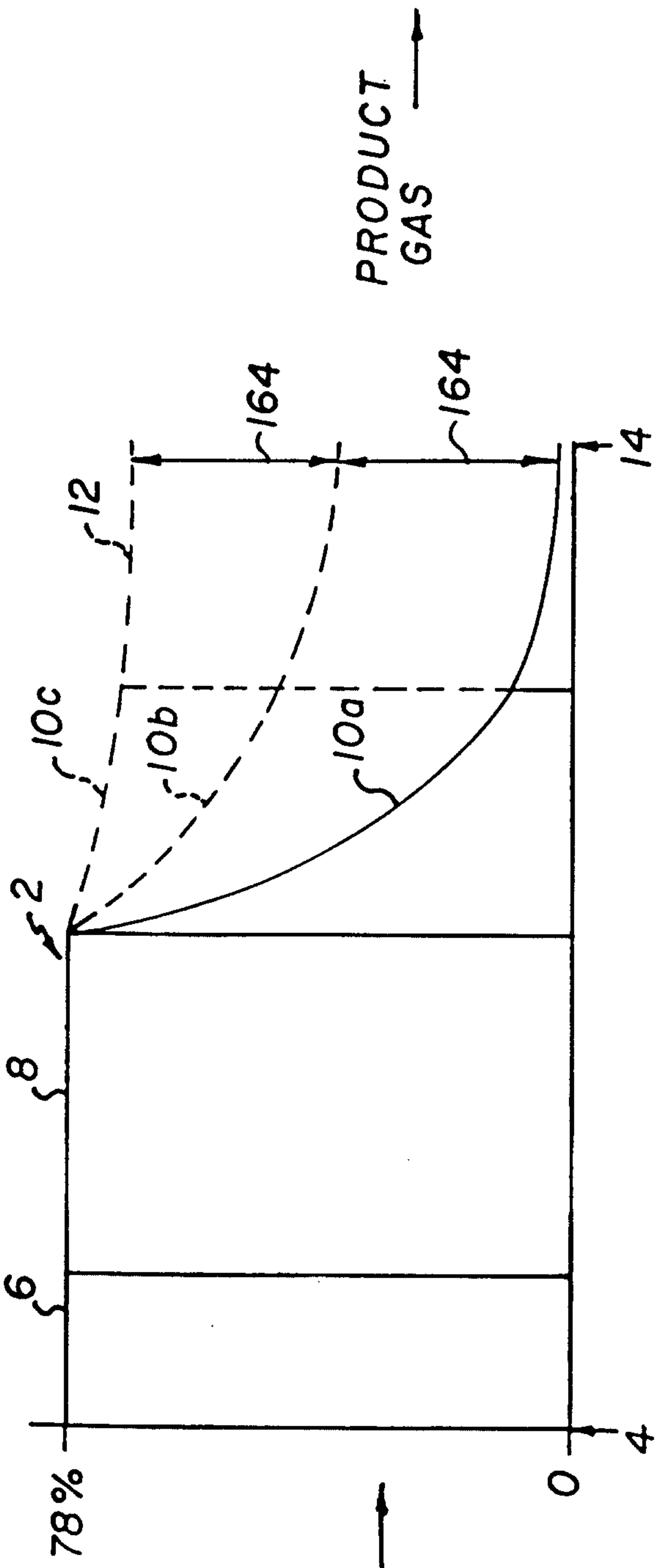

PRODUCT GAS
164
164
12
14
10c
10b
10a
2
8
6
78%
0
4
PERCENTAGE OF CONCENTRATION OF NITROGEN
GASEOUS MIXTURE

FIG. 4

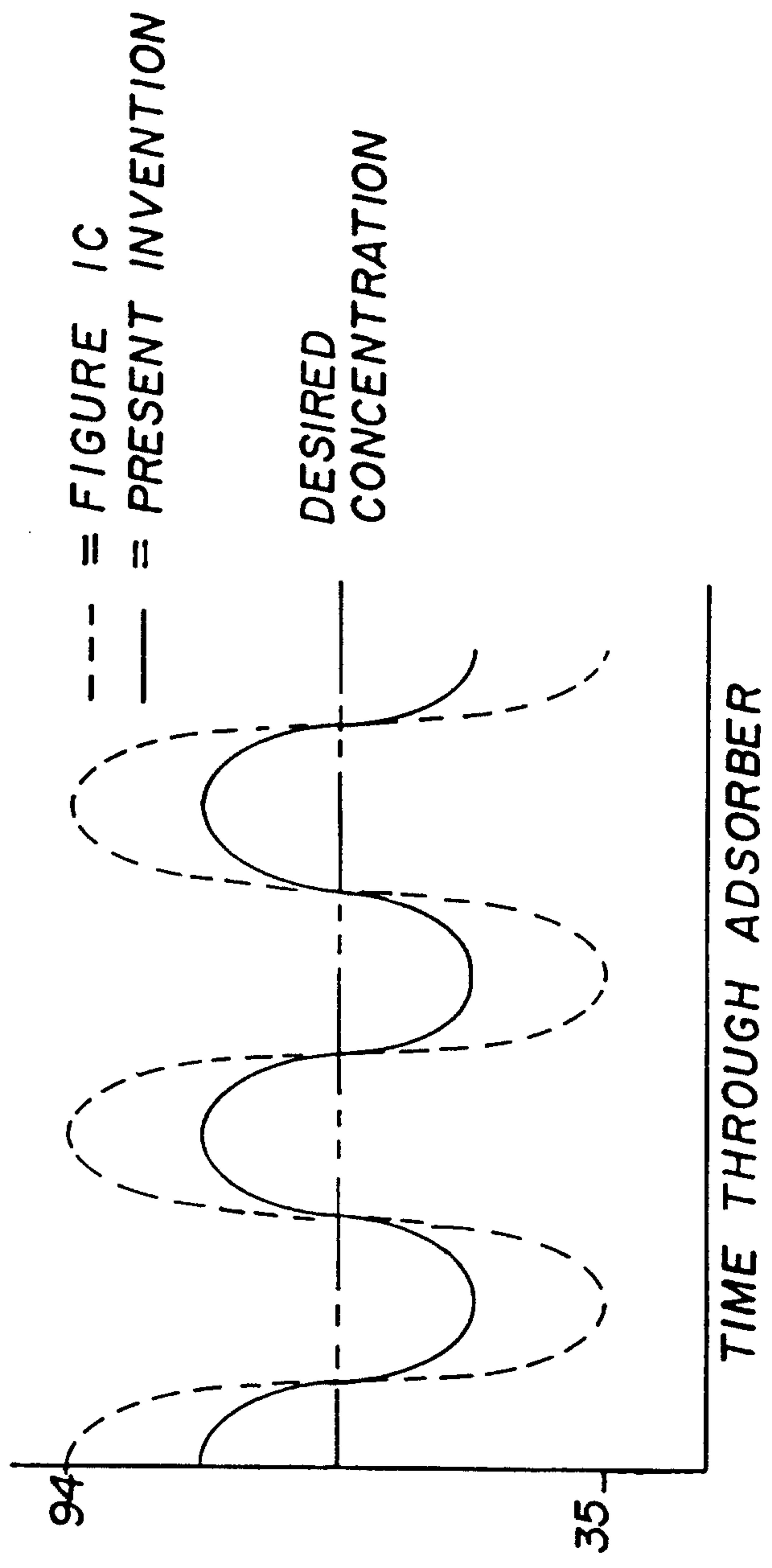

- - - = FIGURE 1C
—— = PRESENT INVENTION
DESIRED CONCENTRATION
TIME THROUGH ADSORBER
94
35
PERCENTAGE OF CONCENTRATION OF PRODUCT GAS

FIG. 5

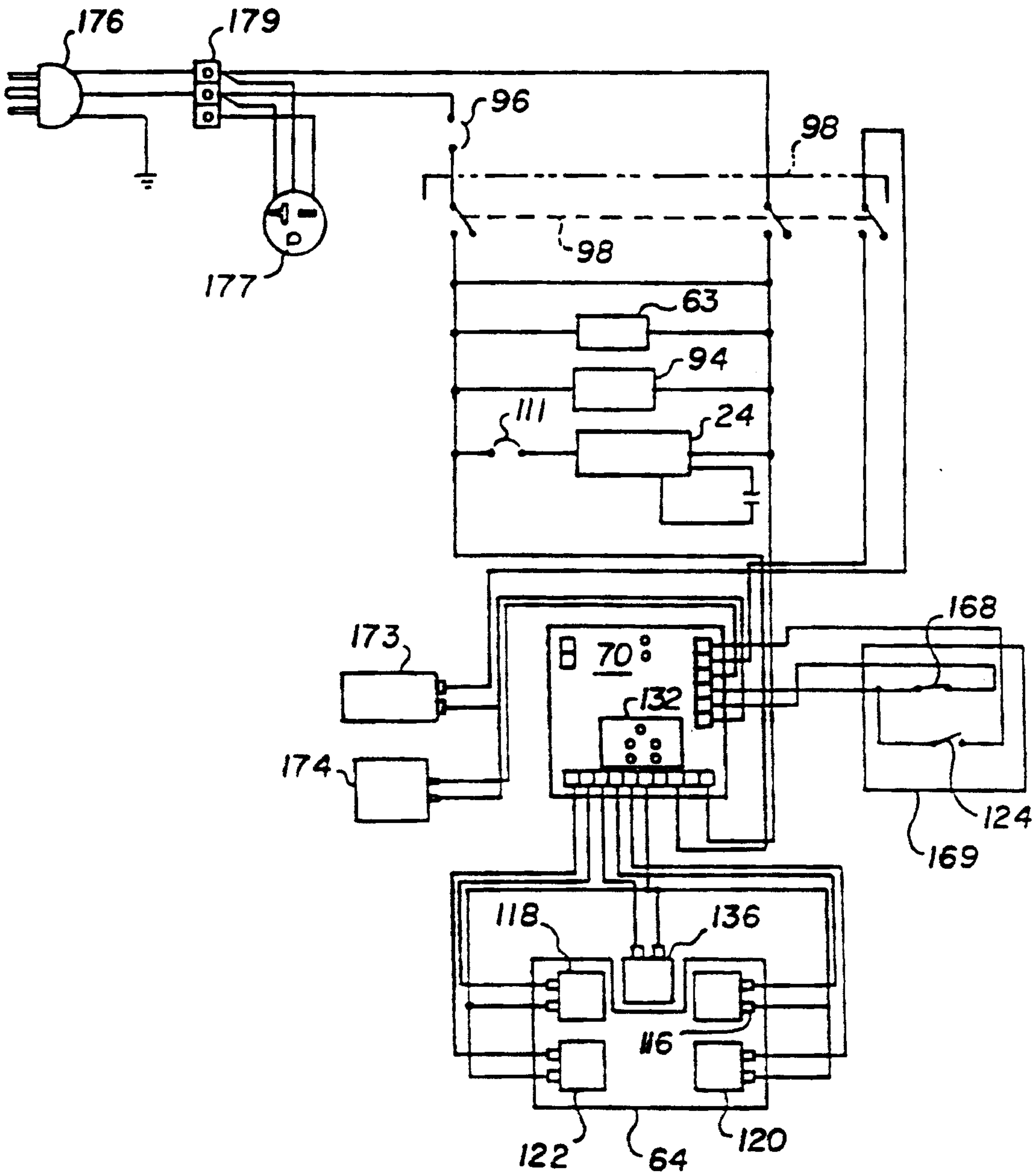
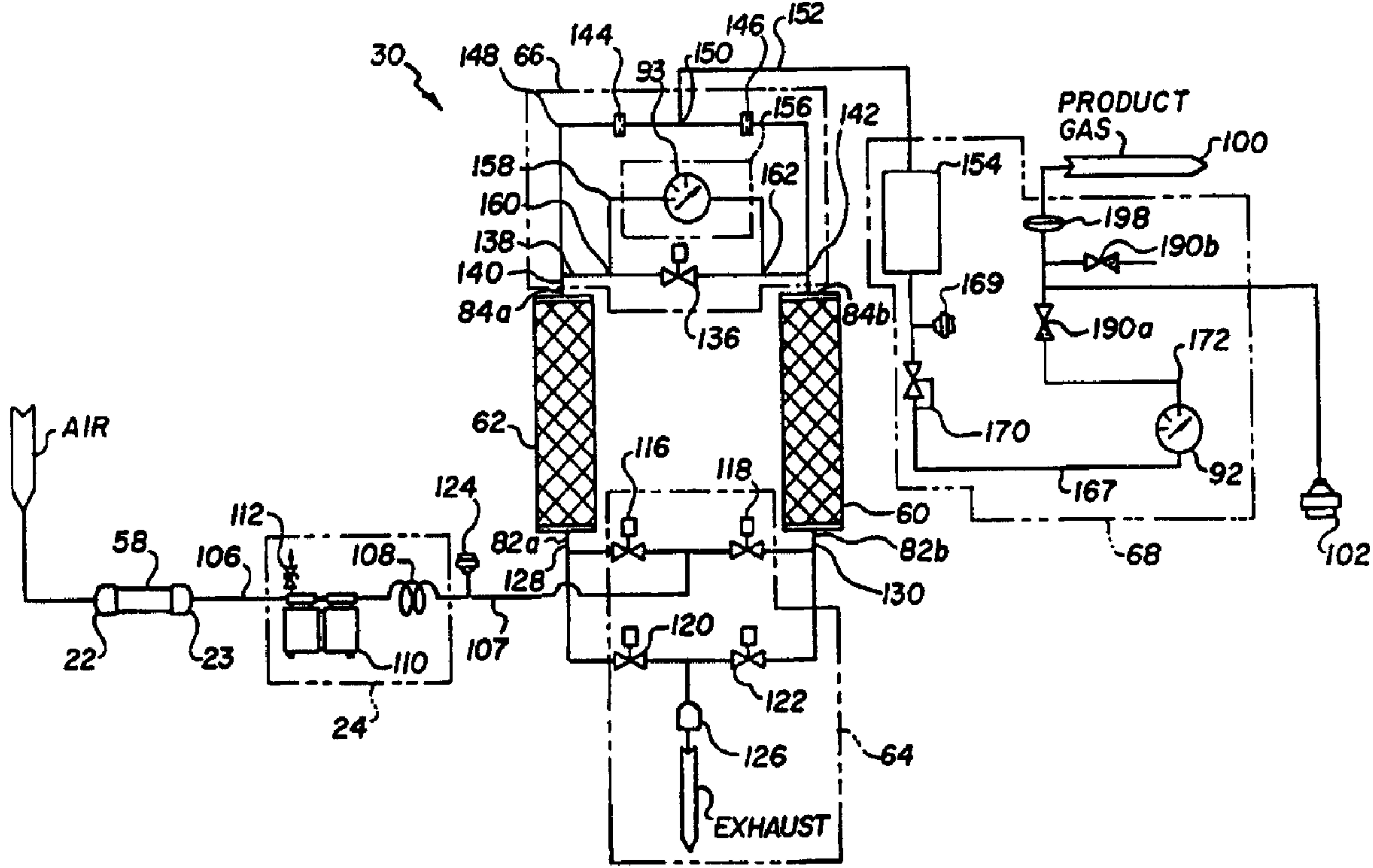

176
179
96
98
98
177
63
94
111
24
173
70
132
168
174
124
169
118
136
116
122
64
120

FIG. 6



30
148
66
144
93
150
146
152
156
142
PRODUCT GAS
100
158
162
154
160
198
138
190b
140
136
84a
84b
169
190a
172
62
AIR
116
118
170
92
124
167
112
58
106
108
82a
60
82b
68
102
128
130
22
23
110
107
120
122
24
126
64
EXHAUST