(12) UK Patent Application (19) GB (11) 2 163 670 A

(43) Application published 5 Mar 1986

(21) Application No 8521456

(22) Date of filing 29 Aug 1985

(30) Priority data
(31) 8421962 (32) 30 Aug 1984 (33) GB

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(51) INT CL⁴
B01D 53/04 F16K 3/24

(52) Domestic classification
B1L 101 102 201 215 217 223 302
U1S 1901 B1L

(56) Documents cited
US 4295863 US 4205967 US 3778967

(58) Field of search
B1L

(54) Improved apparatus for the separation of a gaseous mixture

(57) In an apparatus for the separation of at least one gas from a gas mixture the control of feed gas mixture into two vessels the discharge of product gas from said vessels, the flow of waste gas from said vessels, and the flow of gas between said vessels is controlled by spool valves which are operable by means of a common pneumatic or hydraulic servo system.

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FIG. 1.

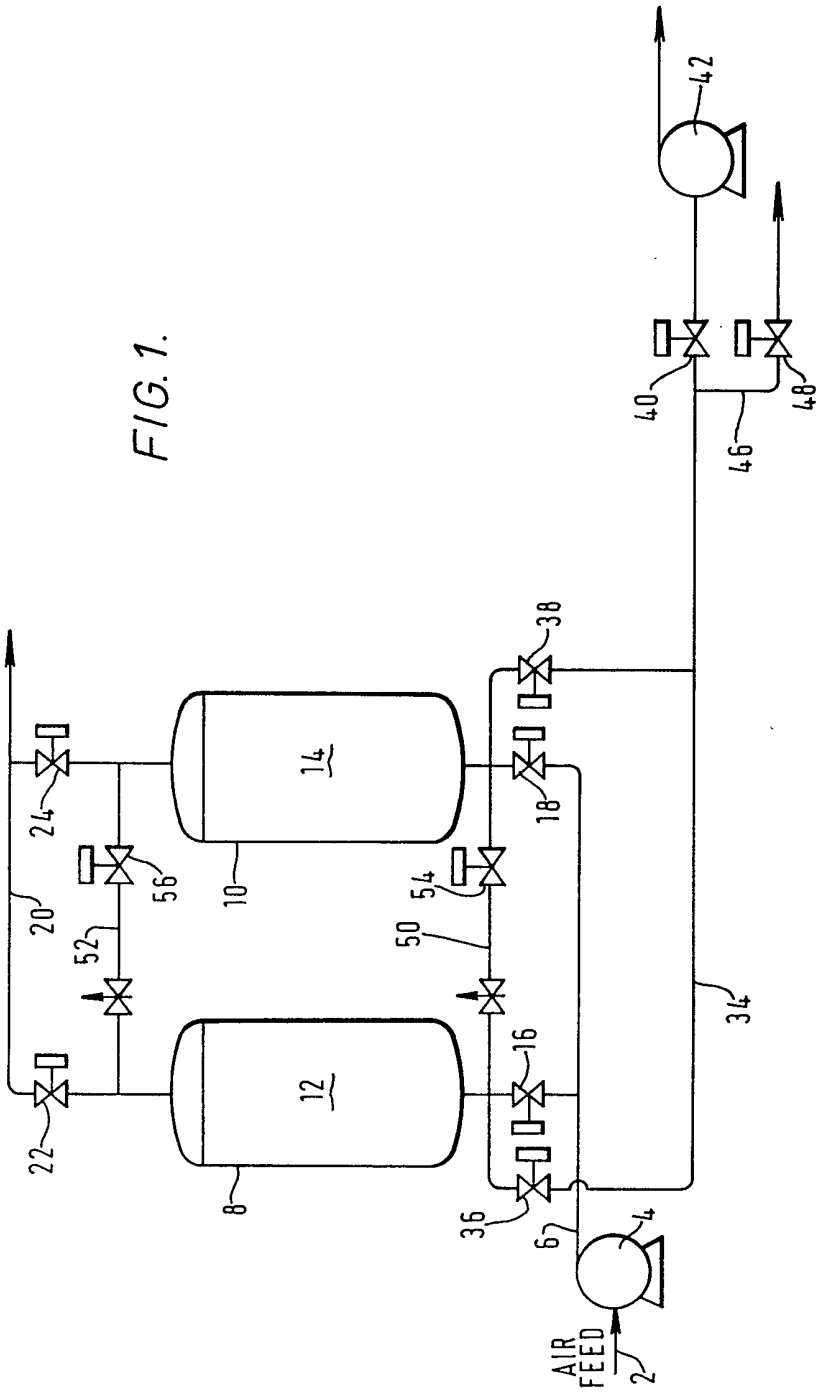
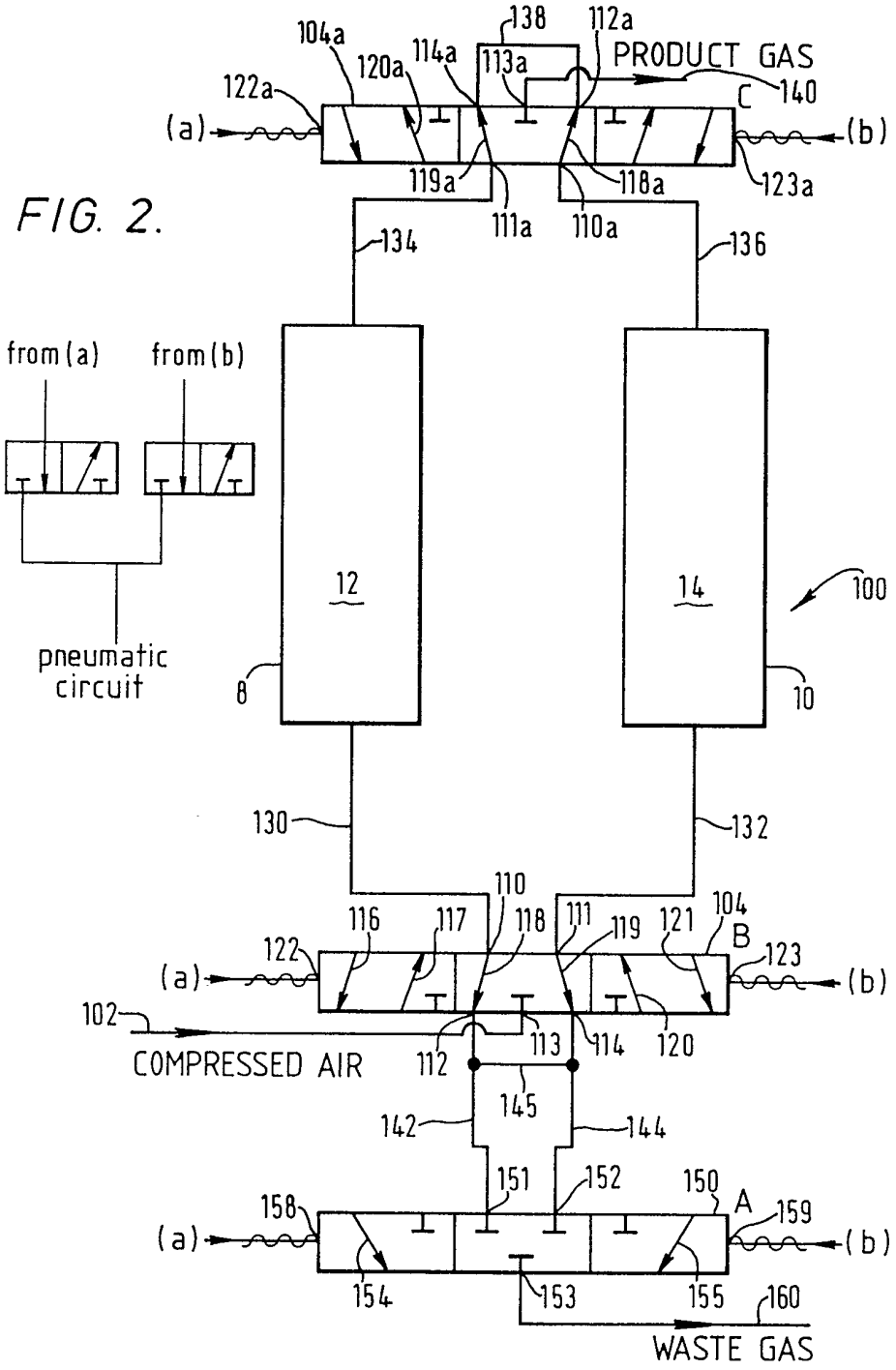


FIG. 2.


104a
120a
114a
138
112a
113a
PRODUCT GAS
122a
140
C
(a)
(b)
119a
118a
123a
111a
110a
134
136
from (a)
from (b)
12
14
100
pneumatic circuit
8
10
130
132
110
116
117
118
111
119
121
104
B
122
123
102
COMPRESSED AIR
112
113
114
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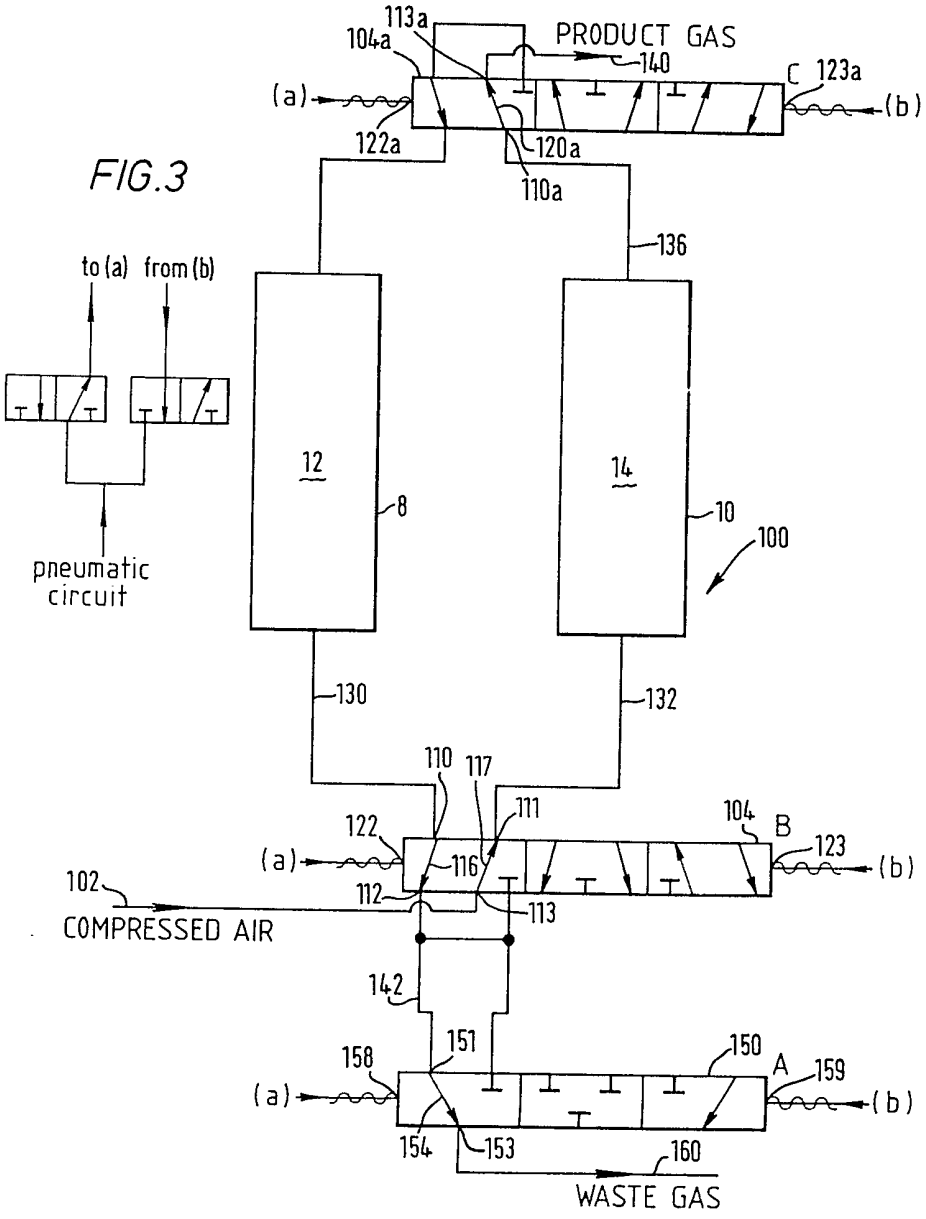
142
144
151
152
150
A
158
159
154
153
155
160
WASTE GAS

FIG.3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(b)
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110a
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to (a) from (b)
12
14
8
10
100
pneumatic circuit
130
132
110
117
111
104
B
122
123
(a)
(b)
116
102
112
113
COMPRESSED AIR
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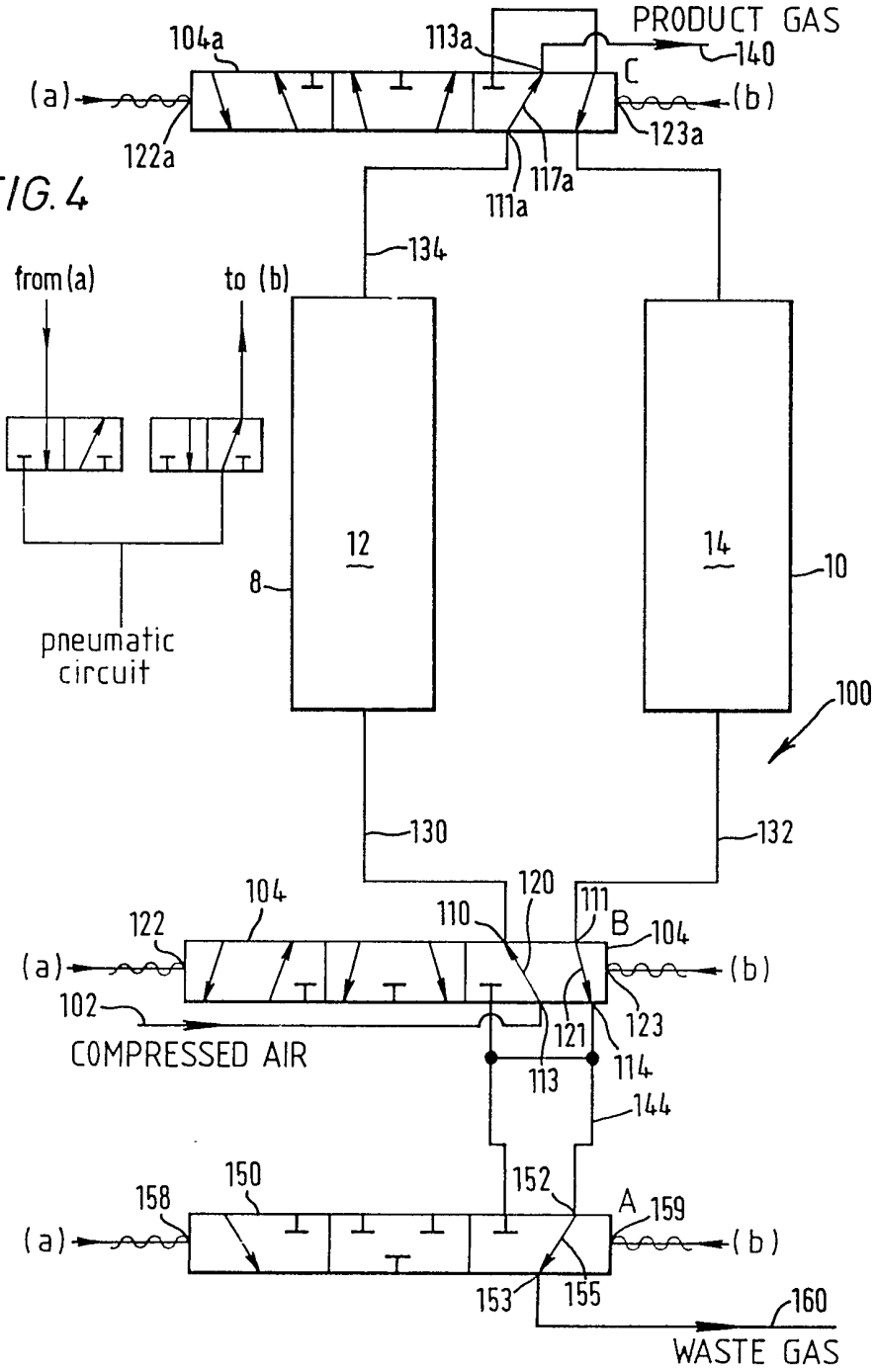
150
158
A
159
(a)
(b)
154
153
160
WASTE GAS

FIG. 4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113a
C
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(b)
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123a
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134
from (a)
to (b)
12
14
8
10
pneumatic circuit
100
130
132
104
120
111
122
110
B
104
(a)
(b)
102
COMPRESSED AIR
121
123
113
114
144
150
152
158
A
159
(a)
(b)
153
155
160
WASTE GAS

SPECIFICATION

Improved apparatus for the separation of a gaseous mixture

The present invention relates to apparatus for the separation of a gaseous mixture and especially to apparatus for the separation of a gaseous mixture using pressure swing adsorption techniques (PSA).

It is known from United Kingdom published patent application No. 2073043A to separate nitrogen from air using an adsorbent which has the ability to effect a separation as between the two major components of air by virtue of its more rapid adsorption of oxygen than of nitrogen. The adsorbent is usually molecular sieve carbon. In operation, a bed of the adsorbent is put through a cycle which includes an adsorption step during which time air is pumped through the bed, most of the oxygen and a proportion of the nitrogen and substantially all of the carbon dioxide and water vapour in the feed are adsorbed and a nitrogen-rich product gas is supplied from the outlet of the bed; and a desorption or regeneration step during which time the outlet of the bed is closed, the bed is vented to atmospheric pressure through its inlet and/or evacuated through its inlet so that the adsorbed gases are substantially removed from the bed thereby preparing it for the next adsorption step.

In practice, two adsorbent beds are employed and operated on similar cycles which are sequenced to be out of phase with one another by 180° so that when one bed is on its adsorption step, the other bed is on its regeneration step and *vice-versa*. Between the adsorption and the regeneration steps, the pressures in the two beds are equalised by connecting the two bed inlets together and connecting the two bed outlets together. With these connections made, the gas within the void spaces of the bed which has just completed its adsorption step flows into the bed which has just completed its regeneration step by virtue of the pressure difference which exists between the beds at this stage. This equalisation step is found to be beneficial in maximising the product output because the gas in such void spaces will have already become somewhat enriched in nitrogen.

The flow of air into and the flow of product gas leaving each bed during the adsorption step is controlled by conventional individually actuated in-line valves such as ball or butterfly valves. Likewise, the flow of waste gas leaving each bed during a regeneration step and the flow of gas between the beds during a pressure equalisation step is controlled by ball or butterfly valves. In a conventional two bed system, there are at least eight ball or butterfly valves and non-return valves controlling the flow of gas into, within and out of the system.

It is an aim of the present invention, in apparatus for the separation of gaseous mixtures, to replace the individually actuated in-line valves with spool valves, thereby reducing the number of valves required and to eliminate or at least minimise the possibility of valves being operated out of sequence.

According to the present invention, an apparatus for the separation of at least two gas from a gas mixture comprises at least two vessels each containing a bed of adsorbent material which preferentially adsorbs at least one constituent of the gas mixture and spool valves for controlling the flow of gas mixture into the vessels and the flow of product and waste gases from the vessels, and the flow of gas from one vessel to another or the other vessel.

In a preferred apparatus according to the invention at least one spool valve in one position has an arrangement of ports such that an inlet port for gas from one vessel communicates with an outlet port for gas leading to another or the other vessel *via* two other ports communicating with opposite ends of a common passage.

Preferably, the apparatus is used employing a pressure swing adsorption technique and includes first and second vessels, each containing a bed of adsorbent material which adsorbs preferentially at least one constituent of a feed gas mixture, each vessel having an inlet for the feed gas mixture, an outlet for waste gas, an outlet for product gas; and a pipeline extending between the vessels to permit the flow of gas between said vessels and in which the flow of gases into and out of the vessels is effected by first, second and third spool valves.

Embodiments of the invention will now be described by way of example, reference being made to the Figures of the accompanying diagrammatic drawings in which:—

Figure 1 is a schematic diagram of a known apparatus using two vessels for the separation of nitrogen from air by pressure swing adsorption techniques;

Figure 2 is a schematic diagram of an apparatus using two vessels for the separation of nitrogen from air by pressure swing adsorption techniques according to the present invention at the pressure equilisation step;

Figure 3 is a schematic diagram of the apparatus of Fig. 2 with one bed at an adsorption step and the other bed at a regeneration step; and

Figure 4 is a schematic diagram of the apparatus of Fig. 2 with said one bed at a regeneration step and said other bed at an adsorption step. Referring first to Fig. 1, this illustrates the known apparatus as described and shown in United Kingdom published patent application No. 2073043A for the separation of nitrogen from air. The apparatus in-

cludes an air feed line 2 leading to a compressor 4. The outlet from the compressor 4 communicates with an air inlet pipeline 6. The air inlet pipeline 6 is able to be placed in communication with either one of vessels 8 and 10 containing beds 12 and 14 of carbon molecular sieve adsorbent. Ball valve 16 is operable to place the bottom of bed 12 in communication with the inlet pipe 6 or to deny communication between the bed 12 and the inlet pipeline 6. Analogously, ball valve 18 is operable to place the bottom of the bed 14 in communication with the inlet pipeline 6 or to deny such communication.

The apparatus includes an outlet pipeline 20. A ball valve 22 is operable to place the top of the bed 12 in communication with the pipeline 20 or to prevent communication between the bed 12 and the pipeline 20. Analogously, a ball valve 24 is operable to place the top of the bed 14 in communication with the pipeline 20 or to deny such communication.

The apparatus includes an outlet pipeline 34 for waste gas. A ball valve 36 is operable to place the bottom of the bed 12 in communication with the pipeline 34 or may be closed to deny such communication. A ball valve 38 is operable to place the bottom of the bed 14 in communication with the pipeline 34 or, when closed, deny such communication. The pipeline 34 communicates with a vacuum pump 42. The outlet of the vacuum pump 42 communicates with the pipeline 34 for the discharge of waste gas from the apparatus. In communication with the pipeline 34 upstream of a ball valve 40 is a vent pipeline 46 communicating with the atmosphere. In the pipeline 46 is a ball valve 48. If desired, the vent pipeline 46 and the ball valve 48 may be omitted from the apparatus. Alternatively, the vacuum pump 42 and ball valves 40 and 48 may be omitted. If the vacuum pump is omitted, the bed will be subject to atmospheric pressure to effect regeneration of the bed which previously adsorbed oxygen. If the vent pipeline 46 and the ball valve 48 are omitted, the beds 12 and 14 will be subjected to a sub-atmospheric pressure in order to effect regeneration of a bed which previously adsorbed gas.

Pipeline 50 connects together the bottoms of vessels 8, 10. A similar pipeline 52 connects together the tops of vessels 8, 10. In the pipeline 50 is disposed a ball valve 54 and in the pipeline 52 is disposed a ball valve 56. When the ball valves 54 and 56 are open, there is communication between the beds 12 and 14.

Describing very briefly a process using the apparatus in Fig. 1 for the separation of nitrogen from air and assuming at the start of a cycle of operations that the bed 12 is at a sub-atmospheric pressure being subjected to vacuum created by the pump 42 and the bed 14 is at its maximum pressure being in communication with the compressor 4. The cycle starts with the beds 12, 14 being placed in communication with one another through the pipelines 50 and 52. In this phase of the cycle ball valves 16, 18, 22, 24, 36 and 38 are all in their closed position and ball valves 54 and 56 are open. Unadsorbed nitrogen-rich gas in the spaces between individual particles of adsorbent in the bed 14 flow through pipelines 50 and 52 into the bed 12. The unadsorbed gas in the bed 14 which passes to the bed 12 is rich in nitrogen. As it passes to the bed 12, so the pressure in the bed 12 increases from below atmospheric pressure and the pressure in the bed 14 undergoes a corresponding reduction.

The cycle will then continue with the bed 12 performing an adsorption step whilst the bed 14 is regenerated in a manner well known in the art.

It will be observed that a minimum of eight ball valves are used in the apparatus illustrated in Fig. 1, namely ball valves 16, 18; 22, 24; 36, 38; and 54, 56. A further 2 ball valves 40, 48 can also be incorporated into the apparatus.

Referring now to Figs. 2, 3 and 4, an apparatus 100 for the separation of at least one gas, for example, nitrogen from a gaseous mixture such as air by pressure swing adsorption comprises an air feed line 102 extending from a compressor (not shown) and communicating via a port 113 with a first spool valve 104. Valve 104 is a three-position spool valve having a housing with five ports 110, 111, 112, 113, and 114 and a spool with six passageways 116 to 121. The spool is spring loaded within the housing at each end and thus the spool normally assumes a central position as illustrated in Fig. 2. At each end of the housing is an inlet 122, 123 for control fluid, for example, air under pressure. Extending from ports 110, 111 in spool valve 104 are two pipelines 130, 132 which communicate respectively with the bottoms (as shown) of vessels 8, 10 containing beds 12, 14 of carbon molecular sieve adsorbent.

Extending from the top (as shown) of each vessel 8, 10 is a pipeline 134, 136 which communicates with ports 111a, 110a, of a second spool valve 104a substantially identical to first spool valve104 and where for convenience like ports, passageways and inlets have been given the same reference numeral with the suffix *a*. A pipeline 138 extends between ports 112a and 114a and a product gas pipeline 140 extends from port 113a.

Referring again to spool valve 104, extending from ports 112, 114 respectively are pipelines 142, 144 which communicate with ports 151, 152, of a third spool valve 150. The pipelines 142, 144 are interconnected by a pipeline 145. The interconnecting pipes 138 and 145 are not features of commercially

available spool valves. We have had specially to provide such pipes (or the like) to enable gas flow between the two vessels to take place. Valve 150 is a three-position spool valve having a housing with three ports 151, 152, 153 and a spool with two passageways 154, 155. As with spool valves 104, 104a, the spool of valve 150 is spring loaded at each end and thus normally assumes a central position (see Fig. 2). At each end of the housing of spool valve 150 is an inlet 158, 159 for control fluid. A pipeline 160 extends from port 153 directly to atmosphere or to atmosphere via a vacuum pump (not shown).

Although not shown, the spool valves 104, 104a and 150 are operated from a common servo system, for example, a pneumatic system.

Referring in particular to Fig. 2, this illustrates the position of the spool valves 104, 104a and 150 when the apparatus 100 is on its pressure equalisation step. All the inlets 122, 123; 122a, 123a; 158, 159 of the valves 104, 104a and 150 are arranged to communicate with atmosphere so that the springs alone exert pressure on the spools, thus causing the spools to assume their neutral or central position.

Assuming for convenience that bed 14 has just finished its adsorption step and bed 12 its desorption or regeneration step, then gas from the high pressure bed 14 will flow either through pipeline 136, port 110a, passageway 118a, port 112a, pipeline 138, port 114a, passageway 119a, port 111a and pipeline 134 into the top (as shown) of the vessel 8; or pipeline 32, port 111, passageway 119, port 114, pipeline 144, pipeline 145, pipeline 142, port 112, passageway 118, port 110, and pipeline 130 into the bottom (as shown) of vessel 8.

Referring now to Fig. 3, this illustrates the position of the spool valves 104, 104a and 150 when bed 12 is being regenerated and bed 14 is on its adsorption step. Pneumatic pressure from the control circuit is applied to inlets 122, 122a and 158 of the spool valves whilst inlets 123, 123a and 159 are connected to atmosphere. This causes the spools to assume their left (as shown) position.

Compressed air/feed gas from the compressor (not shown) flows along pipeline 102, port 113, passageway 117, port 111 and pipeline 132 into the bottom (as shown) of vessel 10. Product gas (nitrogen) will leave vessel 10 and flow through pipeline 136, port 110a, passageway 120a, port 113a and into product gas pipeline 140.

Meanwhile, waste gas in vessel 8 flows through pipeline 130, port 110, passageway 116, port 112, pipeline 142, port 151, passageway 154, port 153 and through waste gas pipeline 160 either directly to atmosphere or via a vacuum pump (not shown) to atmosphere.

Suitable spool valves for use in the invention are available from Cambridge Instruments Ltd, London SE20 8EW under the trade name "Baldwin Fluid Power Direction Control Valves".

The term "spool valve" is used herein to describe a valve which has a reciprocable valve member operable to open and close a plurality of gas ports by means other than the gas flowing through said ports. As shown in Figs. 2 to 4 of the drawings additional control ports are typically provided to actuate the valve member and may be placed in communication with a pneumatic control circuit.

Referring now to Fig. 4, this illustrates the position of the spool valves 104, 104a and 150 when bed 14 is being regenerated and bed 12 is on its adsorption step. Pneumatic pressure in the control circuit is applied to inlet 123, 123a and 159 of the valves whilst inlets 122, 122a and 158 are connected to atmosphere. This causes the spools to assume their right hand (as shown) position.

Compressed air/feed gas from the compressor (not shown) flows along pipeline 102, port 113, passageway 120, port 110 and pipeline 130 into the bottom (as shown) of vessel 8. Product nitrogen gas leaves vessel 8 via pipeline 134, port 111a, passageway 117a, port 113a and into product gas line 140.

Meanwhile, waste gas in vessel 10 flows through pipeline 132, port 111, passageway 121, port 114, pipeline 144, port 152, passageway 155, port 153 and into waste pipeline 160.

It will be apparent that the three spool valves 104, 104a and 150 perform similar functions to the eight ball valves described with reference to Fig. 1 and since there are only three spool valves this represents a considerable economy when compared to the known apparatus of Fig. 1 using conventional ball valves. Furthermore, the risk of faulty process controllers causing the valves to operate out of sequence can be eliminated. Use of a common pneumatic (or hydraulic) servo controlled system enables the spool valves to be operated simultaneously. Moreover, the various valve functions performed by each individual spool valve are inherently performed simultaneously.

Although reference has been made to a pressure swing adsorption technique for producing nitrogen employing two beds, use of spool valves can clearly be made in pressure swing adsorption processes for producing not only nitrogen, but oxygen or other gases and in apparatus that includes more than two adsorbent beds. Clearly, in each particular case there may be different selection of functions performed by the spool valves.

Furthermore, the use of spool valves may also be applied to apparatus that is operated on an essentially temperature swing rather than pressure swing adsorption technique.

CLAIMS

1. An apparatus for the separation of at least one gas from a gas mixture including said one gas comprising at least two vessels each containing a bed of adsorbent material which preferentially adsorbs at least one constituent of the gas mixture and spool valves for controlling the flow of gas mixture into the vessels and the flow of product and waste gases from the vessels, and the flow of gas from one vessel to another or the other vessel.

2. Apparatus as claimed in claim 1, in which at least one spool valve in one position has an arrangement of ports such that an inlet port for gas from one vessel communicates with an outlet port for gas leading to another or the other vessel *via* two other ports communicating with opposite ends of a common passage.

3. An apparatus as claimed in claim 1, in which first and second vessels are provided, each containing a bed of adsorbent material which adsorbs preferentially, by means of pressure swing adsorption techniques, at least one constituent of a feed gas mixture, each vessel having an inlet for the feed gas mixture, an outlet for waste gas and an outlet for product gas and a pipeline extending between the vessels to permit the flow of gas between said vessels, in which the flow of gases into, between and out of the vessels is controlled by first, second and third spool valves.

4. An apparatus as claimed in claim 2, in which the first spool valve is a three position valve which in a first, neutral position permits flow of gas between the vessels, in a second position permits flow of the feed gas into the first vessel and concomitantly permits flow of waste gas from the second vessel towards the third spool valve; and in a third position permits the flow of feed gas to the second vessel and concomitantly permits the flow of waste gas from the first vessel towards the third spool valve.

5. An apparatus as claimed in claim 2 or 3, in which the second spool valve in a first neutral position permits flow of gas between the vessels, in a second position permits the flow of product gas from the first vessel towards a product gas outlet pipeline, and in a third position permits the flow of product gas from the second vessel to the product gas outlet pipeline.

6. An apparatus as claimed in any one of claims 2 to 4, in which the third spool valve is a three position valve which in a first neutral position blocks all flow of gas from the first and second vessels, in a second position permits the flow of waste gas from the second vessel, through the first spool valve towards a waste gas outlet pipeline and in a third position permits the flow of waste gas from the first vessel, through the first spool valve towards the waste gas outlet pipeline.

7. An apparatus as claimed in any one of claims 2 to 5, in which the first, second and third spool valves are operable by means of a common fluid servo pipeline system.

8. An apparatus as claimed in any one of claims 1 to 6, in which the first and second spool valves have five ports and six passageways whilst the third spool valve has three ports and 2 passageways.

9. An apparatus for the separation of at least one gas from a gas mixture including said one gas constructed and arranged and adapted to operate substantially as hereinbefore described with reference to and as illustrated in Figs. 2 to 4 of the accompanying drawings.

Printed in the United Kingdom for
Her Majesty's Stationery Office, Dd 8818935, 1986, 4235.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.