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Energy-saving Analysis of Refrigeration System in Micro-grid with Combined Cooling, Heating & Power Generation

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Abstract. From the theoretical analysis of the primary energy consumption of refrigeration system, energy saving rate and μ value, combined with the application of specific case, the absorption refrigeration system and the compressor refrigeration system in Combined Cooling, Heating & Power Generation (CCHP) system are analyzed. The result of analysis shows that the CCHP system with energy-saving will or will not work in some operation condition and in order to makes the CCHP system more energy-saving, the influence of factors on energy-saving can be to remove by adjusting the working condition.

Introduction

Micro-grid system of combined cooling, heating and power generation (CCHP) is based on the use of energy cascade of cooling, heating and power generation. The CCHP system works in high efficiency by making full use of low-grade heating from the heat loop of power generation. The heat is sent to load of cooling and heating. The technology has been rapidly developed in foreign countries. The CCHP system is popular in in Japan, the United States and the United Kingdom. In China, the application of CCHP system is limited to some special application. It is common sense in industry that the advantages of CCHP system are energy-saving in economy and green power for environmental protection.

The refrigeration systems of the CCHP system work under different conditions. The assessment standards and analysis technology of energy efficiency are different. Therefore, the problem of energy conservation in the absorption refrigeration system of the CCHP system needs to be further studied.

In this paper, a micro-grid with CCHP system including small gas turbines is taken as an example for theoretical analysis of the primary energy consumption in refrigeration system, and energy saving rate of primary energy consumption, and μ value (the high-grade heat produced by per fuel combustion is equivalent to the low-grade heat at the outlet of the steam turbine or the back pressure vent[3]). Combined with the specific cases, the absorption refrigeration system of CCHP system and the compressor refrigeration system were compared. In the aspect of refrigeration, it provides the basic data and basis for further study in the analysis of the CCHP system's energy saving.

Micro-grid with CCHP System

In the micro-grid with the gas-fired cogeneration system, also called as the distributed CHP (Cooling, Heating and Power Generation) systems, the CCHP system uses natural gas as a fuel for power generation and cooling as well as heating. Compared with the conventional sub-production system that uses direct fuel for heating and cooling by fuel combustion, the energy efficiency is greatly improved due to its cascade utilization of energy. In some developed countries, the thermoelectric efficiency has reached 96%.

There are mainly three types of distributed CHP systems:

1) Gas turbine + direct-fired absorption chiller;
2) Gas turbine + waste heat boiler (without combustion) + absorption chiller;
3) Gas turbine + waste heat boiler + turbine + absorption chiller.

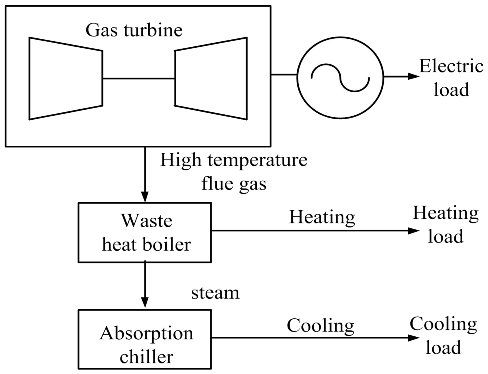


Fig. 1 the Composition of the Triple Supply System

This paper takes the second form of composition for analysis. The system of the composition and working principle is shown in Fig. 1.

Factors of energy-saving Analysis

From the table of 1163kW refrigeration system energy consumption provided in the reference [4], it can be seen that both the compression refrigeration system and the absorption refrigeration system have energy consumption in the cold water pump, the cooling water pump and the cooling tower fan equipment as well as in the chiller and solution pump. The equivalent thermodynamic coefficient is the refrigerating capacity generated by per fuel (1kJ).

The equivalent thermal coefficient of compression refrigeration system is shown as the following.

$$\xi_{ce} = \frac{Q_c \eta_e \eta_n \eta_m}{W_{ce} + W'_{ce}}$$
(1)

The equivalent thermal coefficient of absorption refrigeration system is shown as the following.

$$\xi_{ca} = \frac{Q_c}{Q_h/(\mu\eta_p) + W_{ca}/(\eta_e\eta_n)} \quad (2)$$

In the above expression of the equivalent thermal coefficient, Q_c represents cooling capacity of the refrigeration system; η_e represents the average electricity generation efficiency in a nation such as China; η_n represents power transmission efficiency and the value of this paper is 0.9; η_m represents the overall efficiency of the motor and the value is 0.9; W_{ce} represents chiller consumption; W'_{ce} represents power consumption of the cold water pumps, cooling water pumps and cooling tower fan; Q_h represents the absorption chiller refrigerant heat required for steam; η_p represents heating efficiency of the steam pipe; W_{ca} represents the desired power resulted from absorption chiller refrigeration; The reference [3] states the value of μ, and the reference [6] deduces the value of μ and obtains the following expression.

$$\mu = \frac{1}{\frac{Q_f \eta_b}{D_1(h_2 - h_1)} - \frac{P_v}{D_2 c_p (t_p - t_0)}} \quad (3)$$

The primary energy consumption rate in reference[6] is the ratio of primary energy consumption to required output energy. According to the expression of equivalent thermodynamic coefficient of absorption refrigeration system and compression refrigeration system above mentioned, the corresponding primary energy consumption rate and primary energy consumption of the two systems is shown as the following.

The primary energy consumption rate and primary energy consumption of a compression refrigeration system are shown as the following.

$$PER_{ce} = \frac{1}{\xi_{ce}},\ PE_{ce} = \frac{Q_c}{\xi_{ce}} \tag{4}$$

The primary energy consumption rate and primary energy consumption of the absorption refrigeration system are shown as the following.

$$PER_{ca} = \frac{1}{\xi_{ca}},\ PE_{ca} = \frac{Q_c}{\xi_{ca}} \tag{5}$$

Analysis of Energy Efficiency in Two Refrigeration Systems

The comparison of the energy saving of the two refrigeration systems is based on the premise of the same equivalent thermodynamic coefficient of generator with rated power 1163kW. The impact of primary energy consumption, μ value and primary energy saving rate on the energy saving of absorption refrigeration system is analyzed respectively.

A. Energy-saving Analysis Based on Primary Energy Consumption

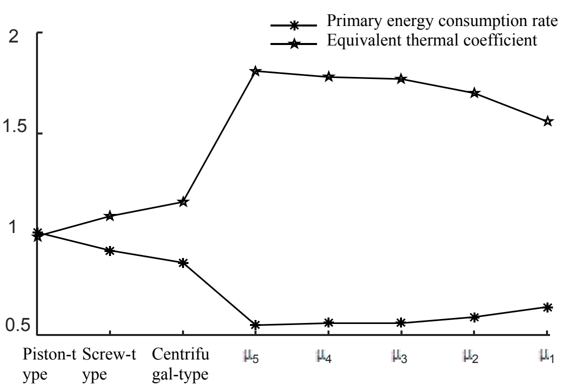
The basic data in this paper is derived from the technical sheet of small solar & gas turbine in reference [4] and the table of energy consumption of refrigeration system. Combining with calculation of μ value above mentioned, the calculated μ value is shown in Table 1. The corresponding primary energy consumption rate, equivalent thermal coefficient and the primary energy consumption are calculated by combining the expression of the equivalent thermodynamic coefficient of the two refrigeration systems and the expression of the primary energy consumption rate and the primary energy consumption of the two systems. The result is shown in Fig. 2 and Fig. 3.

Table 1. μ Value

No.	μ_5	μ_4	μ_3	μ_2	μ_1
μ value	3.08	2.98	2.96	2.73	2.32

The variation of primary energy consumption of the two refrigeration systems is shown in Fig. 3. The primary energy consumption of the absorption refrigeration system is smaller than the primary energy consumption of the compression refrigeration system. In the refrigeration system with CCHP system, the larger the μ value, the smaller the corresponding primary energy consumption value. Therefore, it is concluded that the absorption refrigeration system is energy-efficient relative to the compression refrigeration system, and the larger the μ value in the absorption refrigeration system, the better energy-saving

Coefficient



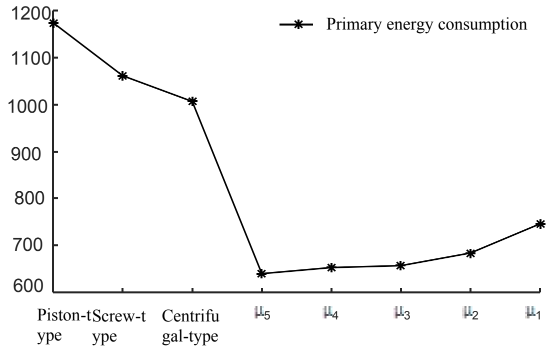


Fig. 3 Primary Energy Consumption

B. Energy Saving Analysis Based on the Value of μ and Primary Energy Saving Ratio

The primary energy-saving and energy-saving rate can directly label whether the refrigeration system is energy-saving. When the primary energy-saving rate $\delta > 0$, it indicates that the system is energy-saving, otherwise the system is not energy-saving. The numerical expression is shown as the following.

$$\delta = \left[\left(\frac{1}{\xi_{ce}} - \frac{1}{\xi_{ca}}\right) / \frac{1}{\xi_{ca}}\right] \times 100\% \tag{6}$$

The energy consumption per primary energy corresponding to μ value of the gas turbine absorption refrigeration system of various models is calculated respectively by the average efficiency of 0.33, 0.40 and 0.55. As shown in Fig. 4 to Fig. 9, two different comparative basic energy-saving and energy-saving rate curves are taken when the average efficiency respectively takes the above values.

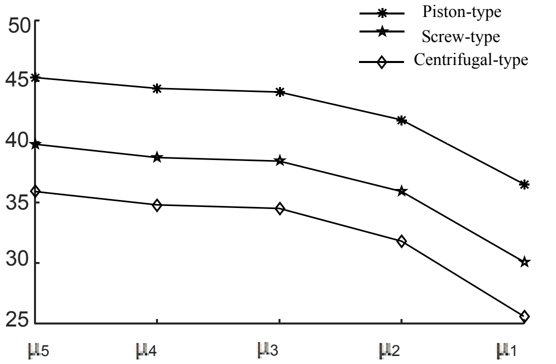


Fig. 4 Comparison Based on Different Absorption Refrigeration Systems

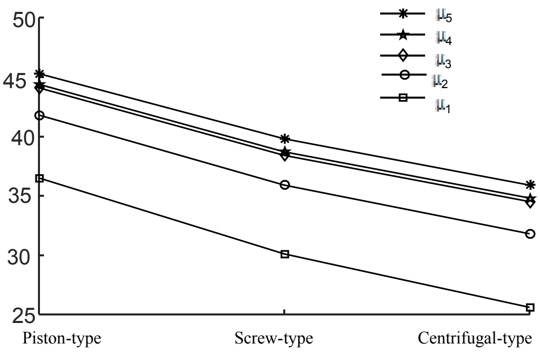


Fig. 5 Comparison Based on Different μ

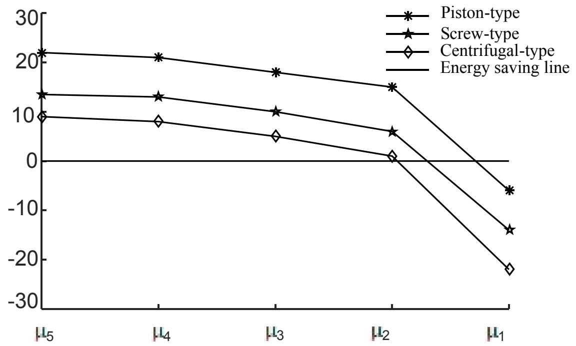


Fig. 6 Comparison Based on Different Absorption Refrigeration Systems

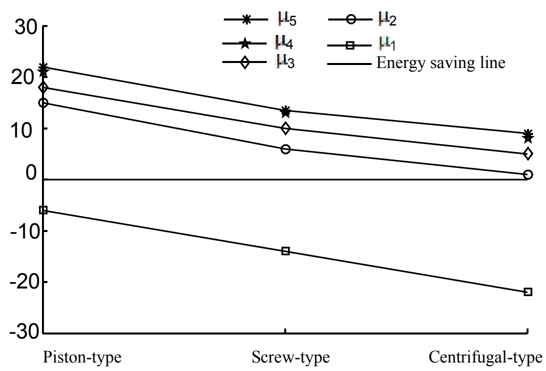


Fig. 7 Comparison Based on Different μ

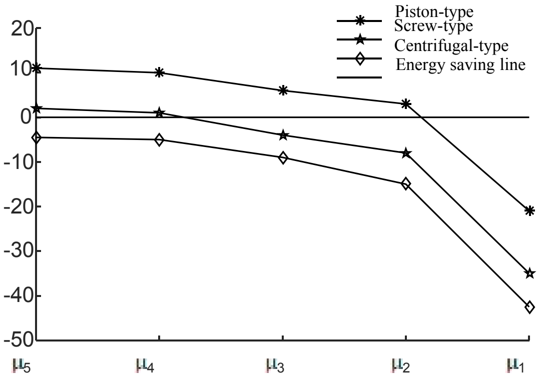


Fig. 8 Comparison Based on Different Absorption Refrigeration Systems

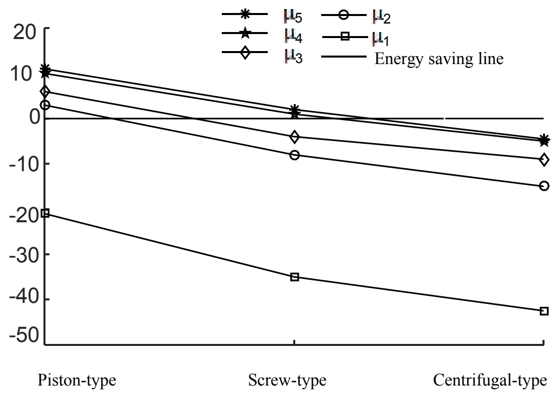


Fig. 9 Comparison Based on Different μ

As shown in Fig. 4 and Fig. 5, when taking the average power generation efficiency of 0.33, it can be seen that the larger the μ value, the higher the primary energy-saving and energy-saving rate, and the more energy-efficient of the absorption refrigeration system compared to the compression refrigeration system. Based on the same μ value, it can be seen that the absorption refrigeration system is more energy-efficient than the piston compression refrigeration system, while the energy-saving rate of the absorption refrigeration system is lower than that of the centrifugal compression refrigeration system.

As shown in Fig. 6 and Fig. 7, compared to the average power generation efficiency of 0.33, the calculation results of the average power generation efficiency of 0.4 show that the primary energy-saving and energy-saving rate obviously decreases. Only the absorption refrigeration system corresponding to μ_1 value is not energy-saving, and it is not energy-efficient for the three compression refrigeration systems of piston type, screw type and centrifugal type.

As shown in Fig. 8 and Fig. 9, when taking the average power generation efficiency as 0.55, most of the absorption refrigeration systems do not have the energy-saving effect, and the energy-saving of the absorption refrigeration system can be shown only when the μ value is large enough.

Conclusions

The energy saving of the CCHP system consisting of gas turbines, waste heat boilers and absorption refrigerators is affected not only by the type of gas turbine but also by the average generation efficiency. In the use of the cooling, gas turbine models should be combined with the power generation efficiency. At the same time, the economic operation strategy of micro-grid in reference [7] is adopted. From the aspects of fuel price, demand for thermal and electric load, and cost of power generation and sale, a reasonable operation strategy of the CCHP system is worked out to show the advantages of energy saving.

Acknowledgements

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