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Performance Characteristics of Cascade Multi-Functional Heat Pump in Cooling-Hot Water Mode With Variation in Secondary Fluid Temperature Conditions

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Abstract

Cascade multi-functional heat pumps have gained much attention in recent times due to their ability to simultaneously meet the cooling, heating and hot water demands of residential buildings. However, the effect of heat source and sink temperature on the performance of cascade multi-functional heat pumps is lacking in open literature. This study experimentally analyzed the performance characteristics of a water-to-water cascade multi-functional heat pump operating in cooling-hot water mode according to variation of indoor heat exchanger entering water temperature (ID EWT), outdoor heat exchanger entering water temperature (OD EWT) and hot water heat exchanger entering water temperature (HW EWT). Capacity of the cooling cycle was affected by variation in ID EWT and OD EWT while capacity of the hot water cycle was affected significantly by variation in OD EWT and HW EWT. Furthermore, system COP decreased with increase in HW EWT and OD EWT, and increased with increase in ID EWT.

Keywords: Cascade multi-functional heat pump, Cooling-hot water mode, Entering water temperature, Capacity, COP

1. Introduction

Heat pumps have been identified as energy efficient systems for space cooling, space heating and hot water generation [1]. While space cooling and heating are needed during summer and winter seasons respectively, hot water is needed all year round. A single heat pump that can simultaneously provide cooling/heating and hot water is of great importance in the aspect of cost, energy savings and efficient space utilization especially in apartment and high rising residential buildings. Multi-functional heat pumps have therefore been developed over the years for this purpose [2, 3]. However, most of the studies done on multi-functional heat pumps have focused on single stage heat pumps with few works on cascade multi-functional heat pumps. Performance characteristics of cascade multi-functional heat pumps is therefore lacking in open literature. This study analyzes the performance characteristics of water-to-water cascade multi-functional heat pump according to variation in secondary fluid temperature. This will provide pathway for the design and control of energy efficient cascade multi-functional heat pumps.

2. Experimental condition and test procedure

The study was done to analyze the performance characteristics of cascade multi-functional heat pump with variation in entering water temperature (EWT) in cooling-hot water mode. The experimental setup used in the study is a multi-functional water-to-water cascade heat pump consisting of a single stage cycle connected in

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parallel with the low stage (LS) side of a cascade heat pump cycle as shown in Fig. 1. The single stage cycle was used for cooling, and generally consisted of the outdoor heat exchanger (OD HX), compressor, indoor heat exchanger (ID HX) and expansion device. The cascade cycle consisted of low stage (LS) side and high stage (HS) side interconnected by cascade heat exchanger, which acted as condenser to the LS side and evaporator to the HS side. Brine with ethylene glycol of 40% concentration was used as secondary fluid, with constant temperature water bath and magnetic pump used to simulate the secondary fluid flow loop.

When in operation, refrigerant from LS compressor divides into two and go through the cascade HX and the OD HX. The divided refrigerant combine, after expansion, and go through the ID HX for cooling. Also, HS refrigerant gains heat from LS refrigerant in the cascade HX, gets compressed and goes into HW HX for hot water generation. Refrigerant from HW HX is then expanded into the cascade HX for the cycle to continue. Different refrigerants were used in the LS and HS cycles due to their different critical pressure and temperature properties.

Test was conducted by varying the outdoor heat exchanger entering water temperature (OD EWT), indoor heat exchanger entering water temperature (ID EWT) and hot water heat exchanger entering water temperature at reference secondary fluid flow rates as shown in Table 1. Sensors were installed in the test rig to measure the performance parameters of the cascade multi-functional heat pump. Capacity of the cooling cycle (Q_C) and capacity of the hot water cycle (Q_{HW}) were calculated using mass flow rate of secondary fluid ($\dot{m}$), leaving water temperature (LWT) and EWT across the ID HX and HW HX respectively as shown in Eq. (1), while COP of the cascade multi-functional heat pump was calculated using Q_C, Q_{HW} and power consumption of LS (W_{LS}) and HS (W_{HS}) as shown in Eq. 2.

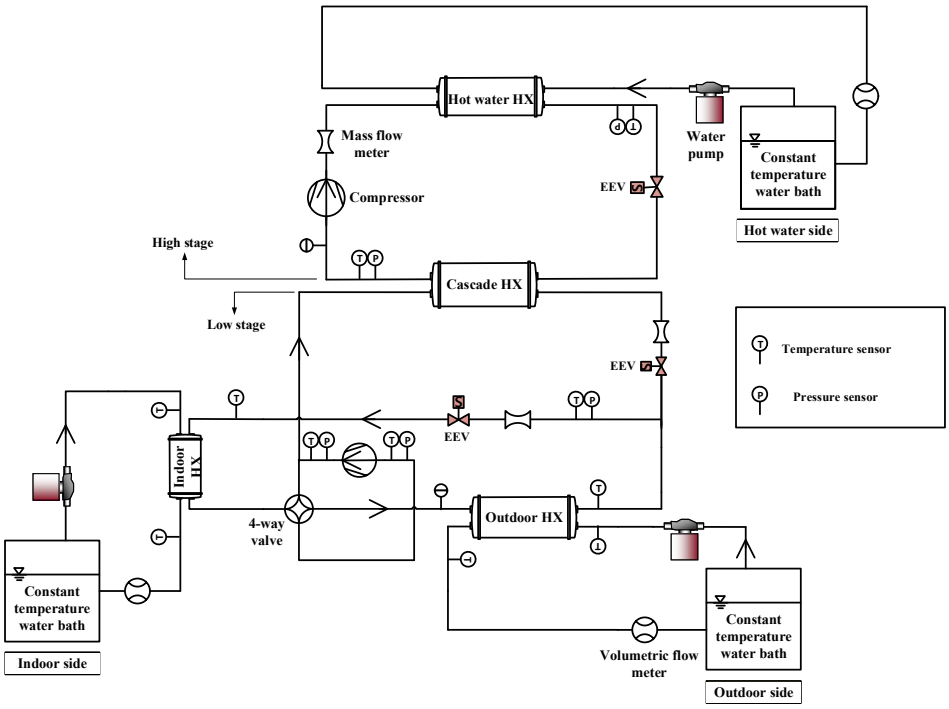


Fig. 1. Schematic diagram of experimental setup

$$Q_C/Q_{HW} = \dot{m} \cdot |LWT - EWT| \quad (1)$$

$$COP = \frac{Q_C + Q_{HW}}{W_{LS} + W_{HS}} \quad (2)$$

Table 1 Test conditions for cooling-hot water mode

Parameter	Unit	Low stage	High stage
Refrigerant	**	R410A	R134a
Optimum charge amount	g	4700	2300
OD EWT	℃	20, 25, 30, 35	-
ID EWT	℃	2, 7, 12, 17	-
HW EWT	℃	-	40, 50, 55, 60, 65
ODHX flow rate	LPM	10	-
IDHX flow rate	LPM	8	-
HWHX flow rate	LPM	-	6
EEV opening	%	Adjusted	Adjusted

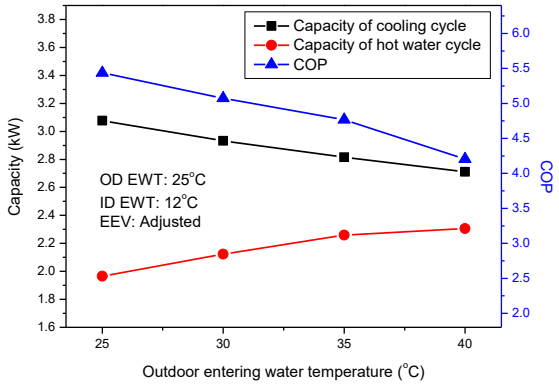


Fig. 2. Capacity and COP variation according to OD EWT

3. Results and discussion

3.1. Performance characteristics according to OD EWT variation

Figure 2 shows capacity and COP variation of the cascade multi-functional heat pump according to OD EWT. Capacity of the cooling cycle decreased with increase in OD EWT due to decrease in heat transfer rate in the evaporator. Capacity of the hot water cycle increased as OD EWT increased due to increase in LS condensing temperature and heat transfer from the LS to the HS while COP of the cascade multi-functional heat pump decreased with increase in OD EWT due to great increase in LS power consumption. Cooling capacity and COP decreased by 13.5% and 29.3% respectively, while capacity of the hot water cycle increased by 14.8% as OD EWT increased from 25℃ to 40℃.

3.2. Performance characteristics according to ID EWT variation

Figure 3 shows variation of capacity and COP according to ID EWT. Capacity of the cooling cycle increased with increase in ID EWT due to increase in refrigerant mass flow rate in the ID HX while COP of the cascade multi-functional heat pump increased with increase in ID EWT due mainly to increase in capacity of the cooling cycle and slight decrease in power consumption of the HS cycle. Furthermore, capacity of the heating cycle was slightly affected by variation in ID EWT. Capacity of the cooling cycle and COP increased up to 27.9% and 26% respectively as ID EWT increased from 2℃ to 17℃.

3.3. Performance characteristics according to HW EWT variation

Capacity and COP variation of the cascade multi-functional heat pump according to HW EWT is shown in Fig 4. Capacity of the cooling cycle was not affected by HW EWT variation. However, capacity of the hot water cycle decreased with increase in HW EWT due to decrease in heat transfer to secondary fluid in the HW HX. Furthermore, COP of the system decreased due to decrease in capacity of the hot water cycle and increase in HS power consumption. Capacity of the hot water cycle and COP decreased up to 15.9% and 28.4% respectively, as HW EWT increased from 40℃ to 65℃.

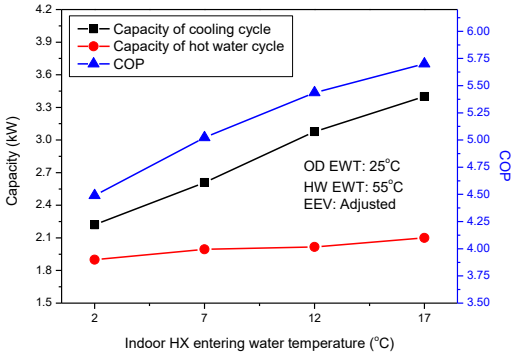


Fig. 3. Capacity and COP variation according to ID EWT

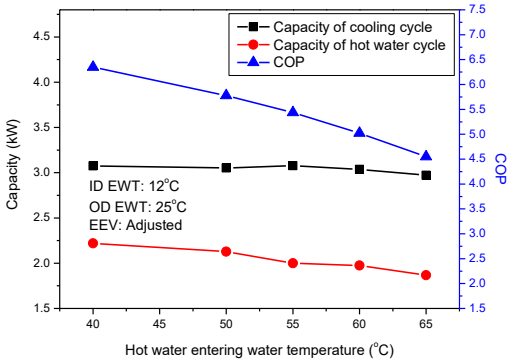


Fig. 4. Capacity and COP variation according to HW EWT

4. Conclusion

This study analyzed the performance characteristics of cascade multi-functional heat pump according to variation of OD EWT, ID EWT and HW EWT in cooling-hot water mode. Heating capacity of hot water cycle increased by 14.8% while cooling capacity and system COP decreased by 13.5% and 29.3% respectively, as OD EWT increased by 15℃ of the standard value. Furthermore, cooling capacity decreased by 27.9% while system COP increased by 27% as ID EWT decreased by 10℃ of the standard value. Capacity of the hot water cycle and system COP decreased by 15.9% and 28.4% respectively as HW EWT increased from 40℃ to 65℃. However, variation of ID EWT and HW EWT had insignificant effect on capacity of the hot water cycle and performance of the cooling cycle respectively.

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