

TITLE OF THE INVENTION

COMBINED CYCLE POWER GENERATION SYSTEM

TECHNICAL FIELD

[0001]

5 The present invention relates to a combined cycle power generation system, and in particular to a gas engine composite power generation system that generates electric power by utilizing waste heat of a gas engine.

BACKGROUND OF THE INVENTION

[0002]

10 In recent years, the combined cycle power generation system has come to be widely used. The combined cycle power generation system improves the power generating efficiency of an internal combustion engine power generation system by using the waste heat of the internal combustion engine to generate electric power. For instance, a known combined cycle power generation system comprises a gas turbine that
15 is powered by combustion gas and a steam turbine that is powered by steam generated by the waste heat of the gas turbine such that the Rankin cycle of the steam turbine using steam as the working fluid uses the waste gas of the gas turbine as a heat source and the power generating efficiency is thereby increased. See Patent Document 1.

[0003]

20 PRIOR ART DOCUMENT(S)

PATENT DOCUMENT(S)

Patent Document 1: JP2005-207259

SUMMARY OF THE INVENTION

TASK TO BE ACCOMPLISHED BY THE INVENTION

25 [0004]

In a combined cycle power generation system using a gas engine, a large part of the waste heat of the gas engine is available in two different temperature levels (engine exhaust gas at 400 to 500 °C and cooling water in the engine water jacket at 85 °C, for instance), and it is highly essential to make best use of such waste heat for maximizing the power generating efficiency and minimizing carbon dioxide emission.

5 [0005]

When the prior art disclosed in Patent Document 1 is applied to a gas engine combined cycle power generation system, the heat from the cooling water in the engine water jacket having a relatively low temperature cannot be effectively used. Also,

10 according to this prior art, because the working fluid consists of steam, a cold source having a temperature lower than the water freezing point (such as the cold of LNG (liquefied natural gas), the brine cold of a refrigeration system, etc.) cannot be used in the cooling process for the working fluid so that the problem of failing to effectively utilize low temperature waste heat is left unresolved.

15 [0006]

The present invention was made in view of such a problem of the prior art, and has a primary object to provide a combined cycle power generation system that allows the power generating efficiency to be improved by effectively utilizing the waste heat of a gas engine.

20 MEANS TO ACCOMPLISH THE TASK

[0007]

To achieve such an object, a first aspect of the present invention provides a combine cycle power generation system, comprising: a gas engine (2) using combustible gas for fuel thereof; a first power generator (4) driven by the gas engine; a

25 refrigerant turbine (3) using hydrocarbon refrigerant for working fluid thereof; a second

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power generator (5) driven by the refrigerant turbine; a first heater (31) for heating the refrigerant using cooling liquid for the gas engine as a heat source thereof; a second heater (11) for further heating the refrigerant heated by the first heater by using exhaust gas of the gas engine as a heat source; and a condenser (22) for condensing the
5 refrigerant expelled from the refrigerant turbine.

[0008]

According to this aspect of the present invention, the refrigerant turbine that uses hydrocarbon refrigerant as working fluid thereof makes use of the waste heat of the gas engine (heat of the exhaust gas and cooling liquid) so that the efficiency of
10 recovering the waste heat from the gas engine can be increased, and the power generating efficiency of the system can be improved.

[0009]

A second aspect of the present invention provides a combine cycle power generation system, comprising: a gas engine (2) using combustible gas for fuel thereof;
15 a first power generator (4) driven by the gas engine; a refrigerant turbine (3) using hydrocarbon refrigerant for working fluid thereof; a second power generator (5) driven by the refrigerant turbine; a first heater (11A) for heating the cooling liquid of the gas engine using exhaust gas from the gas engine as a heat source thereof; a second heater (31A) for heating the refrigerant using the cooling liquid heated in the first heater as a
20 heat source thereof; and a condenser (22) for condensing the refrigerant expelled from the refrigerant turbine.

[0010]

According to this aspect of the present invention, the refrigerant turbine that uses hydrocarbon refrigerant as working fluid thereof makes use of the waste heat of the
25 gas engine (heat of the exhaust gas and cooling liquid) so that the efficiency of

recovering the waste heat from the gas engine can be increased, and the power generating efficiency of the system can be improved. Also, because the combustible hydrocarbon refrigerant does not directly exchange heat with the exhaust gas of the gas engine, and the refrigerant gas is heated by using the cooling liquid which is heated by the exhaust gas of the gas engine as a heat source, the safety of the system can be enhanced.

[0011]

According to a third aspect of the present invention, the condenser is configured to condense the refrigerant by using liquefied natural gas.

10 [0012]

Thereby, the cold of the LNG delivered from the LNG station can be effectively used for cooling the working fluid.

[0013]

According to a fourth aspect of the present invention, the combustible gas consists of boil off gas of liquefied natural gas.

[0014]

Thereby, the boil off gas generated from the LNG station can be effectively used without requiring the adjustment of the calorific value by mixing LP gas or the like as in the utility gas.

20 [0015]

According to a fifth aspect of the present invention, the condenser is configured to condense the refrigerant by using brine.

[0016]

Thereby, the brine can be cooled by using steam or the like having a relatively low pressure (0.2 to 0.7 MPaG, for instance) expelled from a plant or the like so that the

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waste heat of the plant can be effectively utilized.

[0017]

According to a sixth aspect of the present invention, the refrigerant consists of a mixture of methane and propane.

5 [0018]

By adjusting the mix ratio of propane and methane, the working fluid can be easily and appropriately adapted to the low temperature level and the high temperature level of the Rankin cycle in the refrigerant turbine.

[0019]

10 Thus, the waste heat of a gas engine can be effectively utilized, and the efficiency of power generation can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

Figure 1 is a simplified diagram showing a gas engine combined cycle power generation system 1 given as a first embodiment of the present invention;

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Figure 2 is a simplified diagram showing a gas engine combined cycle power generation system 1 given as a second embodiment of the present invention;

Figure 3 is a simplified diagram showing a gas engine combined cycle power generation system 100 given as a third embodiment of the present invention; and

20 Figure 4 is a conventional combined cycle power generation system 201 using a gas turbine.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021]

Preferred embodiments of the present invention are described in the following with reference to the appended drawings.

25

[0022]

<First Embodiment>

Figure 1 is a simplified diagram showing a gas engine combined cycle power generation system 1 given as a first embodiment of the present invention. The combined cycle power generation system 1 comprises a gas engine 2 consisting of an internal combustion engine using combustible gas for fuel thereof and a refrigerant turbine 3 using hydrocarbon refrigerant having a relatively low boiling point (lower than that of water) for working fluid thereof. In this combined cycle power generation system 1 which is provided in conjunction with an LNG base 6 for delivering LNG to urban consumers as utility gas, electric power is generated by a first power generator 4 and a second power generator 5 which are driven by the gas engine 2 and the refrigerant turbine 3, respectively,

[0023]

The gas engine 2 receives boil off gas (BOG) produced from the LNG base 6 as at least a part of the fuel thereof, and the exhaust gas of the gas engine 2 produced as a result of a combustion process therein and having a relatively high temperature (410 °C in this case) is expelled to a heat exchanger 11 for recovering the waste heat therefrom. The gas engine 2 is provided with a water jacket (not shown in the drawing) for cooling the engine, and cooling water of a relatively low temperature (88 °C in this case) is expelled from the water jacket. The expelled cooling water is circulated in a cooling water circulation line 13 including a cooling water pump 12 in the direction indicated by arrows in Figure 1, and is returned to the water jacket. The shaft output of the gas engine 2 is converted into electric power by the first power generator 4.

[0024]

The refrigerant turbine 3 uses a mixed refrigerant consisting of methane and

propane (methane 50-55 % by weight and propane 45-50 % by weight in this case) as working fluid thereof. This working fluid is heated by the gas engine exhaust gas in the heat exchanger 11 before being introduced into the refrigerant turbine 3. The heat exchanger 11 includes a plurality of heating units each including a tube bundle so that an efficient heat exchange may be conducted between the gas engine exhaust gas and the working fluid. The working fluid (gas) of a prescribed temperature and pressure (103 °C, 4.9 MPaG in this case) is introduced into the refrigerant turbine 3 so that the kinetic energy of the working fluid causes turbine blades (not shown in the drawing) to rotate, and the shaft output thereof is converted into electric power by the second power generator 5.

[0025]

The working fluid (temperature: - 5 °C and pressure: 0.4 MPaG in this case) expelled from the refrigerant turbine 3 is forwarded to a condenser 22 via a refrigerant circulation line 21 as indicated by an arrow in Figure 1. The condenser 22 is connected to a delivery pipe 23 of the LNG base 6, and the cold of the LNG (temperature: - 160 °C, pressure: 7.0 MPaG and flow rate: 70 t/hr) is used for cooling the working fluid. The heat of the working fluid is used for vaporizing the LNG.

[0026]

The condensed working fluid is stored in a circulated refrigerant tank 25 provided in the refrigerant circulation line 21, and the working fluid pressurized (temperature: -128 °C, pressure: 5.0 MPaG and 99.4 t/hr in this case) by a refrigerant pump 26 provided in the refrigerant circulation line 21 is forwarded to a refrigerant evaporator 27. The refrigerant evaporator 27 is connected to a seawater introduction pipe 28 for introducing seawater (15 °C in this case) so that the working fluid is preheated by exchanging heat with the seawater to a temperature (5 °C in this case)

which will not cause the jacket cooling water to freeze.

[0027]

The working fluid that has exited the refrigerant evaporator 27 is forwarded to a refrigerant heater 31 which heats the working fluid (to 29 °C in this case) by exchanging heat with the jacket cooling water (88 °C, 270 t/hr in this case). The jacket cooling water is cooled in the refrigerant heater 31 to a temperature (50 to 80 °C in this case) which is suitable for cooling the gas engine 2. The working fluid that has exited the refrigerant heater 31 is forwarded to the heat exchanger 11 to be heated therein (103 °C, 4.9 MPaG) before being supplied to the refrigerant turbine 3.

10 [0028]

The LNG supplied from the LNG base 6 is expelled from the condenser 22, and is then forwarded to an LNG heater 32 via the delivery pipe 23. The LNG heater 32 is connected to a seawater introduction pipe 33 for introducing seawater (15 °C in this case) so that the LNG is heated (to gas of 5 °C in this case) by exchanging heat with the seawater before being delivered to urban consumers as utility gas via a utility gas line.

[0029]

In the gas engine 2, the BOG is supplied at the rate of 1.94 t/hr (which amounts to a fuel consumption of 29,600 kW), and the amount of the exhaust gas of the gas engine is 83.2 t/hr. The power generated by the first generator 4 is 13,500 kW, and the power generated by the refrigerant turbine 3 is 4,060 kW. The total power generating efficiency of the combined cycle power generation system 1 is 59.3% (57.2% when the power consumption of the auxiliary equipment is taken into account), and is therefore significantly higher than those of conventional combined cycle power generation systems using gas turbines.

25 [0030]

For comparison, a conventional combined cycle power generation system 201 using a gas turbine is shown in Figure 4. In this combined cycle power generation system 201, BOG (feed rate: 2.02 t/hr, fuel consumption: 30,706 kW, and pressure: 0.02 MPaG) is compressed to 21 MPaG by a fuel gas compressor 202, and introduced into a gas turbine generator 203. The exhaust gas expelled from the gas turbine generator (temperature: 504 °C, flow rate: 136.2 t/hr) is introduced into an exhaust gas boiler 204 for recovering waste heat.

[0031]

In the exhaust gas boiler 204, heat is exchanged between the gas turbine exhaust gas and steam, and the produced high pressure steam (temperature: 482 °C, pressure: 5.4 MPaG, and flow rate: 14.6 t/hr) is introduced into a steam turbine generator 205. The waste steam (temperature: 41 °C, pressure: 0.093 MPaG) from the steam turbine generator 205 is cooled in a condenser 206, and is circulated back to the exhaust gas boiler 204 via a condensate pump 207, a deaerator 208 and a high pressure water pump 209. The cooling water introduced into the condenser 206 is circulated through an air cooled cooling tower 210.

[0032]

In this conventional combined cycle power generation system 201, the power generated by the gas turbine generator is 9,754 kW, and the power generated by the steam turbine generator is 3,656 kW. The total power generating efficiency of this conventional combined cycle power generation system 201 is 47.3% (41.1% when the power consumption of the auxiliary equipment is taken into account).

[0033]

As can be appreciated from the foregoing description, in the combined cycle power generation system 1 of the first embodiment, electric power is generated by a

binary Rankin cycle system in which the gas engine exhaust gas and the jacket cooling water of the gas engine are used as high temperature heat sources for a refrigerant turbine 3 using a mixed refrigerant consisting of methane and propane as working fluid, and the cold of the evaporating LNG is used as a low temperature cold source. The heat of the gas engine exhaust gas and the jacket cooling water which accounts for a large part of the waste heat of the gas engine 2 can be utilized in an effective manner so that the recovery ratio of the waste heat can be increased, and the power generating efficiency of the combined cycle power generation system 1 can be improved. Instead of the jacket cooling water of the gas engine, cooling fluid (coolant) other than water can also be used. Because the mixed refrigerant is combustible, the heating temperature of the heat exchanger 11 is desired to be low (lower than 130 °C, for instance).

[0034]

Also, by using LNG for condensing the working fluid in the condenser 22, the cold of the LNG delivered from the LNG base 6 can be efficiently utilized for cooling the refrigerant. Also, because BOG is used as the fuel gas (or a part thereof) of the gas engine 2, the BOG generated from the LNG base 6 can be efficiently utilized. In this case, the calorific value of the fuel is not required to be adjusted, for instance, by mixing LP gas, as opposed to the case where the LNG gas is used for utility gas. The cold of the LNG can be effectively utilized in the process of cooling the working fluid.

[0035]

<Second Embodiment>

Figure 2 is a simplified diagram showing a gas engine combined cycle power generation system 1 given as a second embodiment of the present invention. In Figure 2, the parts corresponding to those of the first embodiment are denoted with like numerals. In the following description of the second embodiment, the description of the parts

similar to those of the first embodiment are omitted unless specifically discussed in the following.

[0036]

The second embodiment differs from the first embodiment in that the gas
5 engine exhaust gas exchanges heat with the working fluid indirectly via the jacket cooling water. As shown in Figure 2, the jacket cooling water expelled from the gas engine 2 is forwarded to a heat exchanger 11A to be heated therein by exchanging heat with the gas engine exhaust gas. Thereafter, the jacket cooling water (hot water of 150 to 160 °C under pressure in this case) is forwarded to a refrigerant heater 31A via a
10 cooling water circulation line 13 to heat the working fluid. The jacket cooling water cooled in the refrigerant heater 31A is forwarded back to the water jacket of the gas engine by the cooling water pump 12. The working fluid (temperature: 103 °C, pressure: 4.9 MPaG) which has been heated in the refrigerant heater 31A is supplied to a refrigerant turbine 3.

15 [0037]

The combined cycle power generation system 1 of the second embodiment has the advantage of an increased safety because the gas engine exhaust gas does not directly exchange heat with the combustible working fluid.

[0038]

20 <Third Embodiment>

Figure 3 is a simplified diagram showing a gas engine combined cycle power generation system 100 given as a third embodiment of the present invention. In Figure 3, the parts corresponding to those of the first embodiment are denoted with like numerals.

[0039]

25 The gas engine combined cycle power generation system 100 comprises a

refrigerant turbine 3 using a refrigerant consisting of hydrocarbons having low boiling points as the working fluid and a power generator 4 driven by the refrigerant turbine 3, and is placed in conjunction with a plant (such as a petrochemical plant) not shown in the drawings which can provide sources for steam and hot water.

5 [0040]

The working fluid of the refrigerant turbine 3 may consist of a refrigerant such as pure propane and propane mixed with small amounts of ethane and/or butane. The working fluid is heated in the refrigerant heater 131 by exchanging heat with hot water (100 °C, 24.3 Gcal/hr in this case) before being introduced into the refrigerant turbine 3.

10 The hot water may consist of warm water (hot water) or low pressure steam expelled from the plant. As a result, the working fluid at a prescribed temperature and pressure (90 °C, 3 MPaG in this case) is introduced into the refrigerant turbine 3 so that the kinetic energy of the working fluid rotates turbine blades not shown in the drawing, and the shaft output thereof is converted into electric power by the generator 4.

15 [0041]

The working fluid (gas at 20 °C, 0.5 MPaG in this case) expelled from the refrigerant turbine 3 is forwarded to a condenser 122 via a refrigerant circulation line 121 in the direction indicated by an arrow in Figure 3. The condenser 122 is connected to a brine circulation line 42 of a steam absorption refrigerator 41 so that the cold of the introduced brine (ethylene glycol at -8 °C, 21.4 Gcal/hr in this case) may be used for cooling the working fluid. The steam absorption refrigerator 41 uses low pressure steam (saturated steam at 0.5 to 0.7 MPaG, for instance) expelled from the plant as the heat source.

[0042]

25 The working fluid (2 °C) cooled in the condenser 122 is stored in a circulated

refrigerant tank 25 in the refrigerant circulation line 21. Then, the working fluid is pressurized by a refrigerant pump 26, and forwarded back to the refrigerant heater 131. The working fluid (90 °C, 3 MPaG) heated in the refrigerant heater 131 once again is supplied to the refrigerant turbine 3.

5 [0043]

In the combined cycle power generation system 100 of the third embodiment, because the hot water expelled from the plant is used as a high temperature heat source, and the cold of the brine of the steam absorption refrigerator 41 using the low pressure steam expelled from the plant is used as a low temperature cold source, for generating
10 electric power, the advantage of not requiring any additional fuel (such as LNG) can be gained as opposed to the first and second embodiments. The condenser 122 may also use chiller water obtained from the plant, instead of the brine.

[0044]

The combined cycle power generation system 100 can achieve a highly
15 efficient power generation because the refrigerant expelled from the refrigerant turbine is condensed by using the brine. For comparison, suppose that the hot water introduced into the refrigerant heater 131 and the working fluid introduced into the refrigerant turbine 3 are the same as in the previous embodiments, and cooling water (25 °C, 22.6 Gcal/hr) is introduced into the condenser 122 instead of the brine. In this case, the
20 working fluid has a temperature of 50 °C and a pressure of 1.2 MPaG, and is cooled by the cooling water in the condenser 122. The cooled working fluid (35 °C) is temporarily stored in the circulated refrigerant tank 25 in the refrigerant circulation line 21. The amount of electric power generated by the generator 4 (2,500 kW) is lower than that (4,000 kW) achieved when the working fluid is condensed by using the cold of the brine
25 according to the present invention.

[0045]

The present invention has been described in terms of specific embodiments thereof, but these embodiments are merely exemplary and do not in any way limit the present invention. For instance, the first and second embodiments used the cold of LNG
5 as the source of low temperature cold, but may also use the brine cold as in the third embodiment. The working fluid for the refrigerant turbine is not limited to that mentioned above, but may also consist of hydrocarbon refrigerant such as methane, ethane, propane or butane having relatively low molecular values or mixtures of two or more of these substances. When a mixed refrigerant is used, the composition of the
10 hydrocarbons can be selected according to the temperature levels of the high temperature and low temperature sources of the applicable combined cycle power generation system. The various components of the combined cycle power generation systems given above as the embodiments of the present invention are not necessarily indispensable, but may be omitted and/or modified without departing from the spirit of
15 the present invention.

GLOSSARY

[0046]

- | | |
|--------|--|
| 1 | combined cycle power generation system |
| 2 | gas engine |
| 20 3 | refrigerant turbine |
| 4 | first generator |
| 5 | second generator |
| 6 | LNG base |
| 11 | heat exchanger (second heater) |
| 25 11A | heat exchanger (first heater) |

- 15 -

- 22 condenser
- 31 refrigerant heater (first heater)
- 31A refrigerant heater (second heater)
- 100 combined cycle power generation system
- 5 122 condenser
- 131 refrigerant heater (first heater)

CLAIMS

1. A combine cycle power generation system, comprising:
 - a gas engine using combustible gas for fuel thereof;
 - a first power generator driven by the gas engine;
 - a refrigerant turbine using hydrocarbon refrigerant for working fluid thereof;
 - a second power generator driven by the refrigerant turbine;
 - a condenser for condensing the refrigerant expelled from the refrigerant turbine by using a cold source;
 - a first heater for heating the refrigerant condensed by the condenser using cooling liquid for the gas engine as a heat source thereof;
 - a second heater for further heating the refrigerant heated by the first heater by using exhaust gas of the gas engine as a heat source; and
 - a pipe connecting the condenser and a site where the cold source is generated,, wherein the refrigerant turbine is driven by the refrigerant heated by the second heater.
2. A combine cycle power generation system, comprising:
 - a gas engine using combustible gas for fuel thereof;
 - a first power generator driven by the gas engine;
 - a refrigerant turbine using hydrocarbon refrigerant for working fluid thereof;
 - a second power generator driven by the refrigerant turbine;
 - a condenser for condensing the refrigerant expelled from the refrigerant turbine by using a cold source;
 - a first heater for heating the cooling liquid of the gas engine using exhaust gas from the gas engine as a heat source thereof;
 - a second heater for heating the refrigerant condensed by the condenser using the cooling liquid heated in the first heater as a heat source thereof; and
 - a pipe connecting the condenser and a site where the cold source is generated, wherein the refrigerant turbine is driven by the refrigerant heated by the second heater.
3. The combine cycle power generation system according to claim 1 or 2, wherein the cold source is liquefied natural gas generated at an LNG base, and the condenser is configured to condense the refrigerant by using the liquefied natural gas.
4. The combine cycle power generation system according to any one of claims 1 to 3, wherein the combustible gas consists of boil off gas of liquefied natural gas.
5. The combine cycle power generation system according to claim 1 or 2, wherein the cold source is brine from a refrigerator using plant low temperature waste heat as a heat source, and the condenser is configured to condense the refrigerant by using the brine.
6. The combine cycle power generation system according to any one of claims 1 to 5, wherein the refrigerant consists of a mixture of methane and propane.

7. The combine cycle power generation system according to any one of claims 1 to 6, wherein the condenser is configured to condense the refrigerant by using a cold source having a temperature lower than the water freezing point, and wherein the combine cycle power generation system further comprise a preheater that preheats the refrigerant condensed by the condenser to a temperature which will not cause the cooling liquid to freeze before the refrigerant condensed by the condenser is heated by using the cooling liquid as a heat source.