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(54) **UTILIZATION OF LOW GRADE HEAT IN A REFRIGERATION CYCLE**

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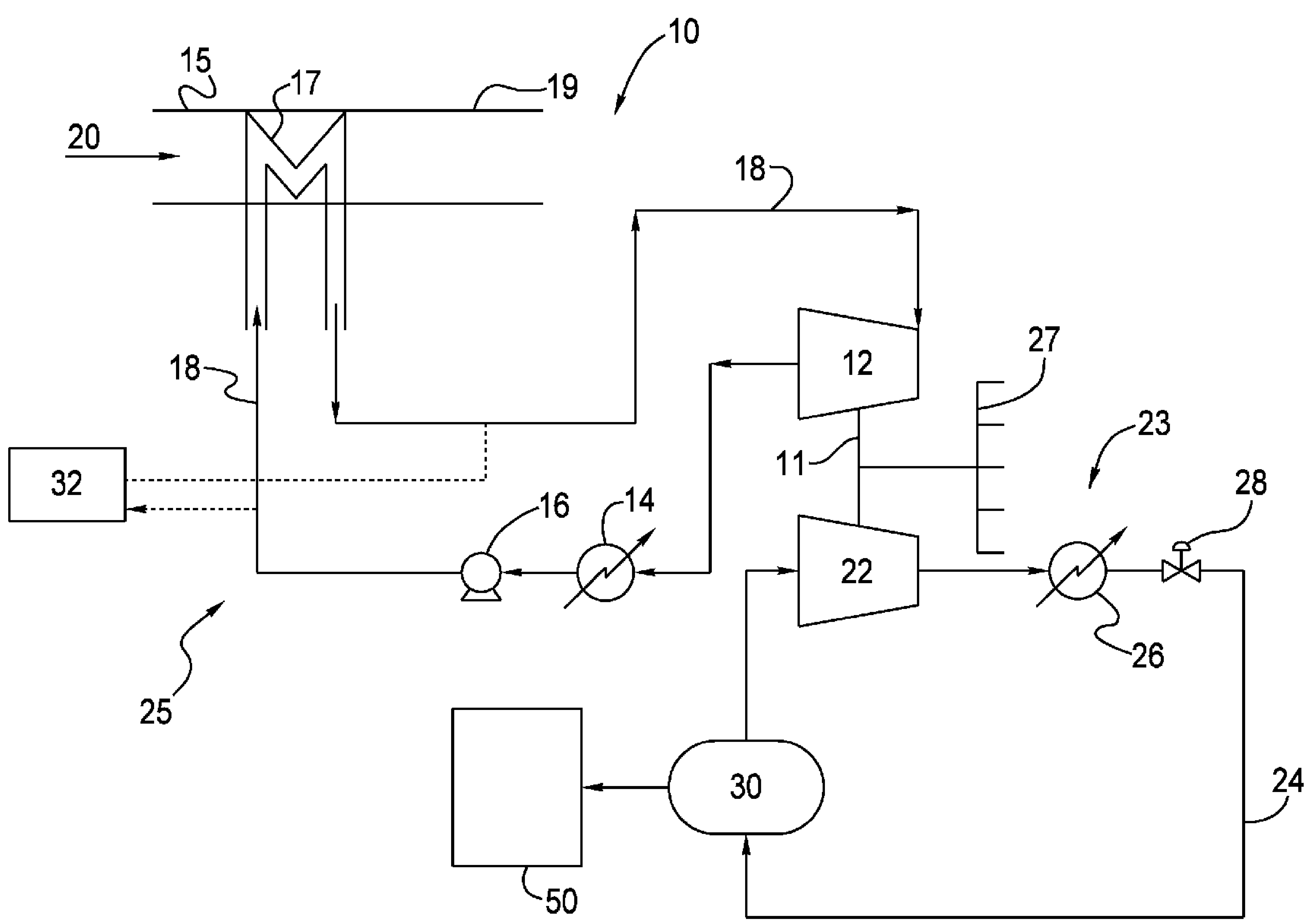
(57) **ABSTRACT**

A system for reducing the power required to cool a combustion gas for cleaning and a method for performing the same are disclosed. The system includes an expander for producing power. Energy in the form of heat is transferred from the combustion gas to a working fluid. The working fluid drives the expander to generate at least a portion of the power required for performing to drive a compressor in a refrigeration system. After the combustion gas transfers energy the combustion gas is cooled with the refrigeration system. In some embodiments the expander and the compressor are arranged along a common shaft.



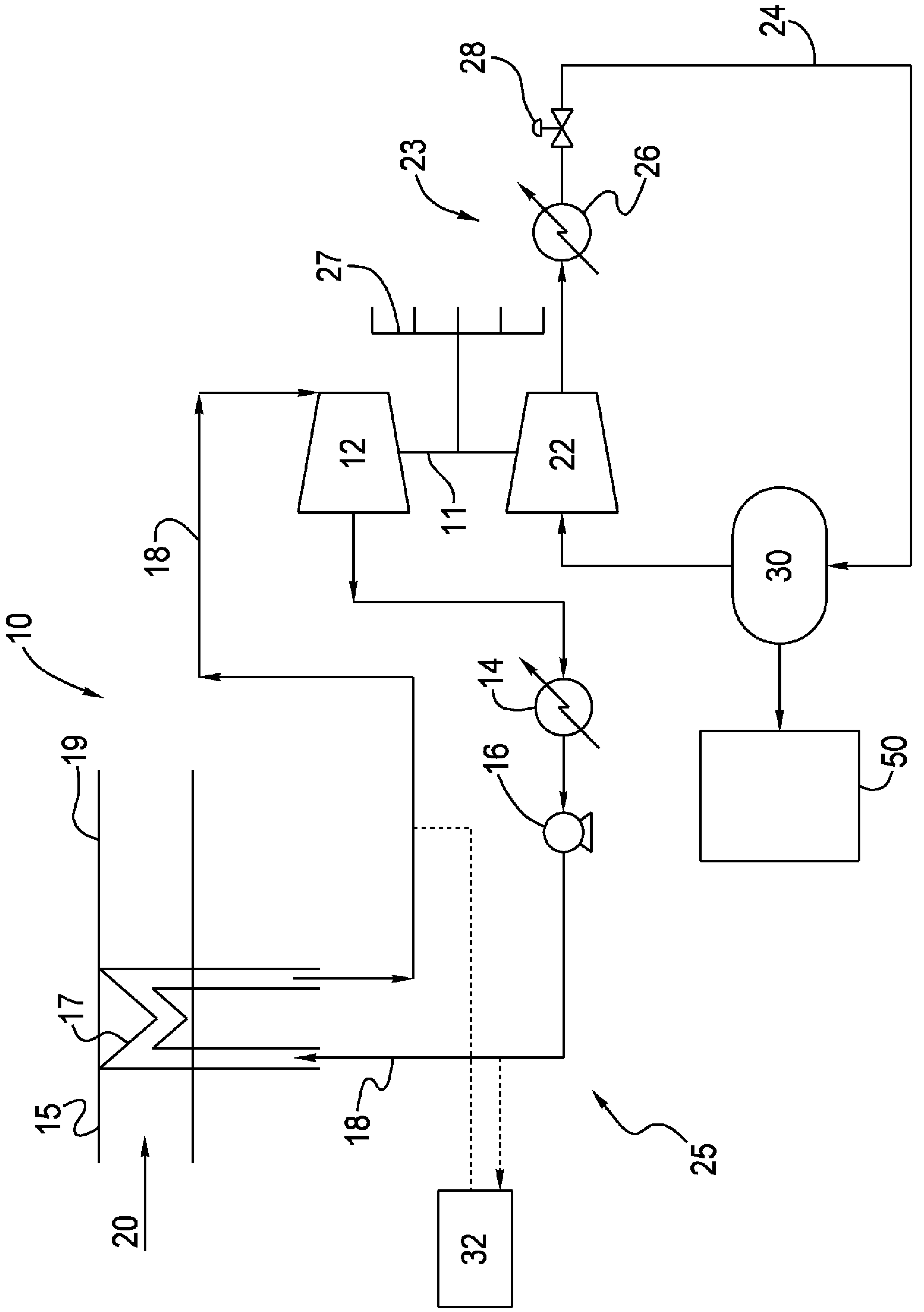


FIG. 1

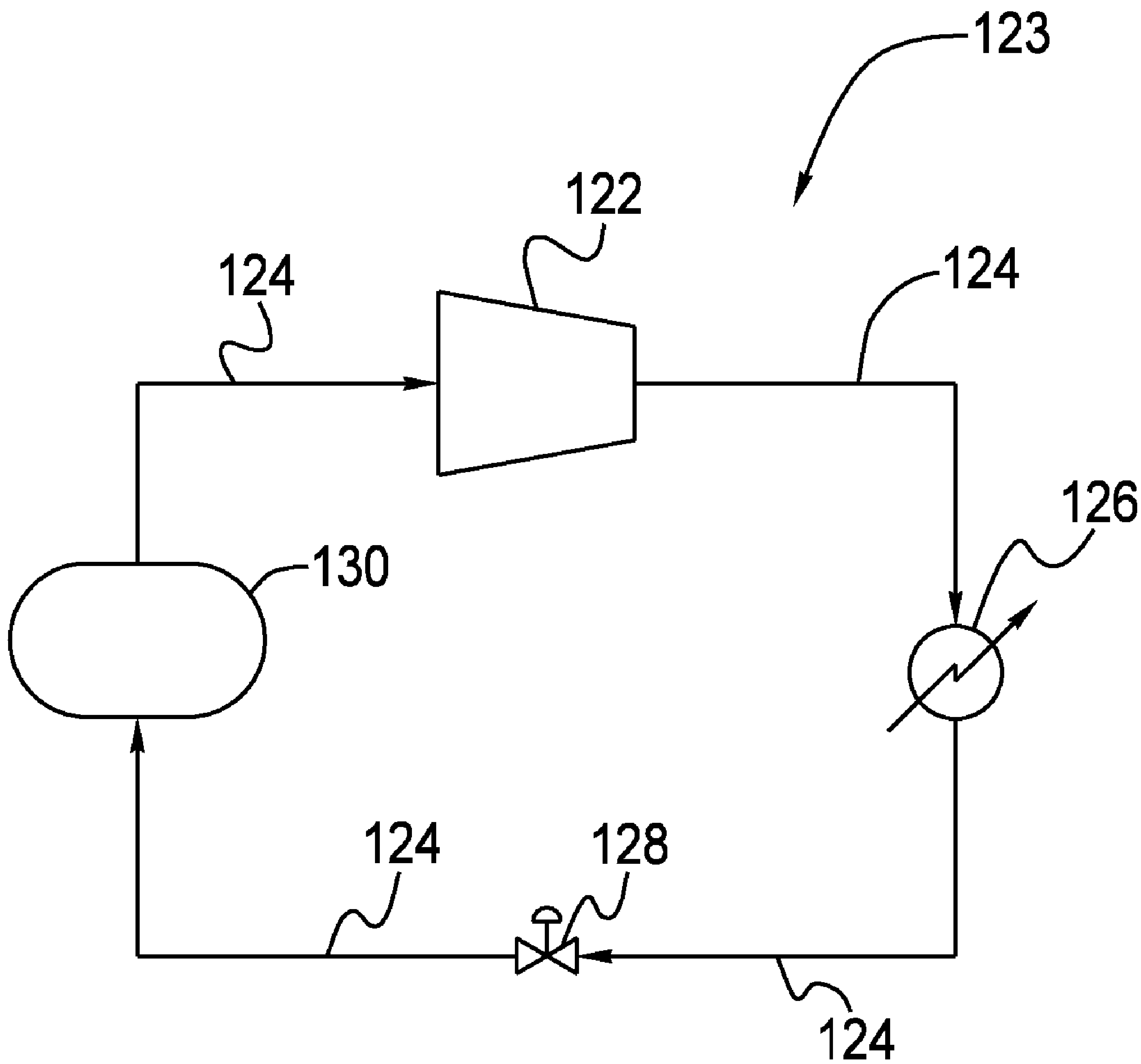


FIG. 2

Prior Art

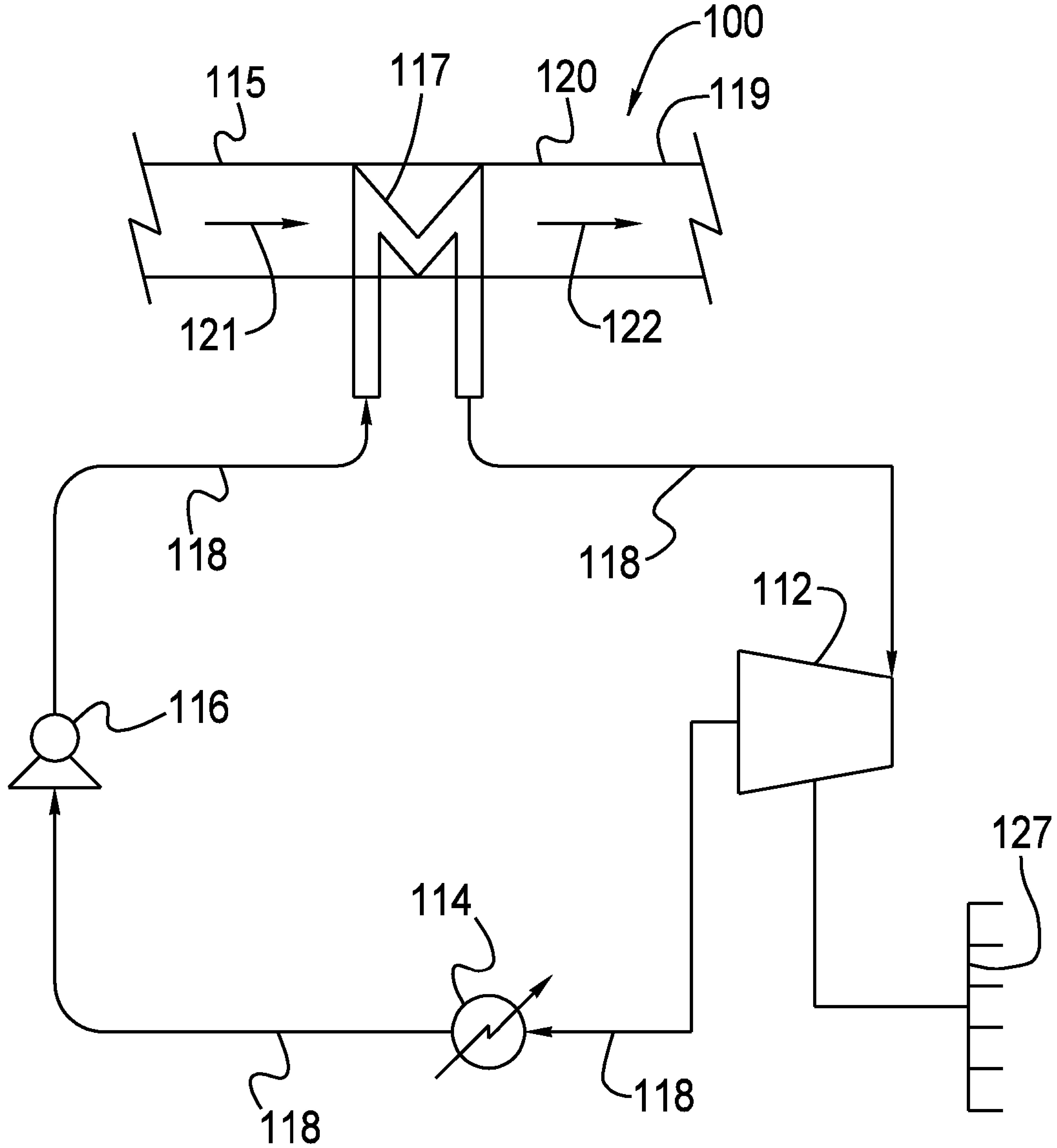


FIG. 3

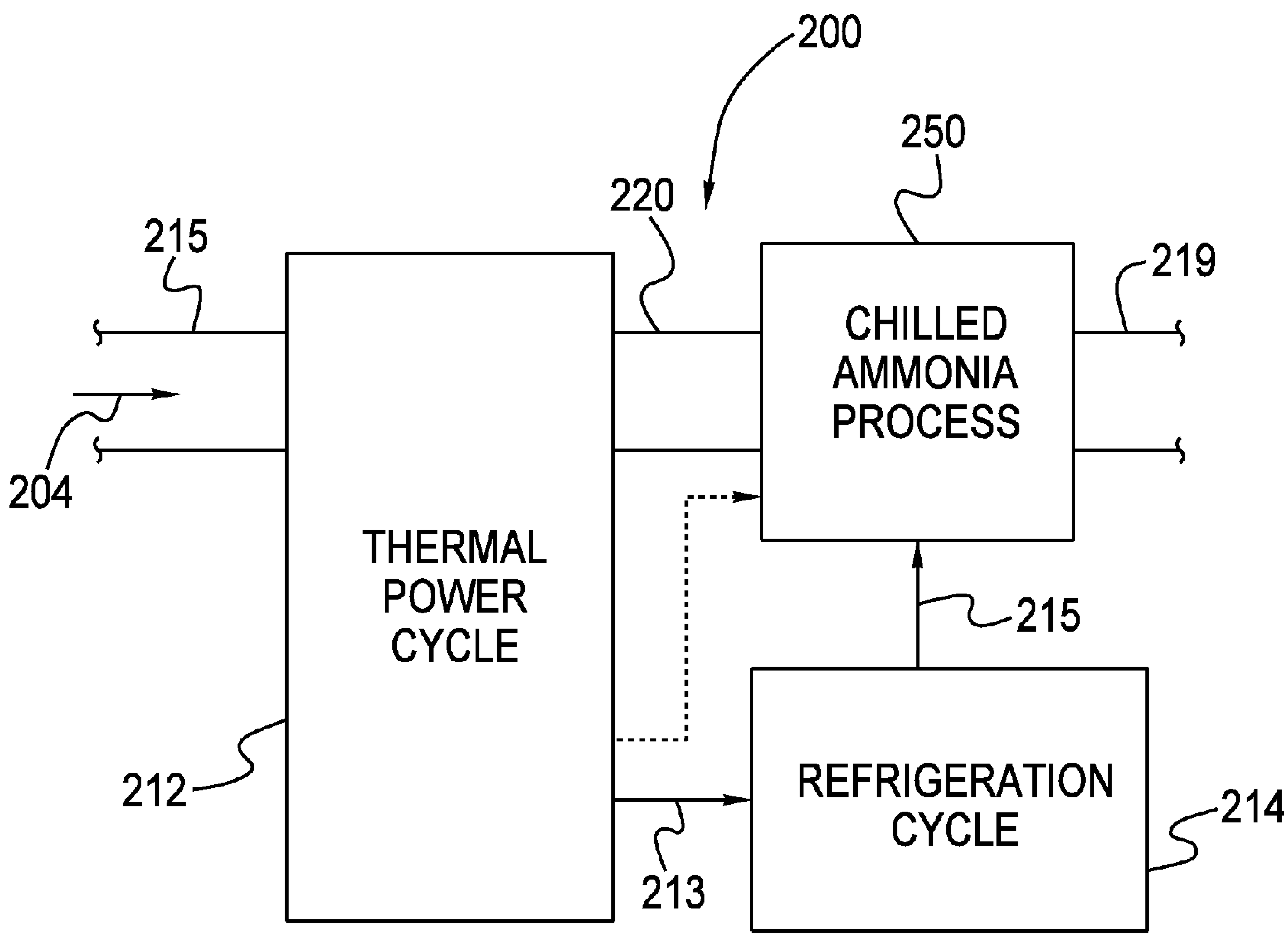

200
250
220
215
219
CHILLED
AMMONIA
PROCESS
204
THERMAL
POWER
CYCLE
215
212
REFRIGERATION
CYCLE
214
213

FIG. 4

UTILIZATION OF LOW GRADE HEAT IN A REFRIGERATION CYCLE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit under 35 U.S.C. §119 (e) of the Provisional Patent Application Ser. No. 61/295,334 filed Jan. 15, 2010.

FIELD

[0002] The present disclosure is generally directed to increasing the efficiency of carbon capture systems. More specifically, the present disclosure is directed to reducing the power consumed during a refrigeration cycle required to perform a carbon capture process. More specifically the present disclosure is directed to a system and method for reducing the power required to perform the Chilled Ammonia Process by using low grade heat.

BACKGROUND

[0003] Most of the energy used in the world today is derived from the combustion of carbon and hydrogen containing fuels such as coal, oil and natural gas. In addition to carbon and hydrogen, these fuels contain oxygen, moisture and contaminants such as ash, sulfur, nitrogen compounds, chlorine, mercury and other trace elements. Awareness of the damaging effects of the contaminants released during combustion triggers the enforcement of ever more stringent limits on emissions from power plants, refineries and other industrial processes. There is an increased pressure on operators of such plants to achieve near zero emission of contaminants and to reduce CO_2 emission.

[0004] The art teaches various processes and technologies designed to reduce the emission of contaminants from combustion gases. Baghouses, electrostatic precipitators and wet scrubbers are typically used to capture particulate matter, various chemical processes are used to reduce sulfur oxides, HCl and HF emissions, combustion modifications and NO_x reduction processes are used to reduce NO_x emission and processes are being developed to capture mercury and other trace elements from combustion gas.

[0005] Significant progress has been made in the last 20-35 years and plants today are a lot cleaner and safer to the environment than in the past. However, there are growing indications that even small concentrations of particulate matter and especially the very fine, less than 2.5 micron size particles (PM2.5), sulfur oxides, acid mist and mercury are harmful to human health and need to be controlled. In addition, in the last few years, there is a growing concern related to the accumulation of CO_2, a greenhouse gas, in the atmosphere. The accelerated increase of CO_2 concentration in the atmosphere is attributed to the growing use of fuels, such as coal, oil and gas, which release billions of tons of CO_2 to the atmosphere every year.

[0006] Reduction in CO_2 emission can be achieved by improving efficiency of energy utilization, by switching to lower carbon concentration fuels and by using alternative, CO_2 neutral, energy sources. However, short of a major breakthrough in energy technology, CO_2 emitting fuels will continue to be the main source of energy in the foreseeable future. Consequently, a low cost low energy consuming process for capturing and sequestering CO_2 is needed to reverse the trend of global warming.

[0007] One such process for capturing and sequestering CO_2 is the proprietary Chilled Ammonia Process ("CAP") developed by Alstom Power. The chilled ammonia capture method developed by Alstom could remove up to 90% of CO_2 from combustion gases. The Chilled Ammonia Process is described in United States Patent Application No. 2008/0072762. That application is incorporated by reference herein.

[0008] In the Chilled Ammonia Process, ultra cleaning of combustion gas to near zero concentration of residual contaminants followed by the capture of CO_2 is provided. The high removal efficiency of residual contaminants is accomplished by direct contact cooling and scrubbing of the gas with cold water. Through this chilling, the temperature of the combustion gas is reduced to 0-20 degrees Celsius to achieve maximum condensation and gas cleaning effect. The CO_2 is then captured from the cooled and clean flue gas in a CO_2 absorber utilizing an ammoniated solution or slurry in the NH_3—CO_2H_2O system. The absorber operates at 0-20 degrees Celsius. Regeneration is accomplished by elevating the pressure and temperature of the CO_2-rich solution from the absorber. The CO_2 vapor pressure is high and a pressurized CO_2 stream, with low concentration of NH_3 and water vapor is generated. The high pressure CO_2 stream is cooled and washed to recover the ammonia and moisture from the gas.

[0009] As discussed above, the first step of the Chilled Ammonia Process is scrubbing and cooling the gas with cold water to reduce the temperature of the gas to 0-20 degrees Celsius thereby achieving maximum condensation and gas cleaning effect. The combustion gas is cooled by passing the gas by Direct Contact Coolers (DCC). The coolers use chilled water to contact and cool the gas. The water is chilled using one or more refrigeration systems. The chilled water is then fed through the DCC which reduces the temperature of the combustion gas, washes and scrubs the gas, captures residual contaminants in the gas, and lowers the moisture content of the gas. It should be understood that different variations are of the Chilled Ammonia process are known. As used in this application, the Chilled Ammonia Process refers generally to any carbon capture process that includes the steps of cooling a combustion gas and using an ammoniated solution or slurry to remove CO_2 from the chilled gas.

[0010] A disadvantage of this known system for reducing CO_2 in combustion gases is that the refrigeration systems required for cooling the combustion gases require a significant amount of power. The necessary consumption of power materially decreases the efficiency of the power plant and increases the overall per unit cost of electricity produced by the power plant. This serves as an incentive against adopting carbon capture systems such as the Chilled Ammonia Process. In addition to the refrigeration systems, additional equipments in the Chilled Ammonia Process consume significant amounts of power, thereby further reducing the overall efficiency of the power plant.

[0011] In the Chilled Ammonia Process combustion gases are cooled with water chilled by one or more refrigeration systems. The water is chilled using vapor compression-direct expansion refrigeration cycles. In reference to FIG. **2**, a known vapor compression-direct expansion refrigeration cycle **123** is shown. The system includes a conduit **124** providing fluid communication between four elements: a compressor **122**, a condenser **126**, a throttle **128**, and an evaporator **130**. A refrigerant, i.e. working fluid, circulates in the conduit **124**. The working fluid, for example Freon, enters the compressor **122** as a vapor. The compressor **122** consumes power to isentropically compress the vapor. The working fluid exits the compressor **122** as a high pressure vapor and flows to the condenser **126**. In the condenser **126** heat is rejected from the working fluid at constant pressure. The working fluid exits the condenser **126** as saturated liquid. Next, the working fluid passes through the expansion valve **128** (also called a throttle valve). The expansion value **128** abruptly decreases the pressure of working fluid, causing flash evaporation and auto-refrigeration. The liquid-vapor mixture then travels through the evaporator **130** and is completely vaporized. The vaporization absorbs surrounding energy, thereby providing the required cooling effect. The absorption of energy during this step is used to chill the water for cooling the combustion gases. The resulting working fluid returns to the compressor **122**, thereby completing the refrigeration cycle **123**. The refrigeration cycle **123**, and specifically the compressor **122**, consumes significant power, thereby reducing the overall efficiency of the power plant.

[0012] Another disadvantage of known implementations of the Chilled Ammonia Process is that they do not take advantage of other available available latent energy sources such as CO_2 compressor intercooling, Wet Flue Gas Desulfurization (WFGD) hydrocyclone overflow, or heat from a Direct Contact Condenser.

[0013] What is desired therefore is a system and a method for reducing the power required to perform the Chilled Ammonia Process for cleaning a combustion gas. The system includes an expander for producing power. The expander has a first working fluid. A low grade heat source transfers energy to the first working fluid in the form of heat. The working fluid drives the expander thereby generating at least a portion of the power required for performing the Chilled Ammonia Process for cleaning combustion gases.

SUMMARY

[0014] A system for reducing the power required for cooling a combustion gas using a cleaning process such as the Chilled Ammonia Process is disclosed. The system includes an expander for producing power. The expander has a first working fluid. The system further includes a low grade heat source. The low grade heat source is harnessed so that energy from the heat source is transferred to the first working fluid. The first working fluid flows into the expander and generates at least a portion of the power required for performing the Chilled Ammonia Process for cleaning the combustion gas. The power generated by the expander offsets the requirement for external electrical power required cool the combustion gas in the Chilled Ammonia Process, thereby reducing the power required to perform the Chilled Ammonia Process. It should be understood that the power generated by the expander may be used to reduce the power required by different equipment and processes used to clean combustion gases.

[0015] In one embodiment the low grade heat source comprises combustion gas or gases generated in the combustion of fuel, for example coal, oil, or natural gas In yet other embodiments the low grade heat source may be derived from CO_2 compressor intercooling, Wet Flue Gas Desulfurization (WFGD) hydrocyclone overflow, or heat from a Direct Contact Condenser. In some embodiments of the present disclosure the low grade heat source may comprise one or more of the above sources.

[0016] In yet a further embodiment, the combustion gases that serve as the low grade heat source are subsequently treated with the Chilled Ammonia Process to clean the combustion gases.

[0017] In yet a further embodiment of the present disclosure, the power generated by the expander provides a least a portion of the power required to drive a compressor of the refrigeration system that is employed in the Chilled Ammonia Process or other gas cleaning process. In yet further embodiments of the present disclosure a least a portion of the power generated by the expander is used to power other elements of the Chilled Ammonia Process or other gas cleaning process.

[0018] In yet further embodiments of the present disclosure, the expander and the compressor are combined to form a coupled compressor-expander assembly. In some embodiments the coupled compressor-expander assembly is arranged along a common drive shaft. The rotational work provided by the expander is transferred to the compressor, thereby reducing or eliminating the requirement for external electrical power for driving the compressor. In some embodiments the coupled compressor-expander generates electricity which is then transmitted to an electrical grid. In yet further embodiments the expander is not coupled to the compressor. The expander, which may comprise a turbine, is connected to an external power grid. The expander generates electricity which may be used to reduce the power for performing one or more steps of the Chilled Ammonia Process.

[0019] In some embodiments of the present disclosure the expander is one component in a thermal power cycle. The thermal power cycle operates using a first working fluid. The compressor is part of a contained refrigeration cycle having using a second working fluid. In some embodiments, the first working fluid and the second working fluid are the same. In yet other embodiments the first working fluid and the second working fluid are different. In yet other embodiments the thermal power cycle and the refrigeration cycle are integrated, sharing the same working fluid. In yet further embodiments the thermal power cycle and the refrigeration cycle use the same condenser.

[0020] The disclosure and its particular features and advantages will become more apparent from the following detailed description considered with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Referring now to the figures which are exemplary embodiments and wherein like elements are numbered alike:

[0022] FIG. **1** is a schematic illustrating one embodiment of the present disclosure.

[0023] FIG. **2** is a schematic illustrating a refrigerant cycle according to one embodiment of the present disclosure.

[0024] FIG. **3** is a schematic illustrating a thermal power cycle according to one embodiment of the present disclosure.

[0025] FIG. **4** is a schematic illustrating one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0026] In reference to FIG. **4**, a schematic of one embodiment of the present disclosure is shown and is generally referred to with reference numeral **200**. In reference to FIG. **4**, a flue **220** of an industrial power plant is shown. The flue has an upstream end (first end) **215** and a downstream end (second end) **219**. A gas stream **204** flows from the upstream end

215 to downstream end 219. The burning of fuel such as coal, oil, and natural gas produces the combustion gas (i.e. gas stream 204). The gas stream 204 typically enters the flue at a temperature range of 100-200 degrees Celsius. In this application the combustion gases may be referred to as a low grade heat or as a latent heat source.

[0027] In reference to FIG. 4, a thermal power cycle 212 harnesses energy from the gas stream 204. Energy from the gas stream 204, i.e a low grade heat source, is transferred to a first working fluid circulating in the thermal power cycle 212. The energy transferred to the first working fluid drives an expander (not shown in FIG. 4). The expander may be, for example, a turbine. The expander generates power. This power is transmitted to the refrigeration cycle 214.

[0028] As discussed above, the Chilled Ammonia Process 250 requires significant power to reduce the temperature of the gas stream 204 to between 0-20 degrees Celsius. The refrigeration cycle 214 is used to chill water, which in turn is used to reduce the temperature of the gas stream 204. Significant electrical power is consumed in the refrigeration cycle 214 to power a compressor. The power generated by the thermal power cycle 212 and transferred to the refrigeration cycle 214 reduces, and in some cases may eliminate, the need for external electric power to drive the compressor. The water chilled by the refrigeration cycle 214 is used by the Chilled Ammonia Process 250 to reduce the temperature of the gas stream. In some embodiments of the present disclosure, the thermal power cycle 212 generates additional power. The additional power may be transmitted to other pieces of equipment required to perform the Chilled Ammonia Process 250. In addition to generating power for use in the Chilled Ammonia Process 250, the thermal power cycle 212 may additionally reduce the temperature of the gas stream 204 as heat is transferred from the gas stream 204 to the first working fluid, thereby further increasing the overall efficiency of the system 200.

[0029] In reference to FIG. 3, a thermal power cycle 100 in accordance with one embodiment of the present disclosure is shown. Combustion gases from a coal boiler or other energy source are expelled into a flue 120 at first end 115. The gas stream 121 flows to the second end of the flue 119. In the embodiment shown, the thermal power cycle 100 is a closed system. The system comprises a number of elements 112, 114, 116, 117. These elements are in fluid communication via conduit 118. A refrigerant fluid, i.e. working fluid, flows through the conduit 118 and through the different elements of the thermal power cycle 100. It should be understood that fluid, as that term is used in reference to both the thermal power cycle and the refrigeration cycle, can refer to different phases of matter or combinations thereof.

[0030] Heat from the gas stream 121 is transferred to the working fluid via a heat exchanger 117. Typically the working fluid enters the heat exchanger 117 as a liquid. Energy in the form of heat is transferred from the gas stream 121 to the working fluid. The heat transferred from the gas stream 121 causes the working fluid to vaporize and increase in pressure. The high pressure vaporized working fluid is then fed via the conduit 118 into an expander 112. In some embodiments of the present disclosure the expander 112 comprises an expansion turbine. The working fluid 118 expands in the expander 112, causing a reduction in the working fluid pressure 118 and rotatably driving the expansion turbine 112. The rotating turbine can be used to generate electricity. For example, the expander 112 is connected to a power grid 127. In other embodiments of the present disclosure, the power generated at the expander 112 is transmitted to another component via a common drive shaft.

[0031] The lower pressure refrigerant exits the expansion turbine 112 and is introduced into a condenser 114 in fluid communication with the expander 112. The vaporized working fluid is liquefied as it passes through the condenser 114. After the working fluid exits the condenser 114 it is pushed through the conduit via a pump 16, the pump 116 being in fluid communication with the condenser 114. The pump 116 moves the working fluid 118 through the conduit 118 and through the heat exchanger 117, thereby completing the thermal power cycle 100.

[0032] In reference to FIG. 2, a known vapor compression-direct expansion refrigeration cycle 123 is shown. In this refrigeration cycle, a circulating refrigerant, i.e. working fluid, circulates in a closed circuit 124. The working fluid, for example Freon, enters the compressor 122 as a vapor. The compressor 122 consumes electric power to isentropically compress the vapor. The working fluid exits the compressor 122 as a high pressure vapor and flows to the condenser 126. In the condenser 126 heat is rejected from the circulating refrigerant at constant pressure. The circulating refrigerant leaves the condenser 126 as saturated liquid. Next, the working fluid passes through the expansion valve 128 (also called a throttle valve). The expansion value 128 abruptly decreases the pressure of the working fluid, causing flash evaporation and auto-refrigeration. The cold liquid-vapor mixture then travels through the evaporator 130 and is vaporized. The vaporization absorbs surrounding energy, thereby cooling the surrounding air. The absorption of energy by the working fluid during this step is used to chill the water for cooling the combustion gases. The resulting working fluid returns to the compressor 122 inlet to complete the refrigeration cycle 123.

[0033] In reference to FIG. 1, a system and method in accordance with one embodiment of the present disclosure is shown. The system includes a thermal power cycle 25 and a refrigeration cycle 23 similar to those discussed above. The thermal power cycle 25 includes a heat exchange 17, an expander 12, a condenser 14, and a pump 16. The elements of the thermal power cycle 25 are in fluid communication via a conduit 18. A first working fluid flows through the conduit 18 and elements 12, 14, 16, 18. The expander 12 is connected to electrical grid 27.

[0034] The system 10 further includes the refrigeration cycle 23. The refrigeration cycle 23 includes a compressor 22, a condenser 26, a throttle 28, and an evaporator 30, also referred to as an expansion tank. The evaporator absorbs energy, thereby providing the cooling power for the Chilled Ammonia Process 50.

[0035] Heat is transferred to from the gas stream 20 in the flue 15 to the first working fluid via the heat exchanger 17. The working fluid then enters the expander 12, wherein the captured energy is converted into rotable energy. In the embodiment shown, the expander 12 is an expansion turbine. The turbine rotates a drive shaft 11, which in turn can be used to generate electricity for powering the compressor 22, or some element of the Chilled Ammonia Process 50.

[0036] In some embodiments of the present disclosure, the expander 12 and the compressor 22 are arranged along a common shaft 11. The expander 12 transmits power to refrigeration cycle 23 via the shaft. More specifically, the expander 12 transmits power to the compressor 22 by providing at least a portion of the power required to rotate the compressor 22. In some embodiments of the present disclosure, the expander **12** provides all of the power required to operate the compressor **22**. In yet other embodiments of the present disclosure, the expander **12** powers the compressor **22** and generates additional electricity for use in the Process **50**. In yet other embodiments of the present disclosure the expander **12** provides a portion of the power required to operate the compressor **22**.

[0037] While a first condenser **14** and a second condenser **26** have been shown and described, the disclosure is not limited in this regard. In some embodiments of the present disclosure a single condenser is used for both the first working fluid of cycle **25** and the second working fluid of cycle **23**, thereby reducing the cost of operating the system. In some embodiments the first working fluid and the second working fluid are the same, in yet other embodiments of the present disclosure the first working fluid and the second working fluid are different. In yet other embodiments of the present disclosure the thermal power cycle **25** and the refrigeration cycle **23**, and the conduits therefore **18**, **24** are self contained. In yet other embodiments of the present disclosure, conduits **18**, **24** are in fluid communication.

[0038] While flue gas **20** has been described as the heat source for use in the refrigeration cycle, the present disclosure is not limited in this regard as other sources of heat can be used in place of or in addition to the flue gas. For example, and as schematically illustrated at **32** in FIG. **1**, heat source resulting from CO_2 compressor intercooling or Wet Flue Gas Desulfurization (WFGD) hydrocyclone overflow, and/or heat from a Direct Contact Condenser can also be employed to transfer thermal energy into the refrigerant.

[0039] It should be understood that the foregoing is illustrative and not limiting, and that obvious modifications may be made by those skilled in the art without departing from the spirit of the disclosure. Accordingly, reference should be made primarily to the accompanying claims, rather than the foregoing specification, to determine the scope of the disclosure.

What is claimed is:

1. A system for generating power from a heat source, the system comprising:
- a heat source;
- a first working fluid;
- a heat exchanger arranged relative to the heat source for transferring energy between the heat source and the first working fluid;
- an expander for generating power, the expander in fluid communication with the heat exchanger;
- wherein the first working fluid flows from the heat exchanger to the expander after the first working fluid receives energy from the heat source;
- wherein the first working fluid drives the expander to generate power for operating a compressor.

2. The system of claim **1**, wherein the compressor is part of a refrigeration system for cooling a combustion gas.

3. The system of claim **2**, wherein the expander generates a least a portion of the power required to perform the Chilled Ammonia Process.

4. The system of claim **2**, wherein the combustion gas is the heat source.

5. The system of claim **4**, wherein the combustion gas transfers energy to the first working fluid in the heat exchanger before the refrigeration system cools the combustion gas.

6. The system of claim **2**, wherein the expander and the compressor are arranged to form a coupled compressor-expander assembly.

7. The system of claim **6**, wherein the compressor-expander assembly is arranged along a common shaft.

8. The system of claim **7**, further comprising a second working fluid for driving the compressor.

9. The system of claim **8**, further comprising a condenser, the condenser being in fluid communication with the expander and the compressor,
- wherein the expander and condenser are arranged so that first working fluid flows into the condenser after exiting the expander;
- wherein the compressor and the condenser are arranged so that the second working fluid flows into the condenser after existing the compressor.

10. The system of claim **9**, wherein the first working fluid and the second working fluid are the same.

11. The system of claim **1**, wherein the heat source is one or more of a combustion gas, CO_2 compressor intercooling, Wet Flue Gas Desulfurization (WFGD) hydrocyclone overflow, or heat from a Direct Contact Condenser.

12. A method for generating power from a heat source, the method comprising the steps of:
- providing a heat source;
- providing a first working fluid;
- transferring energy from the heat source to the first working fluid using a heat exchanger;
- providing an expander for generating power, the expander being in fluid communication with the heat exchanger;
- driving the expander with the first working fluid to generate power;
- operating a compressor with power generated by the expander.

13. The method of claim **12**, further including the step of:
- cooling the combustion gas with a refrigeration system;
- wherein the compressor is a component of the refrigeration system.

14. The method of claim **13**, further comprising the step of:
- performing the Chilled Ammonia process on the combustion gas, wherein the expander generates a least a portion of the energy required to perform the Chilled Ammonia Process.

15. The method of claim **13**, wherein the heat source comprises the combustion gas.

16. The method of claim **15**, wherein the step of transferring energy from the combustion gas to the first working fluid occurs before the combustion gas is cooled with the refrigeration system.

17. The method of claim **13**, wherein the expander and the compressor are arranged to form a coupled compressor-expander assembly.

18. The method of claim **17**, wherein the compressor-expander assembly is arranged along a common shaft.

19. The method of claim **18**, further comprising the step of:
- providing a second working fluid for driving the compressor.

20. The method of claim **19**, further comprising the step of:
- providing a condenser, the condenser being in fluid communication with the expander and the compressor,
- wherein the first working fluid flows into the condenser after exiting the expander;
- wherein the second working fluid flows into the condenser after existing the compressor.

21. The method of claim **20**, wherein the first working fluid and the second working fluid are the same.

22. The method of claim **12**, wherein the heat source is one or more of a combustion gas, CO_2 compressor intercooling, Wet Flue Gas Desulfurization (WFGD) hydrocyclone overflow, or heat from a Direct Contact Condenser.

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