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Experimental Research of Air-Source Heat Pump Water Heater in Low Temperature

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Abstract: A new type of air source heat pump water heater system with scroll compressor through middle injection of economizer in the course of compression is put forward operating reliably long and efficiently in low temperature in this study. The experimental prototype is set up, System fundamentals and the operation modes are introduced, Experimental research on operation characteristics of the unit in three different operation conditions is done in the lab of enthalpy difference; Heating capacity and COP were 8.84 kW and 2.43, respectively under the condition of environmental temperature of which is -7 and -8ºC, respectively for dry bulb temperature and wet bulb temperature. The result shows that the unit operates reliably long and that heating capacity and COP of the unit are improved in low temperature.

Keywords: Air source heat pump water heater, economizer, low temperature, medial injection

INTRODUCTION

To meet the need of quality of life and solve consumption of energy, highly efficient, energy-saving and environment-friendly water heaters in our daily life are required to use and air source heat pump water heater works on heat pump principle which makes low-grade thermal energy transfer from air to water by the cycle of heat pump. Compared to gas water heater, electric water heater and solar water heater, air source heat pump water heater is highly efficient, energy-saving and environment-friendly and it is well-received by customers, the marketing prospect is very broad (Arif and Yildiz, 2009; Zhang *et al*., 2006; Ji *et al*., 2005). But these problems that heating capacity decreases, COP of system diminishes and discharge temperature is too much high would appear when air source heat pump water heater is used to obtain hot water in the winter in cold areas (Stefan and Eckhard, 2005). So developing the technology of heat pump in low temperature is of importance.

To make air source heat pump operate reliably long and efficiently in low temperature, many scholars at home and abroad had developed research on air source heat pump water heater. Tadashi yanagisawad put forward the system with medial liquid injection bypass scroll compressor in the course of compression to solve the problem of extortionate discharge temperature (Dutta *et al*., 2001). Sami adopt the mixture refrigerant of HFC-23, HFC-22 and HFC-152a, average EER reached up to 2.4 under the condition of -13.5 according to test (Sami and Tulej, 1995). Ma guoyuan proposed air source heat pump system consisting of scroll compressor with subcooler, it could operate properly under the condition of -15 (Ma *et al*., 2003). Wang wei measured on the spot the performance of double coupling heat pump system applying in Beijing area and the data showed the heating coefficient of the system is higher in low temperature (Wang *et al*., 2005). Cao feng developed theoretical and experimental research on air source heat pump water heater with enhanced enthalpy injection, the results that the ratio of refrigerant injection should not be higher than 5% were obtained, moreover injection circuit had helpful effect on the system when the temperature ranged from -15 to 20ºC (Cao *et al*., 2009).

A new type of air source heat pump water heater system with scroll compressor through medial injection of economizer in the course of compression is put forward in this study. The experimental prototype is set up; Experimental research on operation characteristics of the unit in three different operation conditions is done in the lab of enthalpy difference.

METHODOLOGY

Fundamentals of air source heat pump water heater system in low temperature: The sketch of air source HPWH system at low temperature is shown in Fig. 1. The system has the following characteristics comparing to conventional air source heat pump water heater. When the environmental temperature is higher than 5ºC, electromagnetic valve15 is shut off, the operation of system is same as the conventional air source heat pump

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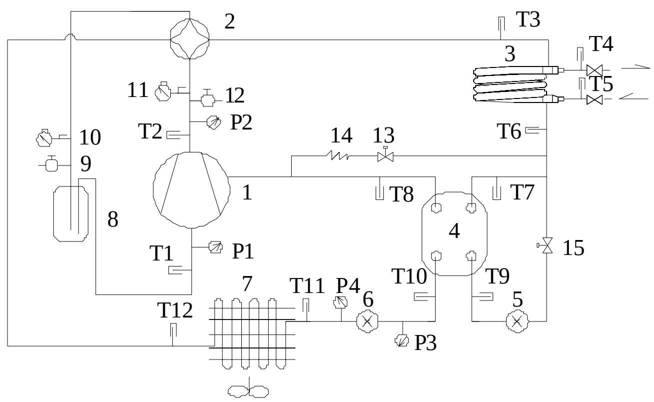

Fig. 1: The principle diagram of air source HPWH system at low temperature

water heater. But when the environmental temperature is less than or equal to 5ºC, electromagnetic valve15 is open and the liquid refrigerant from the condenser is divided into primary and auxiliary pipelines, the primary pipeline enters directly the economizer, the liquid refrigerant of auxiliary pipeline is throttled by thermostatic expansion valve 5 and then changed into the mixture of gas and liquid entering the economizer. After heat of both refrigerants from primary and auxiliary pipelines is transferred in the economizer, the refrigerant from the primary pipeline is changed into subcooled liquid and then the pressure is reduced entering the evaporator. The low temperature and pressure wet vapor absorbs thermal energy in the evaporator and is boiled and then it is sucked in the suction of the compressor. The refrigerant from the auxiliary pipeline is changed into gas and then sucked in the auxiliary suction of the compressor. The refrigerant from the primary and auxiliary pipelines is mixed in the suction cavity of the compressor and then is compressed to discharge from the compressor entering the condenser, now it completes the cycle.

Compressor, 2. four-way valve, 3. heat recovery exchanger, 4. economizer, 5, 6 thermostatic expansion valve 7. air-cooled heat exchanger, 8. gas-liquid separator, 9, 12. check valve, 10, 11. pressure controller, 13, 15. electromagnetic valve 14. capillary tube.

When the discharge temperature of the compressor is higher than 105ºC, electromagnetic valve 13 is open. The liquid refrigerant from the condenser is throttled by capillary tube 14 entering the suction cavity of the compressor, the compressed gas in the compressor is cooled by the refrigerant and discharge temperature is decreased, the reliability of the compressor is improved. When the discharge temperature is less than or equal to 90ºC electromagnetic valve 13 is shut off.

Experimental setup:

Introduction to the experimental unit and method: The experimental prototype was designed as a unit with Copeland scroll compressor, the refrigerant is R22 and the type of compressor is ZW61KS-TFP-542. The condenser is tube-in-tube heat exchanger all together 4 tubes and the material for inner and external tube is outside thread and seamless tube and inner and external tube on the side of the condenser is 28 and 19 mm in diameter, 1.5 and 1.3 mm in wall thickness, 3.46 and 3.71 m in length, respectively. The evaporator is one fin-tube heat exchanger using aluminum foil plat fin with hydrophilic film, the pitch of fin is 2.2 mm, the external diameter of copper tube is 9.52 mm, there are 2 rows in 36 arrays and the total length is 93.8 m. The economizer is the plate heat exchanger with stainless steel-copper brazing and the area for heat exchange is 0.35 m^2. The type of thermal expansion valve for primary pipeline is BAE3HW100 of Emerson, the type for auxiliary pipeline is BAE2HCA of Emerson. The type of four-way valve is DHF-20 made in China, Chunhui Zhejiang. The type of two electromagnetic valves is SV10AW made in China, Fengshen Shanghai. The type of gas liquid separator is KFR120 made in China, Qing'an Dongguan. The water volume of hot water tank is 300 kg.

Three hundred kg water with 15ºC is added into the water tank in advance in the course of experiment. The heated water is circulated between the water tank and the condenser and the temperature is elevated progressively. The average temperature of hot water in the tank is elevated at interval of 10ºC, the recorded data is saved, until the average temperature of 300 kg water reaches up to 55 , the experimental test is over.

Measuring spot arrangement and experimental setup: After the experimental unit is assembled and debugged successfully, it is carried out in a laboratory built on the basis of relevant code and standard. The test method of heating capacity for the unit has room-type calorimeter and air enthalpy difference method, which is adopt the latter in the experiment. Air enthalpy difference laboratory includes indoor environment, outdoor environment and control cabinet. The experimental prototype is set in outdoor environment, the data of heating capacity, power, the voltage, the current and energy efficiency ratio of the unit were obtain. Moreover, to measure temperature, pressure and flow rate, pressure gauges, thermocouples, flow meters and isolation valves were also installed at certain parts of the unit (Fig. 1). The sensors of measuring point were connected with Data Acquisition Instrument of Agilent 34970A, the data of each measuring point were recorded automatically during the experimental test.

EXPERIMETAL TEST AND RESULTS ANALYSIS

Outdoor dry-bulb and wet-bulb temperature for performance test is 38 and 23ºC, 7 and 6ºC, -7 and -8ºC, respectively. The unit is tested under three conditions when the temperature of 300 kg water is heated from 15 to 55ºC, respectively.

Suction and discharge pressure and temperature with the temperature of hot water: Figure 2 and 3 show the change of suction and discharge pressure and temperature of compressor with the rise of water tank temperature. Discharge pressure and temperature of the compressor has represented ascending trend along with the rise of hot water temperature in the tank, The variation range of suction pressure and temperature is not too much great and keep invariable. Because condensing pressure and temperature also gradually increased during the gradual advance of hot water temperature in the course of heating circularly. In the situation of invariable evaporating pressure, compression ratio of the compressor increased and specific volume of suction increased, circulating mass of refrigerant and volumetric efficiency, this is the main cause making discharge pressure and temperature increase.

When the environmental temperature changed, suction temperature decreased with the decline of the environmental temperature. When the temperature of hot water in the tank was 55ºC, discharge temperature reached up to 92ºC under the condition of environmental temperature which is 38 and 23ºC, respectively for dry bulb temperature and wet bulb temperature. Discharge temperature is highest and reached up to 102ºC under the condition of environmental temperature is -7 and -8ºC, respectively for dry bulb temperature and wet bulb temperature. When the environmental temperature decreased, the capacity of heat exchange between the refrigerant and the environment declined, the evaporating

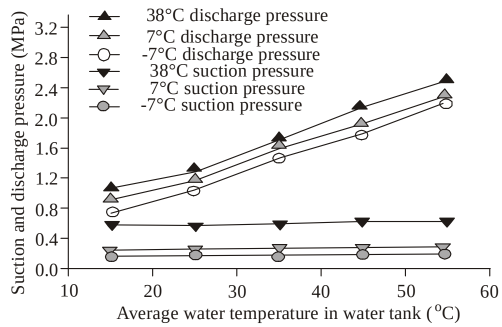

Fig. 2: The curve of suction and discharge pressure with temperature variation of hot water

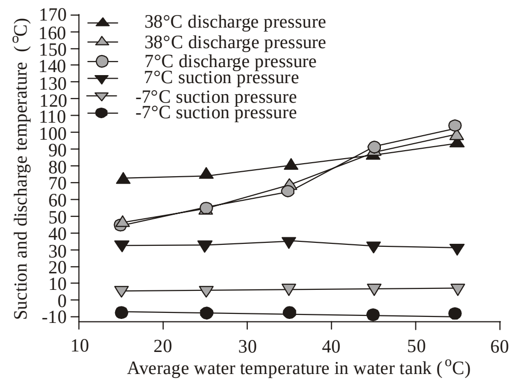

Fig. 3: The curve of suction and discharge temperature with temperature variation of hot water

temperature dropped yet, the low and high pressure difference of the compressor increased. At the same time the superheat degree of the refrigerant diminished, the mass flow rate of the refrigerant lessened for the regulation of thermostatic expansion valve, the refrigerating capacity of the compressor was lowered, inducing that discharge temperature increased. In Fig. 3 discharge temperature of the compressor didn't exceed over 105ºC. It show that discharge temperature of the compressor was controlled effectively through electromagnetic valve 13 by liquid injection into the cavity of the compressor, the reliability and safety of air source heat pump water heater in low temperature was improved.

When the environmental temperature changed, suction and discharge pressure increased with the rise of the environmental temperature. When the temperature of hot water in the tank was 55ºC, discharge pressure reached up to 2.55 MPa under the condition of environmental temperature which is 38 and 23ºC, respectively for dry bulb temperature and wet bulb temperature, the pressure reached up to 2.25 Mpa under the condition of environmental temperature which is -7 and -8ºC, respectively for dry bulb temperature and wet bulb temperature.

Table 1: The comparison of performance under difference conditions

Condition	Heating capacity (kW)	Input power (kW)	COP
Dry bulb temperature 38ºC	16.87	4.67	3.61
Wet bulb temperature 23ºC			
Dry bulb temperature 7ºC	9.54	3.78	2.52
Wet bulb temperature 6ºC			
Dry bulb temperature -7ºC			
Wet bulb temperature -8°C	8.84	3.65	2.43

Performance analysis under difference conditions: Table 1 shows the performance of system under three conditions. Heating capacity, input power and COP of system decreased with the decline of the environmental temperature. Under the condition of environmental temperature which is 38 and 23ºC, respectively for dry bulb temperature and wet bulb temperature, heating capacity, input power and COP of system were maximal. Because auxiliary pipeline started to operate, electromagnetic valve15 is open, when the environmental temperature is less than or equal to 5ºC , heating capacity of the unit was enhanced in low temperature environment. So the decreased extent of heating capacity and COP of system under the condition of environmental temperature which is -7 and -8ºC, respectively for dry bulb temperature and wet bulb temperature was less than that under the condition of environmental temperature which is 7 and 6ºC, respectively for dry bulb temperature and wet bulb temperature. Heating capacity and COP were 8.84 and 2.43, respectively, meeting the heating demand in cold area and having the energy-saving advantage.

CONCLUSION

Conventional air source heat pump water heater operates in low temperature, heating capacity and reliability are decreased vastly, it is difficult to meet the demand of hot water in the winter in cold area. So a new type of air source heat pump water heater system with scroll compressor through medial injection of economizer in the course of compression is put forward in this study. The experimental prototype is set up, Experimental research on operation characteristics of the unit in three different operation conditions is done in the lab of enthalpy difference. The result shows the system could operate safely as follows.

Discharge temperature of the compressor didn't exceed over 105ºC under the difference conditions, It show that discharge temperature of the compressor was controlled effectively through electromagnetic valve 13 by liquid injection into the cavity of the compressor, the reliability and safety of air source heat pump water heater in low temperature were improved.

Heating capacity and COP were 8.84 kW and 2.43, respectively under the condition of environmental temperature which is -7 and -8ºC, respectively for dry bulb temperature and wet bulb temperature, it show that heating capacity and COP of the unit were improved and low-temperature adaptability was enhanced vastly.

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REFERENCES

Arif, H. and K. Yildiz, 2009. A review of heat pump water heating system. Renew. Sustain. Energ. Rev., 13(6-7): 1211-1229.

Cao, F., J.Y. Fei and Z.W. Xing, 2009. Review of air-source heat pumps for low temperature climates study on performance of a heat pump water heater using suction stream liquid injection. Appl. Thermal Eng., 29(14-15): 2942-2948.

Dutta, A.K., Y. Tadashi and F. Mitsuhiro, 2001. An investigation of the performance of a scroll compressor under liquid refrigerant injection. Int. J. Refrigerat., 24(6): 577-587.

Ji, J., G. Pei and T.T. Chow, 2005. Performance of multi-functional domestic heat-pump system. Appl. Energ., 80(3): 307-326.

Ma, G., Y.Q.H. Chai and Y. Jiang, 2003. Experimental investigation of air-source heat pump for cold regions. Int. J. Refrigerat., 26(1): 12-18.

Stefan, S.B. and A.G. Eckhard, 2005. Review of air-source heat pumps for low climates. 8th International Energy Agency Heat Pump Conference.

Sami, S.M. and P.J. Tulej, 1995. A new design for an air-source heat pump using a ternary mixture for cold climates. Heat Recover. Syst. CHP, 1524(6): 521-529.

Wang, W., Z. Ma and Y. Jiang, 2005. Field test nvestigation of a double-stage coupled heat pumps heating system for cold regions. Inte. J. Refrigerat., 28(5): 672-679.

Zhang, J., R.Z. Wang and J.Y. Wu, 2006. System optimization and experimental research on air source heat pump water heater. Appl. Thermal Eng., 27(5): 1029-1035.