250 kW turbine generator based on organic rankine cycle with effective use of low temperature heat source —Green binary turbine

We have developed a "green binary turbine" that uses low-boiling-point alternative CFCs as the working fluid with the aim of recovering distributed waste heat that exists in unused condition (80-120°C).

After a demonstration that used a waste hot water source from a gas engine at the in-house power station of our Kobe plant, we are pushing ahead with the development of products compatible with diversified heat sources by conducting geothermal power generation verification tests jointly with Kyushu Electric Power Corporation and participating in advanced waste heat utilization projects using low-temperature steam such as waste incineration plants.

Preface

With the aim of recovering unused waste heat (80-120°C) from distributed sources such as waste hot water from plants, power stations and city incinerators, we developed a green binary turbine as a simplified version of a Rankine cycle-based, 250 kW class, small binary generator set that uses alternative CFCs, a low-boiling-point substance, as the working fluid. Since it was installed in an in-house power station at our Kobe Works, the Kobe Power Center, the turbine has been operating smoothly. Having an overall power station efficiency of over 50% when combined with Kawasaki's green gas engine, it exhibits unparalleled efficiency among small-scale power stations.

The small-sized binary generator set presented in this article is based on the knowledge obtained from 2 to 4 MW class binary generator sets that were developed and manufactured by us in the early 1980s with a CFC gas working fluid (CFC-11, not produced now as a result of regulations). A turbine generator integrates a turbine and a generator by means of the latest power electronics, and is downsized through the adoption of high-speed rotation. It also has perfectly seals the working fluid circuit to prevent the medium from leaking outside the system.

1 Overview

(1) Main specifications

Table 1 shows the main specifications of the green binary turbine and the heat exchanger installed at the Kobe Power Center.

Table 1 Main specifications

Item		Specification
Cycle		Rankine cycle
Working flluid		Alternative CFCs
Generator terminal end output (kW)		250
Turbine type		Transverse single-stage double impeller type
Generator type		Permanent magnet three-phase AC high-frequency synchronous generator
Generator capacity (kVA)		250 (Power factor 1.0)
Rotational speed (min^{-1})		Approx. 9,000 (Variable speed type)
Evaporator		Falling film shell & fin tube type
(Heat source)	Inlet temperature (°C)	98*1)
Circulating hot water	Flow rate (t/h)	180*1)
Condenser type		Shell & fin tube type
(Cooling source)	Temperature (°C)	20*1)
Circulating cooling water	Flow rate (t/h)	480*1)
Reduction in CO_2		Approx. 550 t-CO_2/year*2)

*1) Rated conditions: Hot water and cooling water conditions necessary for the generation of 250 kW of electric power

*2) Generating output minus auxiliary equipment power in the package

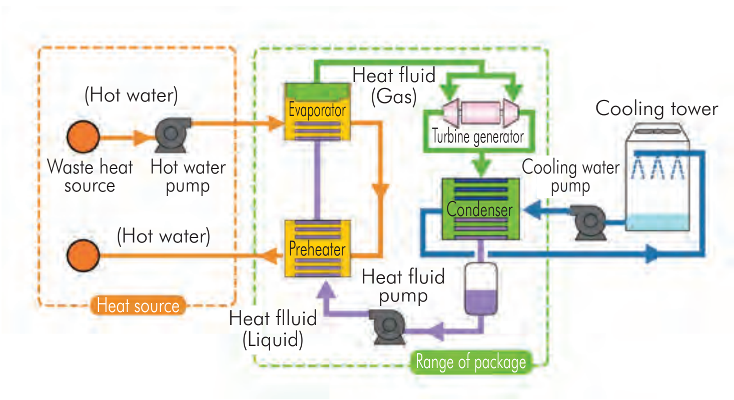

Fig. 1 Cycle composition

(2) Cycle composition

Figure 1 shows the basic composition of the working fluid cycle. A package including a turbine generator and the medium system devices such as an evaporator and a condenser form the basic composition, with the hot water system and the cooling water system placed outside the package. Since various heat sources are available, it is necessary to design systems outside the package accordingly.

The medium first passes through the preheater in the state of a liquid and is heated, and then is changed into saturated vapor by the evaporator. After generating 250 kW of power in the turbine generator, the saturated vapor is condensed into liquid by the condenser. With no leakage of medium from the turbine generator and component equipment, a perfectly sealed cycle is materialized.

The adoption of a water cooling system on the condenser improves the cycle efficiency because the effective heat drop between the main medium vapor and the turbine exhaust is larger than in the case where an air-cooled condenser is adopted.

2 Features

(1) Turbine generator

Figure 2 shows the cross-sectional profile of the turbine generator. The structure integrates the turbine and the generator and inserts a thin cylindrical can between the rotor and the stator of the generator to prevent medium leakage.

The double-flow structure, in which the impeller is attached to both ends of the generator rotor, allows an impeller of smaller diameter to be adopted than in the case of a single-flow structure, making high-speed rotation possible and thereby downsizing the generator. The direct shaft-coupling of the turbine and the generator does not necessitate the use of a reduction gear that is commonly used.

A can is adopted after testing compatibility with the medium, and pressure/running heat cycle tests to make sure that there are no problems with its strength or medium leakage.

The vapor of the medium is used to cool the generator rotor section. In common practice, a fan is attached to the shaft to cool both the rotor and the stator. In this case, however, cooling by means of an air-cooling fan cannot be provided because the rotor section is inside the can. For this reason, a blower fan is installed outside to cool just the generator stator section.

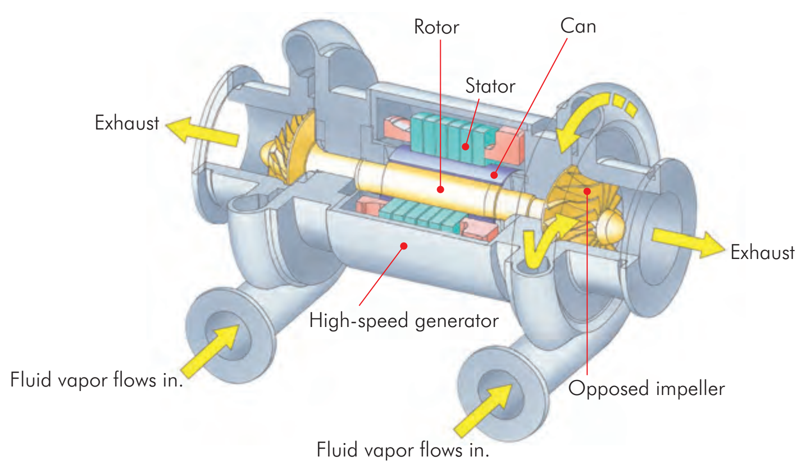

Fig. 2 Turbine cut model

The shape of the impeller and the shape of the generator cooling flow passage are optimized, through analysis based on computational fluid dynamics (CFD), to meet the characteristic of the medium employed.

(2) Heat exchanger

Adopting a falling film evaporator eliminates the necessity of filling the barrel side of the evaporator with medium so as to immerse the entire tube bank, minimizing the inventory of relatively expensive medium. We successfully developed the falling film evaporator and made it relatively compact by applying absorption chiller technology owned by a group company and by fully grasping the characteristics of heat transfer in evaporation through heat transfer analysis.

The condenser adopts an array of cooling tubes and structure proven in past 2 to 4 MW class binary generator sets.

(3) Medium

Having been assessed comprehensively in terms of environment-friendliness, safety, thermophysical properties, ease of handling, availability, regulations, and similar factors, alternative CFCs were selected. They are excellent in environment-friendliness (ozone depletion potential: 0; global warming potential: relatively low), free of toxicity and corrosiveness, and non-flammable, have smaller latent/sensible heat ratios, and are liquid at normal temperatures and atmospheric pressure.

(4) Electric system and control system

Figure 3 shows the configuration of the electrical and control systems.

The binary control panel consists of a converter that turns AC power of a frequency of approx. 450 Hz from the generator into DC and controls the generator rotational speed, an inverter for system interconnection that turns DC into AC of the frequency of the power system, functions for monitoring, controlling, and protecting the entire facility and a control unit for internally controlling the automatic start/stop sequence. In addition, the panel is integrated with the operating system.

Moreover, the panel supports input and output exchanges with remote monitoring equipment and a host computer.

(5) Partial load characteristics

In a binary generator set, the temperature of the heat source is low and cooling is provided at a level equal to the ambient temperature, which leaves little range for using temperature differential. When the air temperature is high as in summer, the difference in temperature is even smaller and the turbine exhaust pressure rises, resulting in considerable deviation from the design point. In such case, operating the system at the rated rotational speed (approx. 9,000 min^{-1}) causes the turbine efficiency to lower considerably. However, thanks to the capability of the power conversion unit that controls the rotational speed of the turbine generator independent of the power system

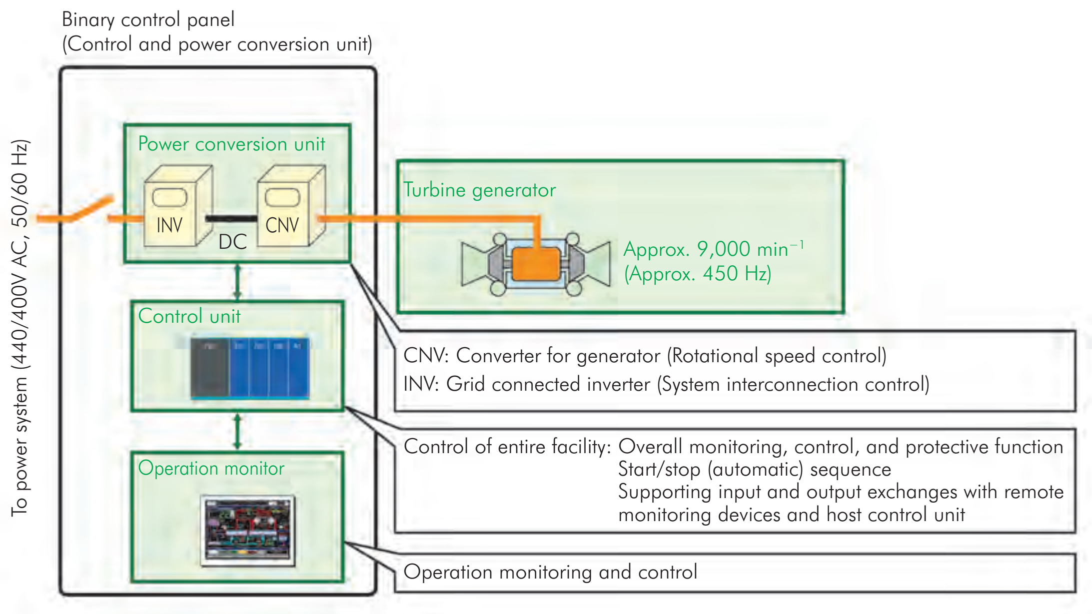

Fig. 3 Diagram of electric and control systems

frequency, it is possible to operate the generator at a high partial loading efficiency by lowering the rotational speed to approx. 7,000 min^{-1}.

3 Examples of applications

(1) Application to gas engines

Figure 4 shows the binary organic Rankine cycle combined with the green gas engine, KG-12-V 5000 kW, at Kawasaki's Kobe Power Center, and Fig. 5 an example layout of the above.

The temperature at the hot water outlet after heat has been used in the evaporator and preheater is adjusted to the temperature of the cooling water supplied to the jacket of the gas engine. Using the jacket cooling heat and exhaust gas heat from the gas engine, hot water of a temperature of 98°C and a flow rate of 180 t/h is obtained to generate 250 kW of electric power (at the generator end).

The green gas engine has achieved the world's highest efficiency of 49% in standalone operation, and when combined with the green binary turbine, has achieved an overall power station efficiency of over 50%.

(2) Application to geothermal power generation

Although this unit was developed as a generator set that uses a low-temperature heat source, we are engaged in verification tests of a geothermal small-scale binary generator set in cooperation with Kyushu Electric Power Co., Inc. with the aim of confirming the applicability of this system to geothermal power generation utilizing renewable energy.

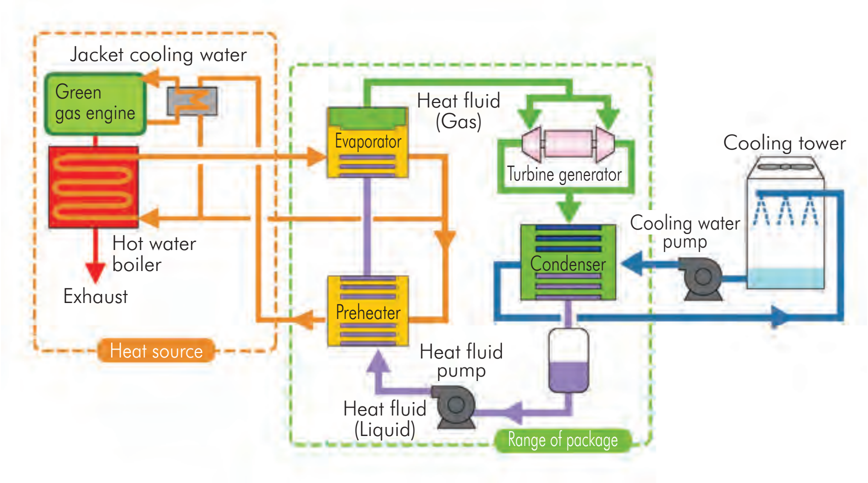

Fig. 4 Composition of binary cycle at Kobe Power Center

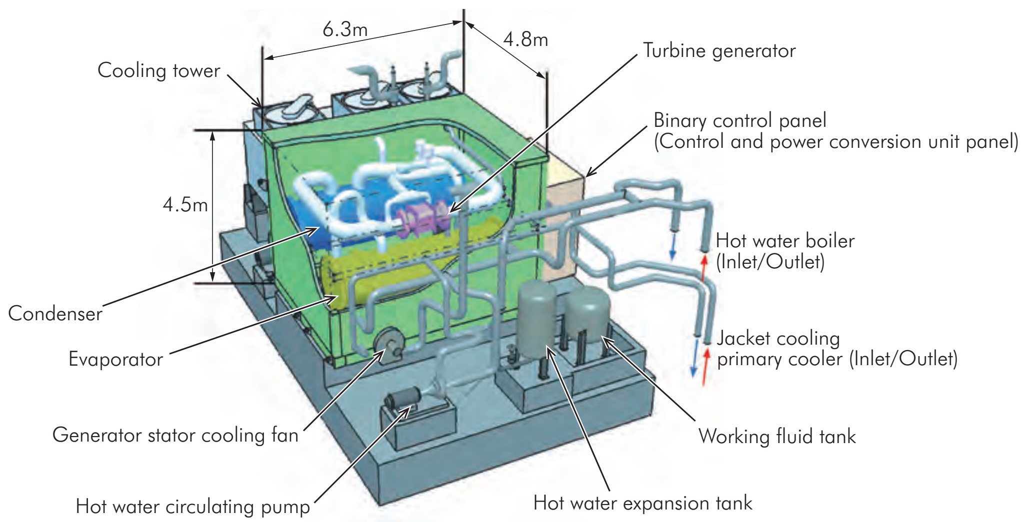

Fig. 5 Example of layout and configuration

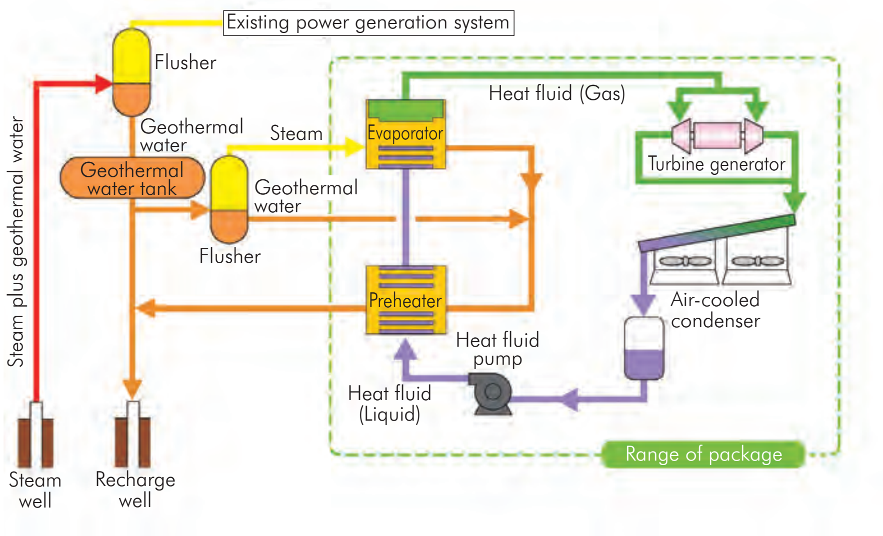

Fig. 6 Composition of cycle in verification test for small-scale geothermal binary power generation

Figure 6 shows the cycle composition of the verification test facility. With conventional geothermal power generation based on steam turbines, only steam is used for power generation although steam and hot water are eructed from the steam well. In this verification test, part of the hot water to be returned to the recharge well is used for binary power generation.

This facility will be installed at the Yamagawa Geothermal Power Station in Ibusuki City, Kagoshima Prefecture, Japan. This facility will be used to assess technologies for heat recovery from geothermal fluid, measures to prevent the growth of scale, measures to prevent corrosion, facility performance, cost effectiveness, and other items by the end of fiscal 2013.

(3) Utilization of waste heat from a city incinerator

The city incinerator of the Environment Bureau of Osaka City produces steam by using the heat generated in garbage incineration, and effectively uses it for power generation, hot water supply and space heating in the plant. The "project for advanced utilization of urban waste heat from city incinerators, etc." a joint demonstration project involving Osaka Gas Co., Ltd., Osaka City, Osaka Prefecture, and Kawasaki, has selected the Taisho Plant as the site for verification tests. The aim of the project is to achieve a 25% improvement in the overall energy efficiency by binary power generation, transport unused heat to the nearby community by a heat storage transfer system, and utilize the power generation and delivery of unused heat via an energy management system (EMS).

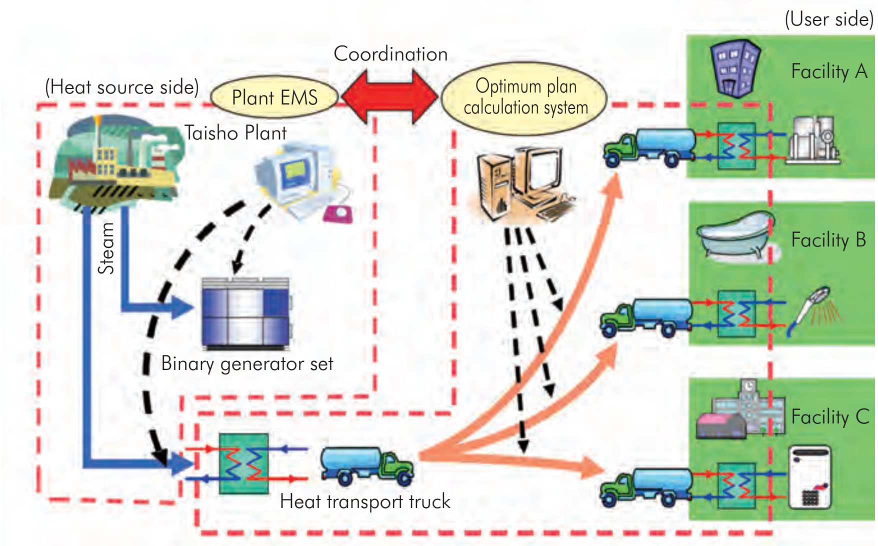

Fig. 7 System configuration for "Waste Heat Utilization from City Incinerators, Etc." project

Figure 7 shows the configuration of the overall system of the project. As the major facilities and systems, a binary generator set and a plant energy management system (EMS) will be provided by Kawasaki and a heat storage transfer system by Osaka Gas Co., Ltd.

① Binary generator set

The heat source is the exhaust heat from the steam turbine installed at the plant. In the past, the temperature was too low to be used for power generation, but power generation has been made possible by using a binary generator set that is capable of using low-temperature heat effectively.

② Heat storage transfer system

The system is capable of storing heat from garbage incineration in a heat storage tank, from which heat can be transferred and supplied to users in the community.

③ Plant energy management system (EMS)

This system optimizes the heat distribution between its conversion from incineration into electricity (power generation) and straight-up use (heat transport) according to how heat is used in the nearby community.

According to the plan of the project, practical operation will be started after trial-runs in fiscal 2012. Technological verifications will be continued up to the end of fiscal 2013.

Concluding remarks

The green binary turbine was developed as a power generation unit to recover heat from dispersed unused low-temperature heat sources, such as exhaust gas, exhaust steam, waste hot water, and geothermal hot water. A number of visitors have come to the Kobe Power Center, where the first unit is installed, making the authors realize that this product is anticipated as an energy-saving appliance.

But when compared with existing generator sets and other energy-saving appliances, the profitability of this product for the customer is still lower is still high because of the utilization of low-temperature heat.

On the other hand, we believes, the application of the feed-in tariff system (FIT), intended for renewable energy, to geothermal power generation will improve the profitability and the accumulation of track records in geothermal power generation through the joint research with Kyushu Electric Power Co., Inc. will build on the momentum for the widespread use of this product in the field of geothermal power generation.

We will widen the application of this product to various dispersed low-temperature waste heat sources and develop the present product into one that will meet needs of a wide variety of users.

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