

System optimization and experimental research on air source heat pump water heater

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Abstract

This paper deals with the system optimization of air source heat pump water heater (ASHPWH), including calculating and testing. The ASHPWH system consists of a heat pump, a water tank and connecting pipes. Air energy is absorbed at the evaporator and pumped to storage tank via a Rankine cycle. The coil pipe/condenser releases condensing heat of the refrigerant to the water side. An ASHPWH using a rotary compressor heated the water from initial temperature to the set temperature (55 °C). The capillary tube length, the filling quantity of refrigerant, the condenser coil tube length and system matching are discussed accordingly. From the testing results, it could be seen that the system performance COP could be improved obviously.

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1. Introduction

The prevailing products in the domestic market of water heater are gas water heater (GWH), electric water heater (EWH) and solar water heater (SWH), while heat pump water heater (HPWH), as the forth kind of water heater, appears in the market recently. Compared with the three formers, HPWH has several advantages such as energy-saving, low running fare and safety in using, which all bring it a promising prospect in domestic water heating. Air source heat pump water heater (ASHPWH), based on the principle of Rankine cycle, could absorb heat from air at lower temperature, and through the work of heat engine, the absorbed heat and the consumed work is transferred into water tank – the higher temperature heat source. From the environment the system gets energy, that is, possibly 3–4 times of the electric power it will consume. Totally, it contributes 4–5 times of the electric energy. So

ASHPWH is preferred by users due to its virtues such as high efficiency and energy saving.

Since the 1950s, researches have been performed on HPWHs, including structure, thermodynamics, working fluids, operation controlling, numerical simulation and economical analysis.

Condenser design underwent two stages-bayonet style with annular flow and U style pipe. Mei et al. tested performance of 8 condensers in a water tank. When considering COP as the function of mean water temperature, they found that the performance of U style pipe system is commonly better than that of bayonet condenser system. System COP and the rate of heat production increase with the loop number increases [1].

Hiller led a group studying dual-tank water heating system from 1991. Elementary research shows that more than 60 kinds of dual-tanks have potential study values. Different pipe connections and control strategies can achieve goals such as optimizing control of hot water supply and power controlling. Continuous tests suggest that the efficiencies of 38 kinds of dual-tank water heating systems are higher than HPWH of other structures. Of course,

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the heat loss of dual-tank water heating system is more than single-tank system with the same volume [2]. Huang and Lin also studied the dual-tank HPWH. The water tank volume was 100 L. Results showed that heating water from 42 °C to 52 °C need 10–20 min, and the all-year COP reached 2.0–3.0. Compared with electrical water, the energy saving fraction was 50–70%, and the hot water discharge efficiency was 0.912 [3].

Hasegawa et al. proposed a two-stage compression and cascade heating heat pump system for hot water supply. Using R12, it could heat water from 10 °C directly to 60 °C. The inlet and outlet water temperatures of evaporator are 12 °C and 7 °C, and the system COP is 3.73 [4]. Ji et al. combined HPWH and conventional air conditioning, and realized a multi-functional domestic heat pump (MDHP). This equipment could implement multi functions in moderate climate areas, and operate long time with high efficiency. When refrigeration and heating run simultaneously, the average of COP and EER could reach 3.5 [5,6].

R12, R22 were the most common used work fluids in HPWH. As the proposal of ozonosphere protection, R22 became the only conventional fluid still been used. In developing countries such as China, the dead line using R22 is 2040. Until now, it is still widely used. So there still have some meaning to do research on the R22 system performance improvement, which is also a means of saving energy. Sloane et al. using ribbed roil pipe in the middle of water tank, in ambient temperature of 24 °C, and water temperature 27 °C, COP is 2.4. Mei et al. also use R22 as refrigerant, the result is that when water temperature is 27 °C, an ambient temperature are 20 °C and 27 °C, the COP can be, respectively, 4.0 and 4.5 [7]. From the literature using conventional working fluids, it could be seen that, when the environmental temperature is moderate and condensing temperature is not high, R22 could get fine thermodynamic performance and efficiency. However, when the system runs in the high temperature area, for example, above 50 °C, the discharge temperature and pressure of compressor are both very high, especially in cold winter. The working condition of compressor is worse than ordinary air conditioning heat pump, which seriously affect system safety and reliability. So it is urgent to find new fluid of better performance.

Much related research has been conducted to enable the ASHPWH to run effectively. Morrison et al. [8] demonstrated a method for annual load cycle rating of ASHPWH. Kim et al. [9] proposed a dynamic model for a water heater driven by a heat pump system. Ding et al. [10] and Yao et al. [11] have done much research on defrosting to improve the ASHPWH system working in the winter. Fan et al. used a 7500 W HPWH to study its energy saving character. Considering the power consumed by fan and water pump, the system COP was 3.3. If only consider the compressor, the COP became 4.18 [12].

However, as far as ASHPWH is concerned, manufacturers have not agreed on the parameters and the matching of

heat pumps and water tanks, mainly due to the different working conditions including areas, living habits and all year-round running. Heat pump water heater system is consisted of out-door heat pump, water tank and connecting pipes etc. Some manufacturers use air conditioning heat pump (out-door machine) directly, and complete the system just by adding a water tank. Obviously, the working conditions of a ASHPWH vary from those of air conditioner. Temperature at the hot side of a ASHPWH rises gradually, but its cooler side is changing according to the climate year round. Thus, it is necessary to standardize the products of ASHPWH.

In order to enhance the system performance (COP), reduce the product cost and optimize the running condition, system components should be investigated first. Besides compressor, condenser, evaporator and thermal valve or capillary, the refrigerant filling quantity, matching between water tank and heat pump unit are also important for the system. This paper deals with the system optimization of the air source heat pump water heater (ASHPWH), including calculating and testing. The capillary tube length, the filling quantity of refrigerant, the condenser coil tube length and system matching are discussed accordingly. From the testing results, it could be seen that the system performance COP could be improved obviously after system optimization. We hope that it could provide some valuable suggestions for future development of ASHPWH.

2. ASHPWH experiment system

The testing system of ASHPWH is shown in Fig. 1. It is composed of a temperature and humidity controlled room, heat pump, water tank, control system and test system. A data logger (Keithley 2700) and a PC are used to record temperatures of water in the water tank. Also, temperatures at the inlet and outlet water pipes, the ambient temperature, the saturated evaporating temperature, and the transient electric input power are stored in the PC automatically as files.

During the ASHPWH system running, the working fluid absorbs heat from air, evaporates in the evaporator, then is compressed into the high pressure and temperature vapor, which is then condensed into liquid and release heat in the coil condenser to heat up the water in the water tank. The liquid goes through capillary tube or thermal expansion valve turning into gas–liquid mixture with low temperature and pressure. The low temperature liquid is vaporized in the evaporator after absorbing heat from the air. In the experiment, a controller sets the start/end temperature points and the running mode. When the water temperature goes up to the end point, the system stops automatically. If it gets down to some temperature, the system will restart to compensate for the water heating. We discuss the parameters just in one heating process, in which we preset the temperature and mix the water in water tank to unify its initial and final temperatures. The COP could be calculated based on the heat gained and the electric power consumed.

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