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Experimental Investigate on the Performance of High Temperature Heat Pump Using Scroll Compressor

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Abstract

A tested loop for high temperature heat pump (HTHP) system with a constant speed scroll compressor using HFC245fa as its refrigerant was designed and built. Theoretical analysis and experiment were carried out under the working condition of condensation temperature from 70℃ to 120℃, temperature rise from 30℃ to 50℃. The theoretical and experimental results both show that heating capacity and coefficient of performance (*COP*) of the HTHP increase with condensation temperature increasing at fixed temperature rise, and the discharge superheating reduces with condensation temperature increasing at fixed suction superheating and temperature rise. The experimental results show that the outlet temperature of the pressurized water can be heated up to 114 ℃, *COP* can be as high as 5.18, when condensation temperature and temperature rise are 120℃ and 49℃, respectively.

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Keywords: high temperature heat pump; HFC245fa; scroll compressor

1. Introduction

Under the background of energy consumption and environmental pollution, as a kind of energy saving technology, heat pump technology has become one of effective solutions for energy and environmental problems. According to temperature demand of industrial processes, high temperature heat pump (HTHP) system whose condensation temperature range is from 100°C to 150°C mostly meets the need of industry.

Investigations on HTHP technology have largely been concentrated on the selection of proper working medium and the increase of system efficiency. Researchers conduct lots of theoretical analyses and experiments of existing working fluids for HTHP and environment-friendly refrigerant, HFC245fa, is attracting more and more attention due to its low discharge temperature and high efficiency.

The characteristics of condensation heat transfer of HFC245fa were investigated experimentally on horizontal tube bundles by Ma et al. [1] and the results showed that the condensation heat transfer coefficients of HFC245fa on single smooth tube could be well predicted by Nusselt model under lower heat flux. Huang et al. [2] conducted the experiment of convective boiling heat transfer characteristics of HFC245fa inside horizontal tube and concluded that Liu Winterton correlation is more precise to predict convective boiling heat transfer coefficients of HFC245fa than Chen correlation and Shah correlation. Ma et al. [3] designed the system of HFC245fa whose delivery temperature of 102℃ was achieved by

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using aqueous solution of ethylene glycol as heat transfer fluid at the condenser. Minea [4] succinctly described a high-temperature heat pump-assisted industrial-scale softwood dryer and pointed out potential problems and simple methods to avoid malfunctions or equipment failures. Tveit et al. [5] presented the performance of a commercial installation of the heat pump that generated 110°C hot water from waste heat, which showed an example that the heat pump can deliver over 400 kW of heat at 105°C with a temperature lift of almost 80K with a COP of 2.

From these previous studies [6-8], it can be seen that many piston compressors and screw compressors are used in HTHPs. High efficiency of scroll compressors considered, a tested loop for HTHP system with a constant speed scroll compressor using HFC245fa as its refrigerant was designed and built. The operating performance of HFC245fa was experimentally investigated under high temperature operating conditions and the outlet temperature of 114℃ was achieved by using pressurized water as heat transfer fluid in the condenser while the *COP* was 5.18.

2. Theoretical Analysis

2.1. Theoretical calculation conditions

The HFC245fa theoretical thermodynamic cycle performance calculation was done within the condensation temperature range from 80℃ to 130℃, including cycle performance of different temperature rise(the difference between condensation temperature and evaporation temperature) and different suction superheating (the difference between suction temperature and evaporation temperature). Table 1 lists the condition of theoretical analysis.

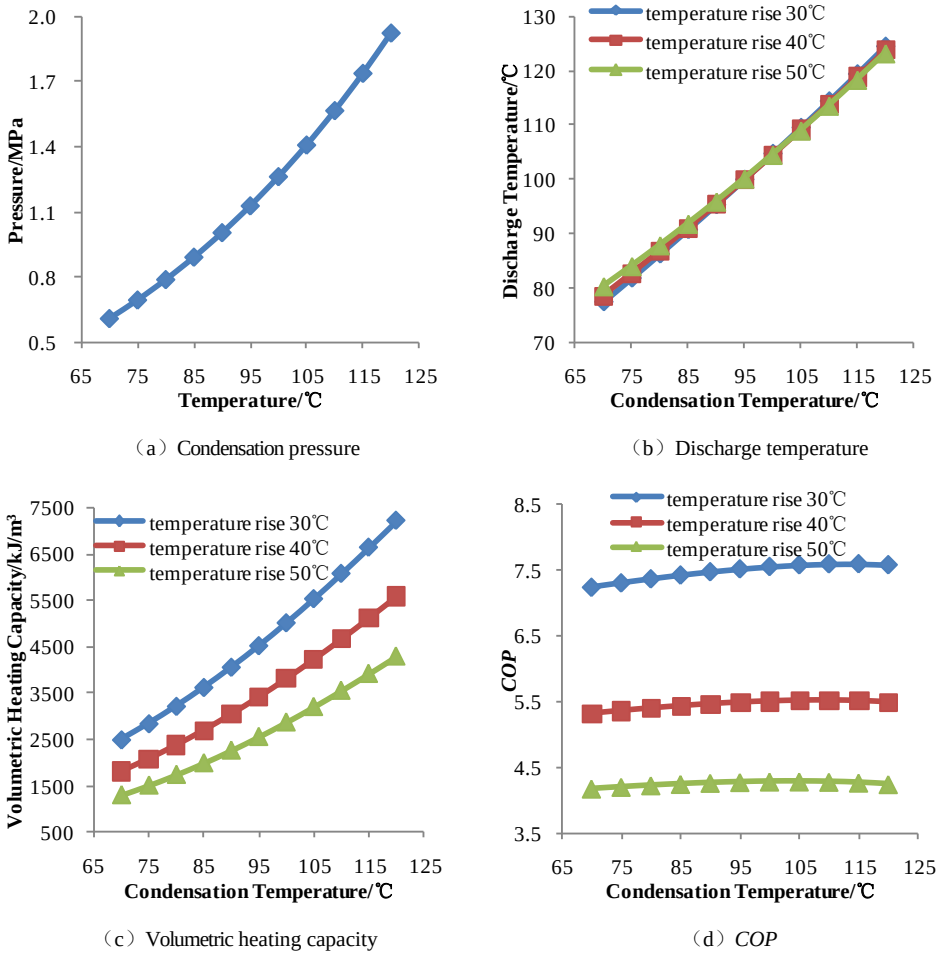
Table 1. *Theoretical calculation conditions*

Parameter	Unit	Value
Evaporating temperature T_{evap}	℃	30~90
Condensation temperature T_{cond}	℃	70~120
Superheating ΔT_{sh}	℃	6
Subcooling ΔT_{sc}	℃	8
Isentropic efficiency η_s	/	0.65
Pressure drop(heat exchangers and connecting pipes)	kPa	0

2.2. Theoretical results

Figure 1 shows the characteristics of HFC245fa theoretical cycle. It shows that HFC245fa has low condensation pressure at high temperature. Furthermore, discharge superheating (the difference between discharge temperature and condensation temperature) is very low and discharge temperature doesn't exceed 125°C even if condensation temperature reaches 120°C. That is to say HFC245fa is suitable for high temperature heat pump.

It can also be seen in Figure 1c that volumetric heating capacity of HFC245fa theoretical cycle enhances greatly with condensation temperature increasing at the fixed temperature rise, but reduces with the fixed temperature rise increasing at same condensation temperature. Figure 1d indicates that when condensation temperature increases at fixed temperature rise, the *COP* increases slowly to maximum and then decreases.



（a）Condensation pressure

（b）Discharge temperature

（c）Volumetric heating capacity

（d）*COP*

Fig. 1. Characteristics of theoretical cycle

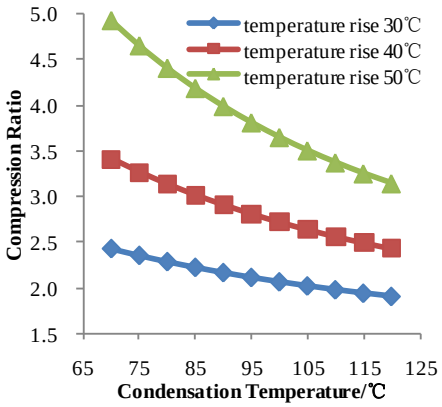
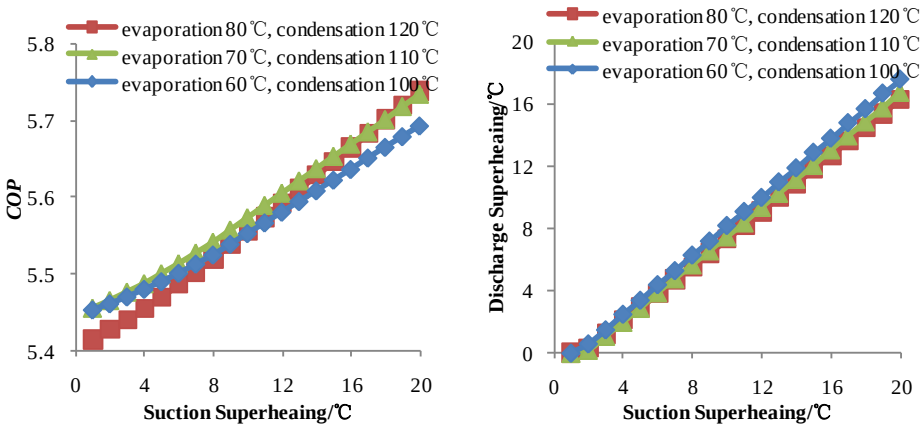


Fig. 2. Compression ratio of different operating conditions

Figure 3 presents variations of the *COP* and discharge superheating with suction superheating. It is shown in Figure 3a that the *COP* becomes higher when suction superheating increases under the same working condition, which is more evident at high temperature running conditions. Theoretical analysis implies that high suction superheating has a beneficial effect on the cycle. However, the heat exchanger and system matching should be taken into consideration in an actual cycle.

It can be seen in Figure 3b that the discharge superheating increases linearly with suction superheating increasing at the fixed operating condition and the discharge superheating of high temperature running condition is lower for the same suction superheating, which implies that during the tests under high temperature conditions, suction state should be drawn attention especially to avoid non-superheating discharge state.



（a）*COP* （b）Discharge superheating

Fig. 3. Variations of *COP* and discharge superheating with suction superheating

3. Experimental Research

3.1. The introduction of test facility

Figure 4 presents the tested loop for HTHP system, and the dotted lines in the graph are the refrigerant cycle while the solid lines show the heat transfer fluid cycle. T and P denote the measurement of temperature and pressure, respectively. The temperature is measured using T-type thermocouple and the pressure is measured by pressure sensors whose measuring accuracy is ±0.5% of the range. N denotes the power consumption of the compressor recorded by a power analyzer of measuring accuracy of ±0.5% of the acquisition.

The compressor of the system is scroll compressor and the throttling device is electronic expansion valves for high temperature when the evaporator and the condenser are both tube-in-tube heat exchangers. The heat transfer fluid of the evaporator and condenser is provided by a pressurized water system where boiling point of water is above 100°C and flow rate of water is measured by the flowmeter.

3.2. Test conditions

The experiments of HFC245fa cycle performance were carried out within the condensation temperature range from 70°C to 120°C. In the experiments, saturation temperature of suction pressure is equal to the evaporation temperature and saturation temperature of discharge pressure is equal to the condensation temperature, which is attained by adjusting the inlet water temperatures and flow rates of the evaporator and the condenser. Furthermore, different suction superheating should be regulated in order to make the performance of the system best for the same test condition.

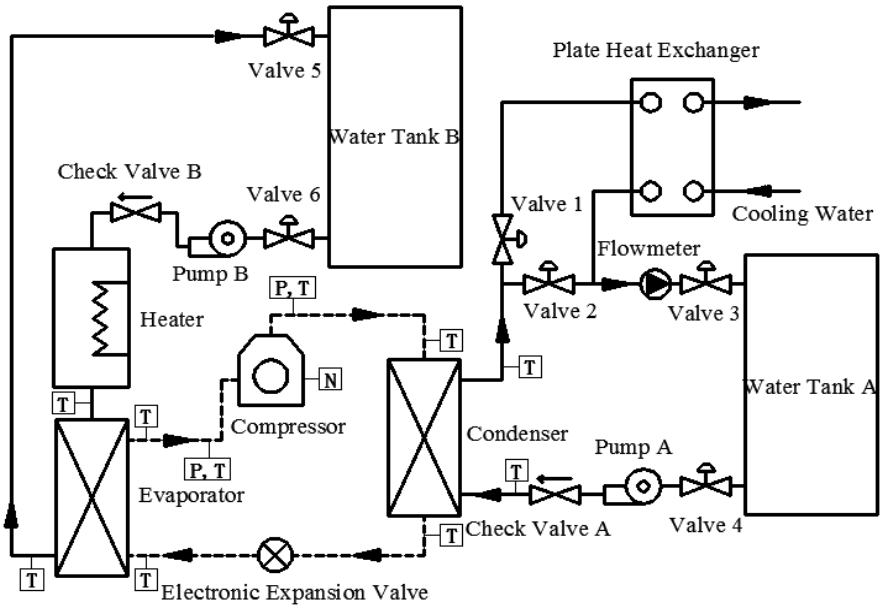
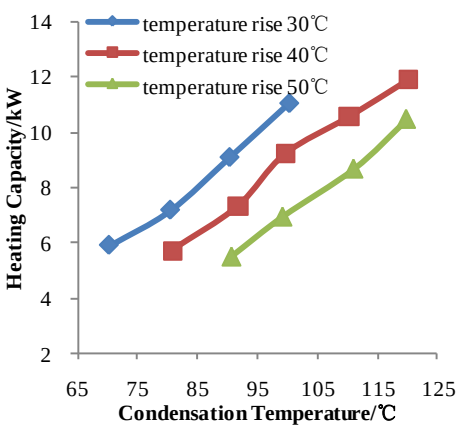


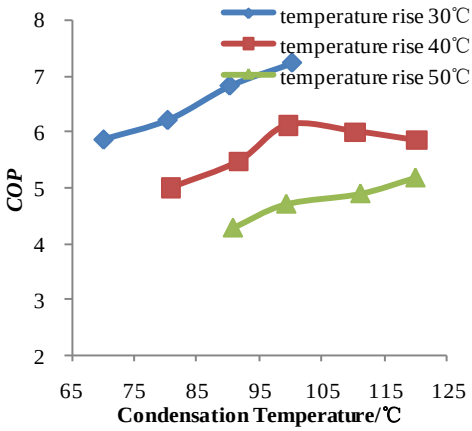
Fig. 4. Schematic diagram of test facility

3.3. Test results

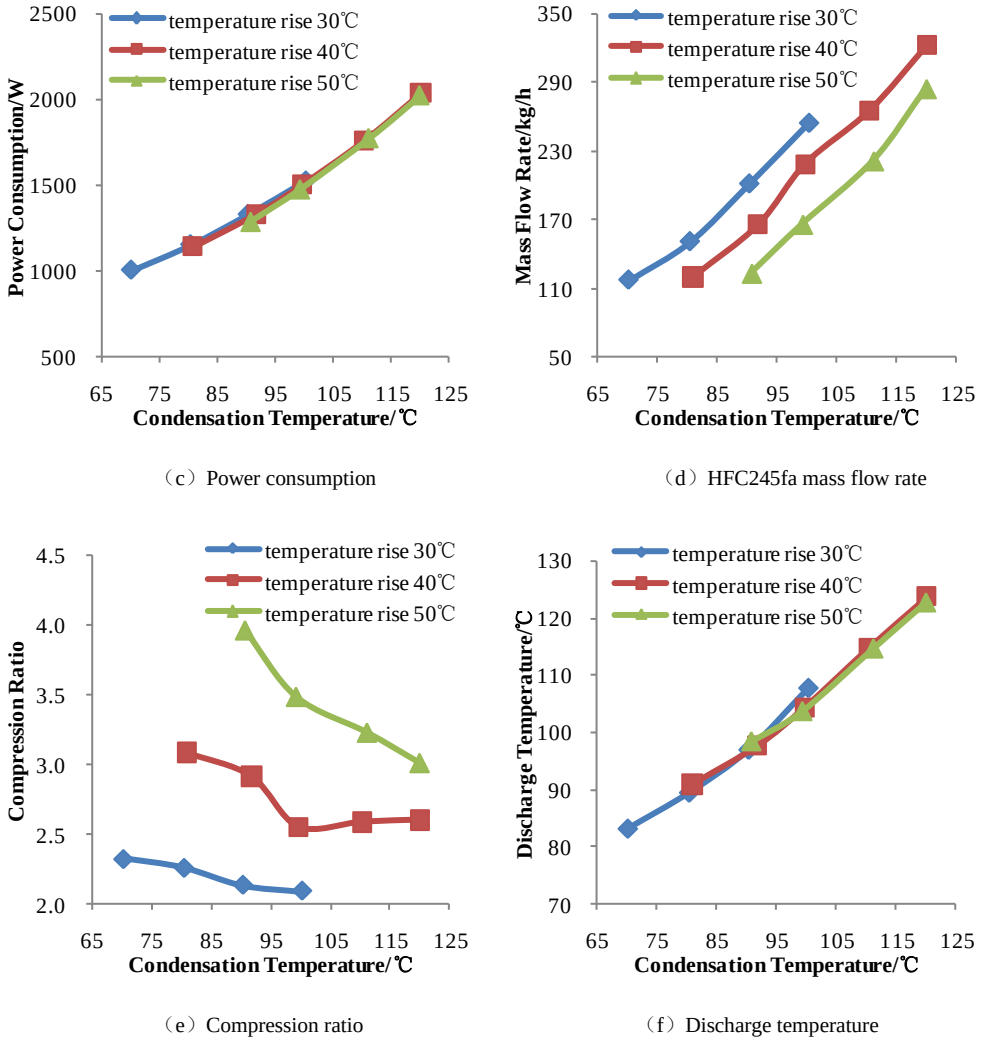
Figure 5 to 7 present experiment results. It is noted that the *COP* is the ratio of heating capacity of the system called *Q* to power consumption of compressor called *N*. *N* is recorded by a power analyzer and *Q* is calculated by the heat balance in condenser ignoring the heat loss whose value is calculated by the water flow rate, the water temperature of outlet and inlet of the condenser. The mass flow rate of refrigerant is calculated by *Q* and refrigerant enthalpy of outlet and inlet of the condenser. The calculating method of heating capacity has been calibrated using an electric heater and the deviation is within ±5%.



（a）Heating capacity



（b）*COP*



（c）Power consumption　　（d）HFC245fa mass flow rate

（e）Compression ratio　　（f）Discharge temperature

Fig. 5. Test results of different operating conditions

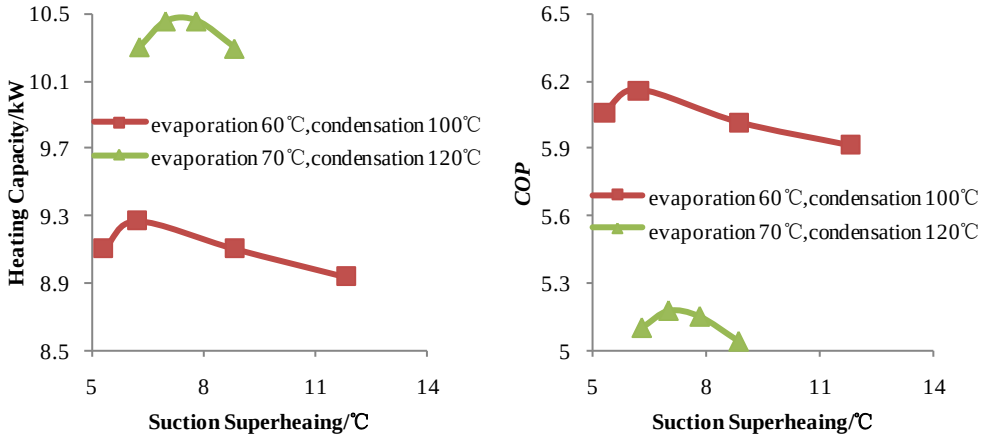
Figure 5a shows that the higher heating capacity of the system is attained at higher condensation temperature at the fixed temperature rise, which is consistent with theoretical analysis. The *COPs* of the tested system increase with the condensation temperature increasing at the 30℃ and 50℃ temperature rise, which are different from theoretical cycle results. The experimental subcooling increases from 6℃ to 13℃and compression ratio decreases (seen in Figure 5e) with condensation temperature increasing at the fixed temperature rise, which leads to the volumetric heating capacity and compressor efficiency both increasing. The increase of experimental subcooling and compressor efficiency leads to the difference from theoretical results. When condensation temperatures are 100℃ and 120℃ at the 40 ℃temperature rise, the actual temperature rises are 37℃ and 43℃, respectively. Figure 5e can explain the reason why the *COP* curves in Figure 5b increase first and then decrease at 40℃ temperature rise. The experimental results show that the outlet temperature of the pressurized water can be heated up to 114℃and the *COP* can be as high as 5.18, when the condensation temperature and temperature rise are 120℃ and 49℃, respectively.

It can be seen in Figure 5c and 5d that the compressor power consumption and the mass flow rate of HFC245fa increase with condensation temperature increasing at a fixed temperature rise. Figure 5(f) shows that discharge temperature varies little with temperature rise increasing at a fixed condensation temperature.

Figure 6 indicates variations of heating capacity and *COP* with suction superheating. It is found that there exists an optimum suction superheating corresponding to the heating capacity or the *COP*, which differs from

theoretical results. The experimental results prove that if suction superheating is extremely high, heating capacity and *COP* will decrease. The optimum suction superheating range is from 6℃ to 12℃ at any saturated suction pressure for the tested system, and moreover, the high temperature working condition needs a higher suction superheating.

Figure 7 shows that discharge superheating increases linearly with suction superheating increasing at the fixed operating condition. The discharge superheating of the high condensation temperature is lower for the same suction superheating than low condensation temperature, which shows the same trend as theoretical results.



（a）Heating capacity　　（b）*COP*

Fig. 6. Variations of heating capacity and *COP* with suction superheating

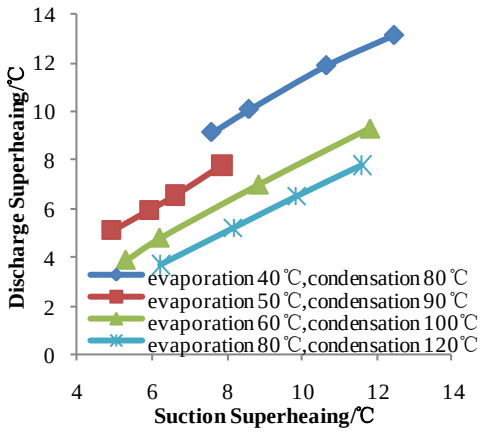


Fig. 7. Variations of discharge superheating with suction superheating

4. Conclusions

Theoretical analysis and experiments were carried out under different working conditions on the performance of HFC245fa high temperature heat pump with scroll compressor.

Main conclusions are as following:

The theoretical and experimental results both show that the heating capacity and *COPs* of the HTHP increase with the condensation temperature increasing at a fixed temperature rise. Theoretical analysis indicates that high suction superheating has a beneficial effect on the cycle; however, the heat exchanger and system matching should be taken into consideration in an actual cycle. The optimum suction superheating range is from 6°C to 12°C for the tested system, and moreover, the high temperature working condition needs a higher suction

superheating.

The experimental results show that the outlet temperature of the pressurized water can be heated up to 114℃ and the *COP* can be as high as 5.18, when the condensation temperature and temperature rise are 120℃ and 49 ℃, respectively

The reliability of the long-term running for the HTHP system needs to be further validated.

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