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A study of Transient Performance of A Cascade Heat Pump System

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Abstract

Transient performance of a cascade heat pump system is experimentally investigated. The cascade heat pump consists of 4 systems: the chilled water system, the low-temperature refrigeration cycle using R22, the high-temperature heat pump cycle using R134a and the hot water system. The cascade heat pump produces both chilled water for cooling application and hot water for heating application. A transient performance is observed when the hot water system is in a closed-loop operation. As the hot water temperature increases, the condensing pressure of the heat pump cycle also increases but the other refrigerant pressures have marginal changes. The operation of the test rig is terminated when the condensing pressure reaches the limit of the system. The condensing pressure at high hot water flow rate increases at a lower rate than that in case of the low hot water flow rate, so the working period is higher. The compressor power of the heat pump cycle increases continuously with time whereas the compressor power of the refrigeration cycle is almost constant. The condensation heat and cooling load rapidly increase at the beginning, and the condensation heat gradually increases whereas the cooling load is almost constant. The COP of the heat pump cycle gradually decreases with time after the rapid increase at the beginning, but the COP of the refrigeration cycle is almost constant. It can be concluded that the variation of the condensing pressure of the heat pump cycle with time has a little influence to the refrigeration cycle. By comparing the high and low hot water flow rate, the COP of the heat pump cycle and the final hot water temperature in the storage tank are higher whereas the others are the same.

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1. Introduction

Waste heat recovery is one of the energy saving program which can be adopted in many applications. For a building with both heating and cooling load, the recovering rejection heat from a refrigeration system saves cost and increases the system efficiency. In a tropical country where the space heating is not required, the heat load in a building is usually the hot water demand especially for a hotel or hospital. Shao et al. [1] modified a home air conditioning to produce hot water by rejection heat. The system was run along with the air conditioning system which generated hot water from a heater. After one-year experiment, the COP of the modified system was 10% and 90% more than the COP of the original system in winter and summer respectively. Energy cost of the modified system was 31.1% less than that in case of the old one. Huimin et al. [2] replaced an air cool condenser by a hot water tank that embedded refrigerant tubes to transfer condensation heat to water. The COP is improved by 10% with this modification. The compressor power was directly proportional to the hot water temperature and inversely proportional to the ambient temperature. Yokoyama et al. [3] numerically studied hot water production from a CO₂ heat pump system. The system performance was dependent on the ambient temperature and the condenser water temperatures. Bhattacharyya et al. [4] studied a cascade refrigeration system performance and performed a parametric analysis. The system performance was dependent on the evaporating temperature of the refrigeration cycle, the condensing temperature of the heat pump cycle and the temperature difference between both cycles at the cascade heat exchanger. The COP of the refrigeration cycle was directly proportional to the evaporating temperature and the COP of the heat pump cycle was indirectly proportional to the condensing temperature. Jung et al. [5] compared the performance between a single heat pump system and a cascaded one. The hot water temperature produced by the cascade system was higher than that in case of the single system. The stability of the cascade system is observed.

This paper focuses on an experimental study of transient performance of a cascade heat pump system. The transient effect is presented by circulating the hot water through the heat pump condenser causing the rise in the hot water temperature. The effect of the low and high hot water flow rate is investigated.

2. Experimental setup

2.1. A cascade heat pump system

Fig.1 shows the experimental setup of a cascade heat pump system. The system consists of 4 systems: the chilled water system, the low-temperature refrigeration cycle using R22, the high-temperature heat pump cycle using R134a and the hot water system. The chilled water supplied heat to the evaporator of the refrigeration cycle with the maximum cooling load of 8.45 KW. Heat is transferred to the heat pump cycle through the cascade heat exchanger. The hot water is pumped from the storage tank to take the rejection heat at the condenser and recirculates back to the tank. In this study, the comparison between the low hot water flow rate of 6 litre/min and the high hot water flow rate of 16 litre/min is made.
2.2. Experimental procedure and data analysis

The chilled water temperature, the hot water temperature, the refrigerant temperature and pressure are measured at the location shown in fig.1. The water temperature is measured by type-PT-100 RTD. The refrigerant temperature is measured by type-K thermocouple. The refrigerant pressure is measured by pressure transducer. The compressor power of both cycles is measured by power meter. All measuring data are recorded in a personal computer using the data logger.

The cooling load can be determined by the multiple of the chilled water flow rate, the specific heat capacity of water and the temperature difference of the chilled water across the evaporator. The condensation heat can be determined by the multiple of the hot water flow rate, the specific heat capacity of water and the water temperature difference of the hot water across the condenser. The COP of the refrigeration cycle can be determined by the ratio of the cooling load and the compressor power of the refrigeration cycle. On the other hand, the COP of the heat pump cycle can be determined by the ratio of the condensation heat and the compressor power of the heat pump cycle.

3. Result

The variation of the refrigerant pressures with time is depicted in fig. 2. The condensing pressures of the heat pump cycle continuously increase with time. The evaporating pressures of the heat pump cycle decrease in a short period at the beginning and gradually increase. The condensing pressures of the refrigeration cycle gradually increase with time and the evaporating pressures of the refrigeration cycle remain the same. It should be noted that the operation of the test rig will be terminated when the condensing pressures of the heat pump cycle reach 22 barg. By comparing the low and high hot water flow rate, the condensing pressure of the heat pump cycle increases at a higher rate. As a result, the working period of the test rig in case of the low hot water flow rate will be shorter than that in case of the high hot water flow rate.
The variation of the condensation heat, the cooling load and the compressor powers of both cycles with time is depicted in fig. 3. The condensation heats rapidly increase at the beginning and gradually increase with time. The cooling loads rapidly increase at the beginning and are constant later. The compressor powers of the heat pump cycle increase continuously with time whereas the compressor powers of the refrigeration cycle remain the same. By comparing the low and high hot water flow rate, the compressor power of the heat pump cycle is higher.
The variation of the COP of both cycles with time is depicted in fig. 4. The COPs of the heat pump cycle rapidly increase in a short period at the beginning and decrease with time later. The COPs of the refrigeration cycle rapidly increase in a short period at the beginning and remain constant later. By comparing the low and high hot water flow rate, the COPs of the heat pump cycle is lower whereas the COPs of the refrigeration cycle are the same.

![Fig.4 The COP of refrigeration and heat pump cycle vs time](image)

The variation of the hot water temperature in the storage tank with time is depicted in fig. 5. The hot water temperatures in the storage tank continuously increase with time. By comparing the low and high hot water flow rate, the final water temperature is lower.

![Fig. 5 The hot water temperature in the storage tank vs time](image)
4. Conclusions

The transient performance of a cascade heat pump system has been experimentally investigated in this study. The result indicates that as the hot water temperature increases with time, the condensing pressure of the heat pump increases also whereas the other refrigerant pressures have only marginal changes. In addition, the compressor power of the heat pump cycle also increases whereas the compressor power of the refrigeration cycle remains the same. The condensing pressure at the high hot water flow rate increases at a low rate than that in case of the low hot water flow rate. However, since the condensing pressure is limited at a certain value, the working period at the high hot water flow rate becomes longer. The condensation heat rapidly increases at the beginning and gradually increases with time. The cooling load rapidly increases at the beginning and remains constant later. The COP of the heat pump gradually decreases after reaching the peak whereas the COP of the refrigeration cycle is almost constant. By comparing the high and low hot water flow rate, the COP of the heat pump cycle and the final water temperature in the storage tank are higher.

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