(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 541 175 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
02.01.2013 Bulletin 2013/01

(51) Int Cl.:
F25J 3/04 *(2006.01)*

(21) Application number: **12173515.3**

(22) Date of filing: **26.06.2012**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **30.06.2011 US 201113174056**

(71) Applicant: **General Electric Company**
Schenectady, NY 12345 (US)

(72) Inventors:
- **Gonzalez Salazar, Miguel Angel**
  Niskayuna, NY New York 12309 (US)
- **Kulkarni, Parag Prakash**
  Niskayuna, NY New York 12309 (US)
- **Knott, Gregory Matthew**
  Katy, TX Texas 77494 (US)

(74) Representative: **Cleary, Fidelma**
GE International Inc.
Global Patent Operation-Europe
15 John Adam Street
London WC2N 6LU (GB)

(54) Air separation unit and systems incorporating the same

(57) A system 50 comprising an air separation unit (ASU) 12 is provided. The ASU 12 is configured to produce liquid nitrogen and pressurize to higher pressure using a pump. ASU 12 may be further configured to produce liquid oxygen that can be directly pressurized to be used in required applications 14. System 50 may further include oxy-fuel combustion system 14, integrated gas turbines 64 and integrated enhanced oil and / or gas recovery units 78. Methods of operating the system included.

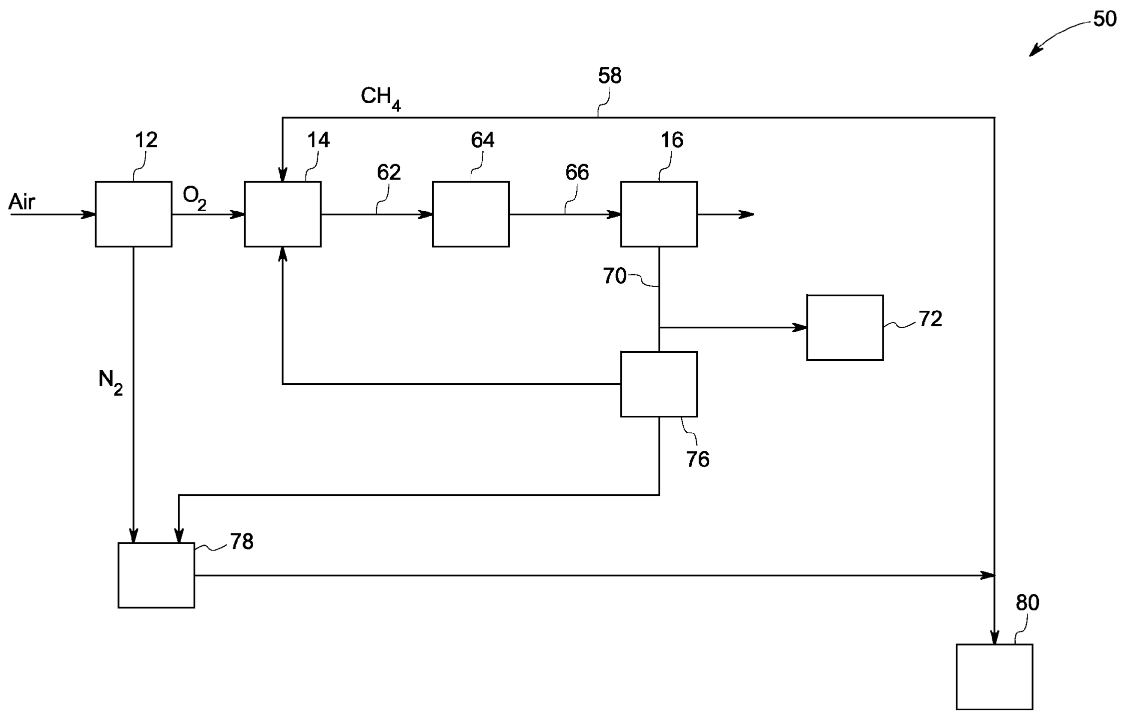

FIG. 4

EP 2 541 175 A2

Description

BACKGROUND

[0001] The invention relates generally to air separation units and systems incorporating the air separation units. More particularly, the invention relates to separation of nitrogen and oxygen from air in liquid form and systems incorporating these products for use in, for example, such applications as power generation and natural resource recovery.

[0002] Exhaust streams generated by the combustion of fossil fuels in, for example, power generation systems, contain nitrogen oxides (NO_x) and carbon monoxide (CO) as byproducts during combustion. A method for achieving near-zero NO_x, without the need for removal of NO_X from the exhaust, is the oxy-fuel combustion process. In this method, pure oxygen (typically in combination with a secondary gas such as carbon dioxide) is used as the oxidizer, as opposed to using air, thereby resulting in a flue gas with negligible NO_x emissions. Additionally, oxy-fuel combustion is an attractive technology for applications, such as carbon dioxide (CO_2) production or sequestration, that benefit from production of CO_2 with low levels of oxygen contamination. In gas turbines that operate by way of an oxy-fuel process, a CO_2 separation unit is not needed, because the main component of combustion exhaust includes primarily CO_2, and water (H_2O). By condensing H_2O a high concentration stream of CO_2 may be produced and can be used for CO_2 sequestration or other CO_2 applications.

[0003] An air separation unit (ASU) separates oxygen and nitrogen and is useful as an oxygen source for an oxy-fuel process and for separately providing high purity nitrogen. The high purity nitrogen obtained by ASU can be used for any of various applications, such as oil or gas reservoir management in an enhanced oil or gas recovery system, for instance. Nitrogen and carbon dioxide can be used as injection fluids in enhanced oil recovery (EOR). Nitrogen can be an economic alternative to carbon dioxide for EOR application.

[0004] It is advantageous if the pressure of nitrogen injected into an oil well is greater than the minimum miscible pressure (MMP) of nitrogen and that oil. Nitrogen forming a miscible slug with oil aids in freeing the oil for recovery. Therefore, generally the gaseous low-pressure nitrogen supplied by the ASU is compressed to higher pressure before injecting into the oil reservoirs. However, in these systems the nitrogen separated from the oxygen in the ASU is afterwards compressed in gaseous phase to the desired pressure, which demands a significant amount of power.

[0005] Therefore, there remains a need for a system and method for power generation that provides low levels of NOx and CO emissions, along with reduced power consumption.

BRIEF DESCRIPTION

[0006] Briefly, in one aspect, the present invention resides in a system including an air separation unit. The air separation unit includes an air compression unit configured to produce compressed air at a pressure greater than about 3 bars; a heat-exchanger unit configured to receive and cool the compressed air to produce cooled air; a first distillation unit configured to receive the cooled air and produce a first output stream comprising liquid-nitrogen; and a first pump in direct communication with the first distillation unit and configured to pressurize the first output stream to a pressure greater than atmospheric pressure.

[0007] In another aspect, the invention resides in a method including the steps of compressing air in an air compression unit to a pressure greater than about 3 bars; cooling the compressed air by passing through a heat-exchanger unit; distilling the cooled air stream in a distillation unit to produce a first stream comprising liquid-nitrogen, and a second stream; and pressurizing the first stream to a pressure greater than atmospheric pressure.

DRAWINGS

[0008] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 illustrates a combined oxy-fuel turbine system;

FIG. 2 is an air separation unit, according to an embodiment of the present invention;

FIG. 3 is an air separation unit, according to an embodiment of the present invention; and

FIG. 4 illustrates a turbine system, according to another embodiment of the invention.

DETAILED DESCRIPTION

[0009] Embodiments of the present invention include an ASU that may provide clean, pressurized liquid nitrogen and oxygen output and systems integrated with the ASU.

[0010] In the following specification and the claims that follow, the singular forms "a", "an" and "the" include plural referents unless the context clearly dictates otherwise.

[0011] In general, an oxy-fuel combined cycle power plant system 10 includes an air separation unit (ASU) 12, a combustor 14, and a power plant with cooling system 16, as depicted in FIG. 1. The ASU 12 separates oxygen from air, providing a supply of oxygen as an oxidizer to the combustor 14. The combustor 14 is configured to burn fuel in the presence of this supplied oxygen, either alone or after mixing with CO_2. Nitrogen from the ASU

12 can be stored in a reservoir management unit 18 and/or used for other applications, such as, for example, recovering natural gas from gas fields or for oil recovery. Products of combustion normally contain mainly CO_2, H_2O and trace emissions of CO and O_2. The cooling system 16 embedded in power plant condenses H_2O from exhaust downstream of combustor 14, resulting in exhaust gases exceeding 95% CO_2 composition.

[0012] In one embodiment of the present invention, a system including an ASU is provided. The ASU is configured to liquefy nitrogen at very low temperatures. In one embodiment, the ASU is also configured to liquefy oxygen. The liquid oxygen may be pumped to a pressure suitable for oxy-fuel combustion. Additionally, in some embodiments the liquid nitrogen may be pumped to a very high pressure (300-500 bars) and injected into an oil/gas reservoir for enhanced oil /gas recovery. By liquefying both nitrogen and oxygen in the high-pressure ASU, it is possible to pump them at very low temperatures, thereby increasing the overall efficiency of the plant compared to existing plants that use gaseous nitrogen and oxygen supplied by low-pressure ASUs.

[0013] In one embodiment, the system is configured to produce a carbon dioxide stream from exhaust products of the oxy-fuel combustor. In one embodiment, the carbon dioxide stream produced here is a high-content CO_2 stream. As used herein, a "high-content CO_2 stream" is defined as a stream having more than about 80% by volume of CO_2. In another embodiment, a high-content CO_2 stream contains more than about 90% by volume of CO_2. In a further embodiment, the high-content CO_2 stream contains more than about 95% by volume of CO_2. A stream "substantially free of oxygen" is defined as a stream containing less than about 1% by volume of oxygen. In one embodiment, an oxygen level of less than 10 ppm in the CO_2 exhaust stream is desirable. One example of an application where a high-content CO_2 stream is desirable is oil recovery from depleted oil recovery wells, where CO_2 stream injection is used to force oil from the well. A portion of the high-content CO_2 exhaust gases may also be recirculated to the combustor 14, for mixing with the separated O_2 from the ASU 12. Maintaining minimum CO emissions from the combustion helps in maintaining high combustion efficiency.

[0014] In one embodiment, system 10 comprises an ASU 12, as shown in FIG. 2. The ASU 12 includes an air compression unit 20; a heat-exchanger unit 22; a first distillation unit 26; and a first pump 28. As used herein, a "unit" may be made up of a single component or made up of more than one component. For example, an air compressor unit may be one compressor or may have more than one compressors combined to produce the required air compression.

[0015] The air compression unit 20 is configured to produce compressed air to a pressure greater than about 3 bars. In one embodiment, the air compression unit 20 is configured to produce a compressed air to a pressure greater than about 7 bars. In a further embodiment, the air compression unit 20 is configured to produce a compressed air at a pressure in a range from about 15 bars to about 60 bars. In one particular embodiment, the air compression unit 20 is configured to produce compressed air to a pressure up to about 40 bars. The compressed air passes through the heat-exchanger unit 22, where the air is cooled. The cooling of compressed air is attained by the heat-exchange between different streams that pass through the heat-exchanger unit 22. For example, cool nitrogen and / or oxygen streams separated from air may pass through the heat-exchanger unit 22 absorbing heat from the compressed air and, thereby, cooling the compressed air.

[0016] After passing through the heat-exchanger unit 22, the cooled, compressed air may be subjected to expansion in an expander 24, which further cools the already cooled air. In one embodiment, an expander 24 is a valve introducing a pressure difference to the incoming cooled compressed air. In the expander 24, the cooled compressed air gets expanded suddenly to a lower pressure, resulting in further cooled, reduced pressure-compressed air. In one embodiment, the pressure of the compressed air, after passing through the expander 24 is less than about 5 bars. In one embodiment, the pressure of the air after passing through the expander 24 is less than about 3 bars. In one particular embodiment disclosed further below, the expanded air coming out of the expander 24 is at atmospheric pressure.

[0017] In one embodiment, the cooled air passed through the expander 24 enters the first distillation unit 26. In one embodiment, the first distillation unit 26 is configured to operate at a pressure greater than about 2 bars and is called as a "high-pressure distillation unit". In one embodiment, an inlet pressure of the first distillation unit is in the range from about 3.5 bars to about 5 bars. In one embodiment, the first distillation unit 26 operates at atmospheric pressure.

[0018] The compressed air entering the first distillation unit 26 is generally at relatively low temperature. In one embodiment, the temperature of the air entering the first distillation unit 26 is in between about -150°C and about -210°C. In one further embodiment, the temperature of the air is in the range from about -165°C to about - 185°C.

[0019] The temperature of the air entering first distillation unit 26 is determined in part by the initial pressure of the compressed air, the ability of the heat-exchanger unit 22 to cool the compressed air and the configuration of the expander 24 to expand the cooled air. A high pressure compressed air ends up giving out more heat at the time of expansion compared to air compressed to a lower pressure. Similarly, a heat-exchanger unit 22 that has low temperature coolant streams will effectively extract more heat from the compressed air compared to a heat exchanger unit 22 having higher temperature coolant streams. The volume, pressure difference, and the temperature of the expander 24 may change the heat extracted from the air passing through the expander 24.

[0020] In one embodiment, a first output stream 30 produced from the first distillation unit 26 comprises liquid nitrogen. In one embodiment, the first output stream 30 produced from the first distillation unit 26 comprises more than about 25 % of the inlet compressed air mass flow and comprises high purity liquid nitrogen. In one embodiment, the liquid nitrogen of first output stream 30 is of greater than 95% purity. In one embodiment, the liquid nitrogen is more than about 99% pure. In a particular embodiment, the liquid nitrogen is of more than 99.9% purity. In one embodiment, the temperature of first output stream 30 produced from the first distillation unit 26 is less than about -175°C. In one embodiment, the temperature of first output stream 30 is less than about -178°C. In one particular embodiment, the temperature of the first output stream 30 is in the range from about -178°C to about -185°C.

[0021] In one embodiment, the pressure of the first output stream 30 is greater than atmospheric pressure. In one embodiment, the pressure of the first output stream 30 is greater than about 3 bars. In one particular embodiment, the pressure of the first output stream ranges from about 3.5 bars to about 5 bars. Depending on the particular application requirements, in one embodiment, the first output stream 30 is further pressurized using a first pump 28. In one embodiment, the first pump 28 is in direct communication with the first distillation unit 26. As used herein the "direct communication" between the pump 28 and distillation unit 26 means that the first output stream 30 from the distillation unit 26 is directly pumped to high pressure without intervening expansion or gas-liquid separation. In one embodiment the first output stream 30 is pressurized to greater than about 300 bars. In a further embodiment, the first output stream is pressurized to greater than about 400 bars. In one embodiment, the first output stream 30 is pressurized up to about 500 bars. In one embodiment, the first pump 28 is coupled to the heat-exchanger unit 22 so that the first output stream 30 pressurized by the first pump 28 passes through the heat-exchanger unit 22 thereby cooling the incoming compressed air. As used herein "coupled" merely implies fluid communication and does not prohibit the usage of intervening parts such as valves.

[0022] The first output stream 30 may be transported for different applications. In one embodiment, the first output stream 30 passes through the heat-exchanger unit 24, thereby removing some heat from the incoming compressed air from the compressor unit 20. The low-temperature liquid form of the first output stream 30 is comparatively more effective than gaseous nitrogen in reducing the temperature of the incoming compressed air.

[0023] After distilling out liquid nitrogen, in one embodiment, the distillation unit 26 is left with a second output stream 32 that comprises nitrogen and oxygen (FIG. 2). The second output stream 32 may be drawn out from the distillation unit 26 and may be subjected to further distillation, using, for example a second distillation unit 36. Depending on the pressure of the second output stream 32, it may be further subjected to expansion in a second expander 34, as shown in FIG. 2. In one embodiment, the outlet pressure of the second expander 34 is near atmospheric and the temperature of the contents in a range from about -190°C to about -195°C. In one embodiment, the vapor fraction of the output contents of second expander 34 is in the range from about 0.12 to 0.18. Depending on the temperature of the second output stream 32 and pressure ranges of second expander 34, the stream coming out from the second expander 34 may be in a liquid state, gaseous state, or in a liquid-gas mixed state. Therefore, depending on the requirement, the second output stream 32 optionally may be subjected to a gas-liquid separation in a separator 35. In one embodiment, both the gaseous part and liquid part of the second output stream 32 are fed into the second distillation column 36. In one embodiment, the second distillation unit 36 is a low pressure distillation unit. The pressure at the distillation unit may be less than about 2 bars. In one embodiment, the low pressure distillation unit 36 works at atmospheric pressure.

[0024] The second distillation unit 36 may have one or more outputs. One distillation output is third output stream 38 comprising liquid oxygen. In one embodiment, the third output stream 38 is about 15 mass % or more of the inlet compressed air and comprises high purity liquid oxygen. In one embodiment, the liquid oxygen of the third output stream 38 is of greater than 95% purity. In one embodiment, the liquid oxygen is more than about 99% pure. In a particular embodiment, the liquid oxygen is of more than 99.9% purity. In one embodiment, the temperature of the third output stream 38 produced at the distillation unit 36 is less than about -175°C. In one embodiment, the temperature of the third output stream 38 is less than about -178°C.

[0025] In one embodiment, the pressure of third output stream 38 is greater than atmospheric pressure. Depending on the particular application requirements, in one embodiment, the third output stream 38 is further pressurized using a second pump 39. In one embodiment, the third output stream 38 is pressurized to greater than about 20 bars. In a further embodiment, the third output stream 38 is pressurized in a range from about 30 bars to about 60 bars. In a particular embodiment, the third output stream is pressurized up to about 100 bars of pressure.

[0026] The third output stream 38 produced by the distillation may be transported for different applications including oxy-fuel combustion. Similar to the first output stream 30, during conveyance to the intended application, the third output stream 38 may be routed through the heat-exchanger unit 22, thereby helping to remove heat from the compressed air from the compressor unit 20. The low-temperature liquid form of the third output stream 38 comprising oxygen is comparatively more effective than the gaseous oxygen in reducing the temperature of the incoming compressed air.

[0027] In one embodiment, one output of the second distillation unit is a fourth output stream 40 comprising nitrogen and oxygen. In one embodiment, the fourth output stream 40 includes both nitrogen and oxygen in gaseous form. In one embodiment, the temperature of this stream is about -190°C. In one embodiment, depending on the usage of second expander 34 and/or the distillation conditions at the second distillation unit 36, the fourth output stream 40 measures about 40-60 % of the inlet compressed air mass flow. In this embodiment, the composition of the mixed stream 40 includes about 87 mole % (of fourth output stream 40) of nitrogen and 12 mole % of oxygen.

[0028] The fourth output stream 40 may be used for different applications, including as an oxidizer in a combustion turbine. For example, if used in a combustor that generally uses air as an oxidizer, the fourth output stream 40 will reduce the NOx emission of the combustor. In one embodiment, the stream 40 may be recycled to the air compression unit 20 or to the distillation unit 26.

[0029] Similar to the first output stream 30 and third output stream 38, in one embodiment, the fourth output stream 40 may contribute to the cooling of compressed air passing through the heat-exchanger unit 22.

[0030] The pressures of compressed air supplied by the compression unit 20, the pressure differences and the resultant cooling obtained through the expanders 24, 34, and the distillation conditions in the distillation units 26, 36 may be greatly varied to achieve higher purity, higher content liquid nitrogen and/or liquid oxygen streams. All such variations are believed to be apparent to one skilled in the art considering the teachings of this disclosure.

[0031] In one variation shown in FIG. 3, compressor unit 20 is configured to produce compressed air to a pressure greater than about 35 bars. In one embodiment, the pressure of the compressed air is about 40 bars. The high-pressure compressed air is passed through the heat-exchanger unit 22 and cooled. The cooled compressed air from the heat-exchanger unit is subjected to expansion in an expander 24. The heat-exchanger unit 22 as used herein may be one unit or a combination of multiple heat-exchanger units. In one embodiment, the expander 24 expands the compressed air by quickly reducing pressure ("flashing") to atmospheric pressure such that the air rapidly cools to a liquid form with a temperature less than about -185°C. The cooled liquid is subjected to distillation in the first distillation unit 26 to directly produce high-purity first output stream 30 comprising liquid nitrogen and a second output stream 32 comprising liquid-oxygen. In one embodiment, both the first output stream 30 and the second output stream 32 are in liquid forms. Therefore, in one embodiment, the first distillation unit 26 is a liquid-liquid separator. In one particular embodiment, the first output stream 30 is a liquid nitrogen stream and the second output stream 32 is a liquid oxygen stream. The second output stream comprising liquid oxygen may be further subjected to pressurizing by using a pump 39 and used in different applications.

[0032] A number of heat-exchanger units and coolant streams may be effectively used to cool the air stream that is subjected to distillation in the first distillation unit 26. In one such variation, the incoming compressed air from the compressor 20 is split in to a first stream 41 and a second stream 42 using a splitter 43. The first stream passes through a second heat-exchanger unit 44 and third heat-exchanger unit 45 to be cooled further. The first stream 41 cooled through the multiple heat-exchangers 44, 45 is expanded in the expander 24. Optionally, the cooled air coming from expander 24 may be subjected to a liquid-gas separation in a separator 25, using the liquid part for distillation unit 26 and leaving a gaseous waste stream 46 that may be routed through one or more heat-exchanger units 22, 44, 45 to further cool the incoming compressed air.

[0033] The second stream 42 of the compressed air from splitter 43 may be optionally used in a turbine 48 and the cooled stream 42 is mixed in a mixer 49 with the gaseous waste stream 46. Depending on the temperature of the second stream 42, the gaseous waste stream 46, and the cooling demands of the heat-exchangers 44 and 45, the second stream 42 and the gaseous waste stream 46 may be mixed before passing through any of the second heat-exchanger units 22, 44, and 45. In one embodiment, the gaseous waste stream 46 is passed through the third heat-exchanger 45 and then mixed with the second stream 42 before passing through the second heat-exchanger unit 44, thereby effectively cooling the cooled air stream 41 passing from the third heat-exchanger 45 to the expander 24.

[0034] One particular, advantageous application of the ASUs described above is in the integration of these ASUs to an oxy-fuel gas turbine combined cycle as shown in FIG. 4. The system 50 includes an ASU 12 providing oxygen output; a combustor 14 configured to receive oxygen from ASU 12 and to combust a fuel stream 58, thereby generating a flue gas 62. In one embodiment, cooling system 16 is fluidly coupled to the combustor 14 through a turbine combined cycle 64. The gas turbine combined cycle 64 may receive flue gas 62 from the combustor 14, and use at least a part of the energy associated with the flue gas 62 to generate electricity or perform some other work, releasing an exhaust flue gas 66. Exhaust flue gas 66 from the gas turbine combined cycle 64 may be passed through the cooling system 16, such as, for example, a water condensation system or HRSG, to condense water from the exhaust gas 66, and to create a carbon dioxide stream 70. The carbon dioxide stream 70 may be stored in a storage unit 72. In another embodiment, the carbon dioxide stream 70 may be directed to applications that use "high-content" carbon dioxide, such as for example, a an oil/gas recovery system 78 after optional compression in a CO_2 compressor 76. In another embodiment, at least a part of the carbon dioxide stream 70 is redirected to the combustor 14, after optional compression in a CO_2 compressor 76, to be mixed with the oxygen.

[0035] In one embodiment, a method of generating energy in a power plant that includes a gas turbine is provided. The method includes operating an ASU 12 (FIG. 4) to separate oxygen from air, passing fuel to the combustor 14, and combusting the fuel stream 58 in the combustor 14, in the presence of oxygen. In this manner, a flue gas 62 is generated, comprising carbon dioxide and water. The flue gas 62 of the combustor 14 may be used in operating the turbine 64, e.g., to generate electricity. The exhaust flue gas 66 of the turbine 64 can be passed through a water condensation system 16 to separate water from the exhaust gas 66, and to produce a high-content carbon dioxide stream 70. The high-content carbon dioxide stream 70 is substantially free of oxygen, for safety considerations in those situations where the presence of oxygen is a serious concern. As explained above, the carbon dioxide stream 70 may be stored, directed to other applications such as an oil recovery system, and / or compressed and fed back to the combustor 14, e.g., in combination with the compressed oxygen.

[0036] While the liquid oxygen obtained by the ASU 12 may be pumped to the pressure suitable for oxy-fuel combustion in the combustor 14, the liquid nitrogen may be pumped to a very high pressure (300-500 bars) and can be injected to the oil/gas recovery system 78. In one embodiment, the oil/gas recovery system 78 is a natural gas recovery system. The natural gas 58 recovered from the system 78 may be fed back to the combustor 14 for the oxy-fuel combustion or stored in a natural gas storing unit 80 for using in other applications.

[0037] Advantageously, liquefying both nitrogen and oxygen in the high-pressure ASU as described above allows for these products to be pumped at very low temperatures, thereby increasing the overall efficiency of the combined gas turbine plant compared to existing plants that compress nitrogen and oxygen in gaseous phases.

[0038] Additionally, as the operation pressure of the ASU (-3-40 bar) is much lower than the pressure (300-500 bar) at which the nitrogen is injected in to the recovery system 78, the system 50 is expected to potentially provide not only a higher overall energy efficiency but also a more compact and therefore cost-effective design compared to conventional systems using a low-pressure ASU. In one embodiment, the power consumption of the integrated systems explained herein is about 20% less compared to a conventional integrated system.

[0039] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

Claims

1. A system (10,50), comprising:

an air separation unit (ASU) (12) comprising:

an air compression unit (20) configured to produce compressed air at a pressure greater than about 3 bars;

a heat-exhanger unit (22) configured to receive and cool the compressed air to produce cooled air;

a first distillation unit (26) configured to receive the cooled air and produce a first output stream (30) comprising liquid-nitrogen; and

a first pump (28) in direct communication with the first distillation unit (26) and configured to pressurize the first output stream (30) to a pressure greater than atmospheric pressure.

2. The system (50) of claim 1, wherein the first pump (28) is configured to pressurize the first output stream (28) to a pressure in a range from about 300 bars to about 500 bars.

3. The system (50) of claim 1 or 2, further comprising a natural gas or oil recovery well configured to receive the first output stream (30) from the first pump (28).

4. The system (50) of any of claims 1 to 3, wherein the first pump (28) is fluidly coupled to the heat-exchanger (22).

5. The system (50) of any of claims 1 to 4, wherein the first distillation unit (26) is configured to produce a second output stream (32) comprising nitrogen and oxygen.

6. The system (50) of any of claims 1 to 5, wherein the ASU (12) further comprises a second distillation unit (36) configured to receive the second output stream (32) from the first distillation unit (26) and produce a third output stream (38) comprising liquid oxygen.

7. The system (50) of claim 6, wherein the ASU (12) further comprises a second pump (39) in direct communication with the second distillation unit 36 and configured to pressurize the third output stream (38) to a pressure in a range from about 30 bars to about 60 bars.

8. The system of claim 7, wherein the second pump (39) is fluidly coupled to the heat-exchanger (22).

9. The system of any preceding claim, further comprising an oxy-fuel combustor (14) configured to receive the third output stream (38) from the ASU (12) and produce a flue gas, a turbine (48) that is configured to receive the flue gas from combustor (14) and produce a turbine exhaust flue gas, a condenser configured to receive the turbine exhaust flue gas and produce a carbon dioxide stream, and an oil recovery well (78) configured to receive the carbon dioxide stream.

10. The system of any preceding claim, wherein the air compression unit (20) is configured to produce compressed air at a pressure in a range from about 15 bars to about 60 bars.

11. The system of claim 10, wherein the ASU (12) further comprises an expander (24) in fluid communication with heat-exchanger unit (22) and first distillation unit (26) and configured to expand the cooled air to atmospheric pressure.

12. A method, comprising:

compressing air in an air compression unit (12) to a pressure greater than about 3 bars;
cooling the compressed air by passing through a heat-exhanger unit (22);
distilling the cooled air stream in a distillation unit (26) to produce a first stream (30) comprising liquid-nitrogen, and a second stream (32); and
pressurizing the first stream (30) to a pressure greater than atmospheric pressure.

13. The method of claim 12, further comprising distilling the second stream (32) in a second distillation unit (36) to produce a third stream (38) comprising liquid oxygen.

14. The method of claim 12 or 13, further comprising pressurizing the third stream (38) to a pressure in a range from about 30 bars to about 60 bars.

15. The method of any of claims 12 to 14, further comprising pressurizing the second stream (32) to a pressure in arange from about 30 bars to about 60 bars.

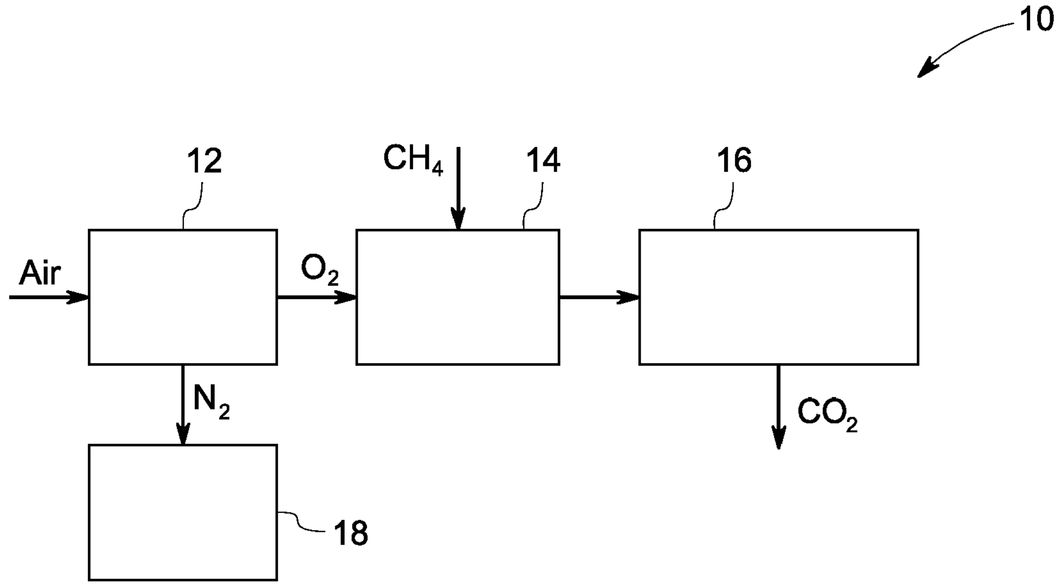

FIG. 1

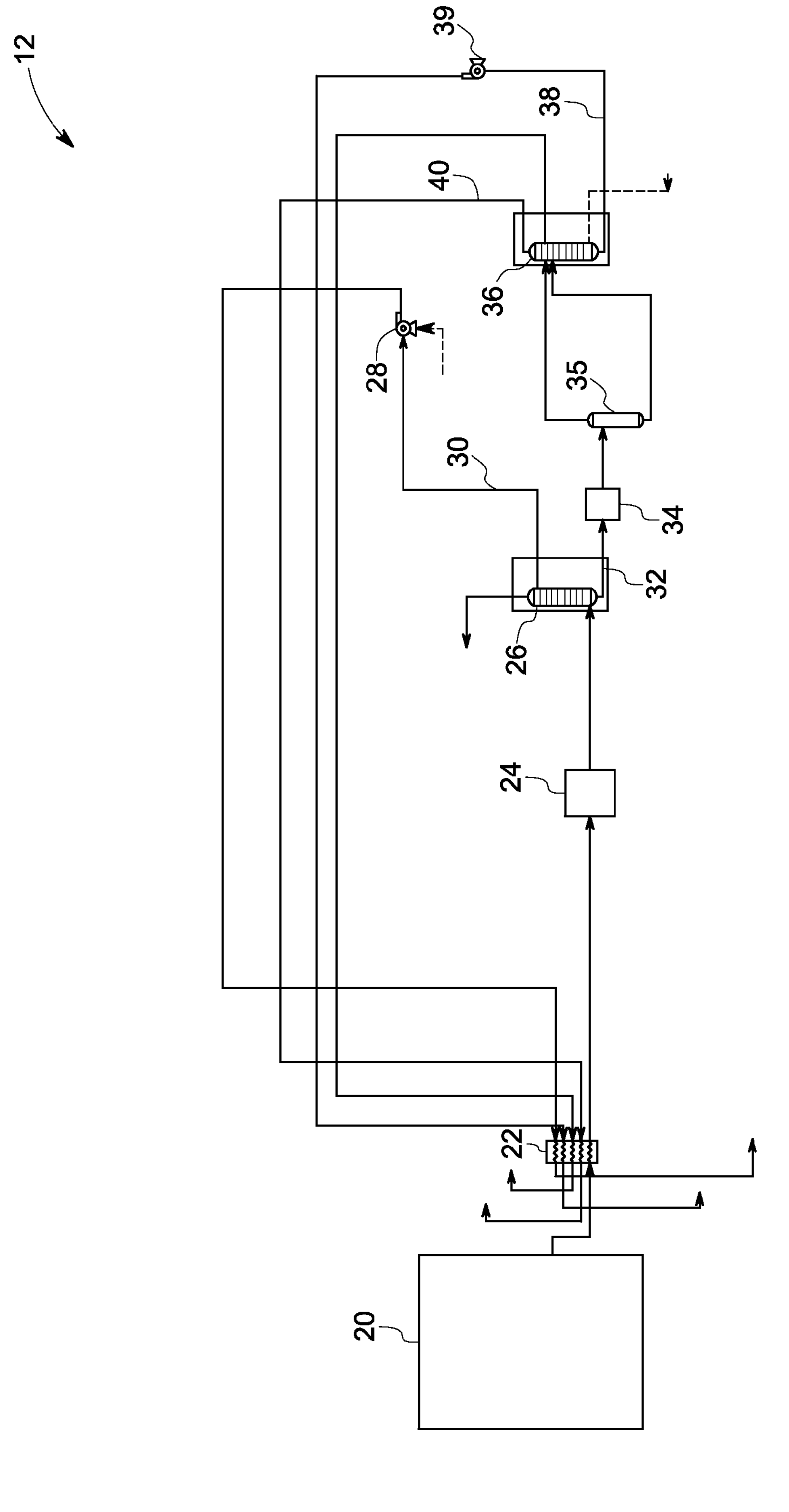

FIG. 2

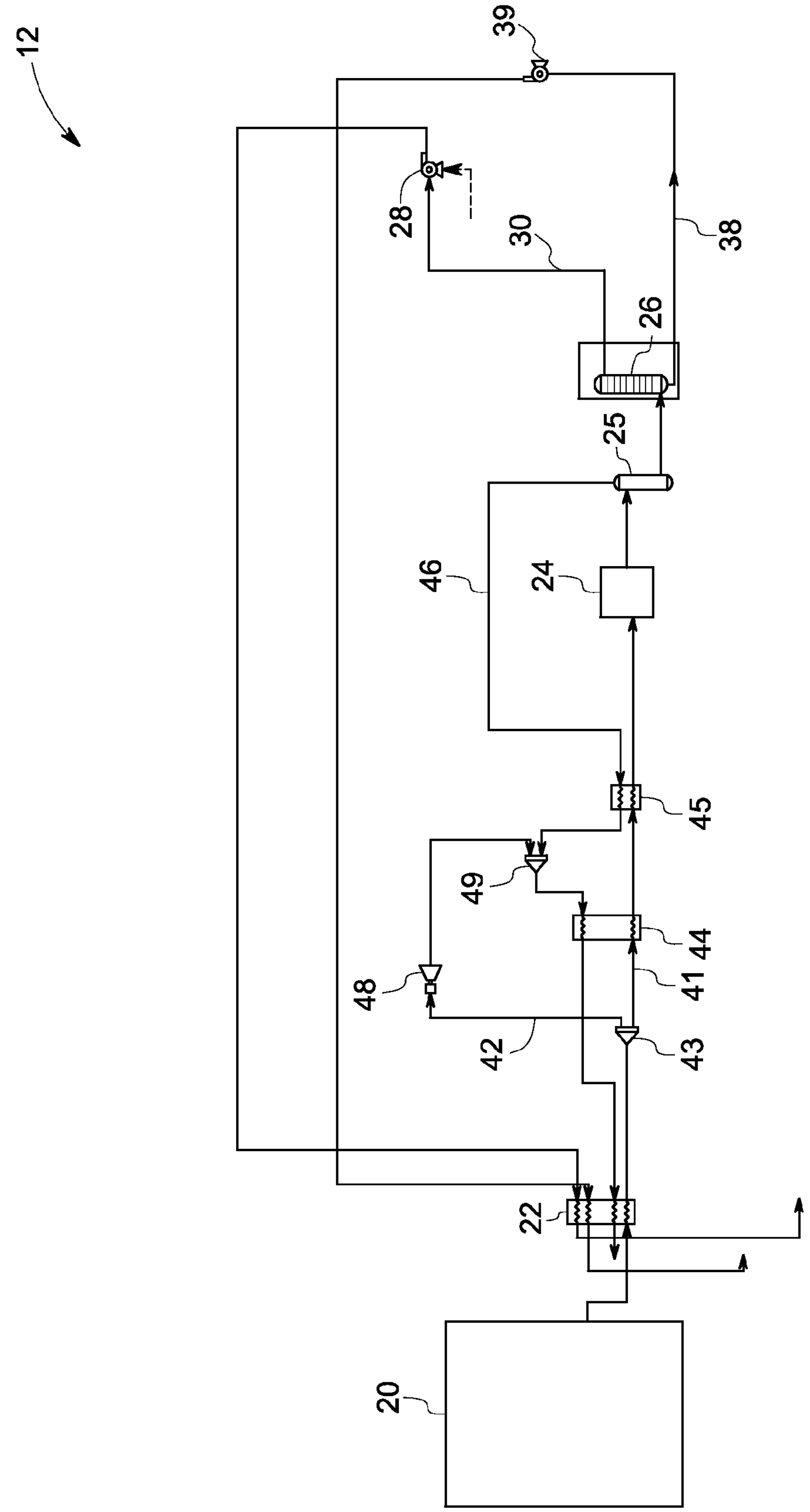

FIG. 3

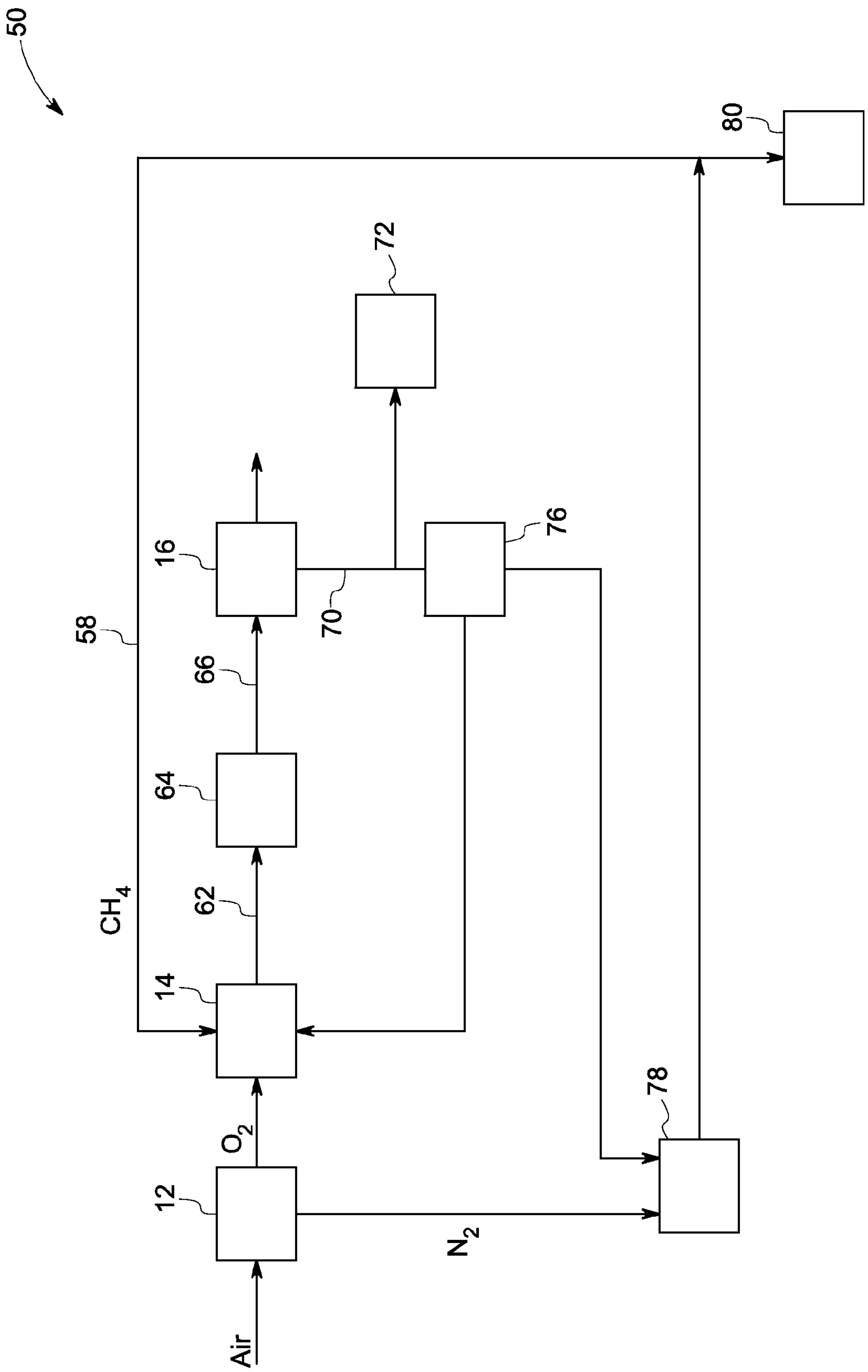

FIG. 4