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Analysis of combined cooling heating and power generation from organic Rankine cycle and absorption system

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ABSTRACT

This paper focuses on the feasibilities of energy, economic and environment of a method to enhance an ORC (organic Rankine cycle) efficiency by CCHP (combined cooling heating and power) generation from an absorption system for reducing the ORC condenser temperature. A projection of a 25 kW_e R245fa ORC integrated with a 20 kW LiBr-water absorption unit was considered. The experimental data of both units were generated as performance curves and used to find out the suitable operating conditions. It could be found that the ORC with the absorption system gave higher total efficiency compared with the normal ORC. The ORC efficiency could be increased around 7%, with 15 °C of cooled water temperature supplied from the absorption system. But, in term of the economic result, a LEC (levelized electricity cost) of the modified system was around 0.0891 USD/kWh, which was higher than that of the normal system at around 0.0669 USD/kWh. In term of the environmental impact, a released carbon dioxide intensity of the new unit was lower than the normal unit at around 0.203 and 0.216 kg CO_2 eq/kWh, respectively.

1. Introduction

ORC (Organic Rankine cycle) is a cycle that uses an organic working fluid as a working fluid instead of water. Since the boiling point of the organic fluid is lower than that of water then it could be applied with various kinds of low temperature heat sources such as geothermal energy, solar energy, biomass energy and waste heat. Today, rising of fossil fuel prices and the environmental aspects on fossil fuel combustion, a significant market for the ORC is open and there is a challenge to develop an appropriate scale to meet both economic and environmental needs.

Many studies on the ORC technique were reported. Walraven et al. [1] studied a system optimization of ORCs cooled by air-cooled condensers or wet cooling towers and powered by low-temperature geothermal heat sources. The results showed that it was economic to use mechanical-draft wet cooling towers instead of air-cooled condensers. Suna and Li [2] presented the ORC heat recovery power plant using R134a as working fluid mathematical models to evaluate and optimize the plant performance. Thawonngamyingsakul and Kiatsiriroat [3] used a solar water heating system with a climate of Thailand to generate and supply heat to ORC system. Thermo-economic analysis was used to analyze the system performance for CHP (combined heat and power) generation similar to other reports on CCHP (combined cooling heat and power) [4–6].

Selection of ORC working fluid was also an interesting topic and various literatures [7–14] were reported. R-134a and R-245fa were always the recommended working fluids. Moreover, improvement of the ORC efficiency by reducing condensing temperature such as a design of high performance heat exchanger [15] and design of the condensation temperature with respect to the expander characteristics [16,17] were carried out.

From the above mentioned literature review, it could be found that many studies reported about the ORC applications. Techniques to enhance the ORC efficiency such as selection the suitable working fluid and the optimal design were represented. It could be noted that technique of reducing the working fluid temperature at the ORC condenser by using an absorption chiller did not represent in the recent literatures.

An interesting approach, a method to enhance the ORC efficiency by CCHP (combined cooling heating and power) generation from the absorption system for reducing the ORC condenser temperature is considered. The experimental results of each technology are performed to evaluate the optimal integrating system performance.

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The aims of this study are as follows:

1. To evaluate performance curves of the ORC and absorption systems based on the testing results.
2. To find out systematic determination of optimum design parameters of the integrating unit.
3. To analyze economic result of the normal and new systems in term of a LEC (levelized electricity cost).
4. To analyze environmental impact of the normal and new systems in term of a carbon dioxide intensity.

2. System description

The operating principle of the ORC system is manifested in Fig. 1, hot fluid as heat source at temperature around 90–120 °C enters a boiler to heat and vaporize the working fluid at point 1 h and the outlet temperature of heat source is dropped at around 15–20 °C at point 2 h. The super-heating working fluid exiting the boiler at point 1 is expanded in a screw expander to produce a mechanical work at point 2. An expander-generator set is used in this study. The expander operates at around 8000 rpm for feeding power and driving a reduction gear box. The output of the gear box is around 3000 rpm and directly drives an induction generator. The expander-generator set is constructed to be a semi-hermetic screw type, where the expander is integrated with the generator and installed inside a common casing to avoid from vapor leak-off. A lubrication system is used to reduce friction of a rotor (point 2), which consists of oil and vapor separator (point 3), filter and oil pump (points 4–5). The presence of lubrication system has lower the maintenance costs [18,19]. Lubricant and the vapor working fluid are separated at the oil and vapor separator (point 6). After that, the vapor is then condensed in a condenser by cooling water at temperature around 25–35 °C to a low pressure (P_{Low}) as the sub-cooled working fluid at point 7. The fluid at liquid state is compressed by a refrigerant pump as a multi-stage centrifugal pump to a high pressure (P_{High}) at point 8 and the new cycle restarts.

Fig. 2 shows the operating procedure of the combining unit, which the absorption system is used to reduce the working fluid temperature at the ORC condenser. Heat source supplies heat to the ORC boiler (point 1 h) and sends to a generator of the absorption system (point 2 h) at temperature around 90–120 °C and 70–90 °C, respectively. Released heat temperature at the generator will drop down to be around 60–75 °C (point 3 h). A binary liquid mixture consisting of a volatile component (absorbate) and a less volatile component (absorbent) is obtained at the generator. The binary mixture (weak solution) is heated and part of the absorbate boils at a high pressure ($P_{High,Ab}$) and temperature (T_G) at point 1a. The vapor absorbate condenses in a condenser1 (T_{C1}) to be liquid at point 2a. After that, the absorbate in liquid phase is throttled to a evaporator at point 3a of which a low pressure ($P_{Low,Ab}$) is lower than that of the condenser1. The evaporator is heated by cooling water at temperature around 10–20 °C (point 3c), after that cooling water will drop down temperature to be around 5–15 °C (point 4c). In this study, cooling water comes from a cooling tower of the ORC system (points 1c-2c), which is the cascade connection. This technique could be increased the cooling capacity and decreased the cooling water temperature of the integrating system. The absorbate at the evaporator is boiled to be vapor at point 4a and enters an absorber. Meanwhile, the strong solution from the generator, at point 8a is sent through a heat exchanger and a pressure reduction valve at points 9a and 10a, respectively, into the absorber at the low pressure. In the absorber, the strong solution absorbs the absorbate vapor to be the weak solution again. This liquid mixture leaves the absorber at point 5a at a medium temperature (T_A) around 40–50 °C, which is similarly the condenser temperature (T_C). The weak solution at point 6a is compressed by a solution pump to the high pressure (point 6a) through the heat exchanger (point 7a) into the generator again and new cycle restarts.

Fig. 2 also shows the concept of combined cooling heating and power, which waste heat recovery from the ORC boiler is the useful heating mode. In cooling part, cooled water from the evaporator of absorption chiller is combined with power generation to reduce the ORC condenser and the ORC efficiency could be enhanced.

3. Materials and methods

3.1. The ORC test rig

In the past, several working fluids were considered with the ORC cycle such as Hydrochlorofluorocarbon (HCFC), Hydrofluorocarbon (HFC) including of mixture refrigerants etc [7–14]. In this study, a

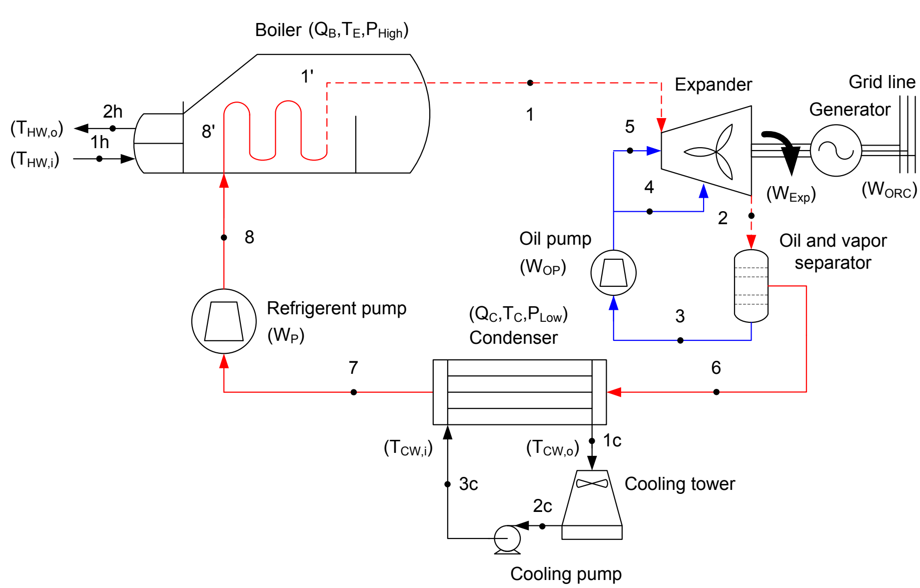

Fig. 1. Schematic diagram of organic Rankine cycle.