

EXPERIMENTAL RESEARCH ON HEAT TRANSFER IN A COUPLED HEAT EXCHANGER

by

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The heat exchanger is a device used for transferring thermal energy between two or more different temperatures. The widely used heat exchanger can only achieve heat exchange between two substances. In this paper, a coupled heat exchanger is proposed, which includes a finned heat exchanger and a double pipe heat exchanger, for multiple heat exchange simultaneously. An experiment is conducted, showing that the average heating capacity increases more than 35%, and the average heating efficiency increases more than 55%, compared with the ordinary air-source heat pump.

Key words: *coupled heat exchanger, coupled heat transfer characteristic, heat pump*

Introduction

A heat exchanger is a heat-transfer device that is used for transfer of internal thermal energy between two or more fluids available at different temperatures. In most heat exchangers, the fluids are separated by a heat-transfer surface, and ideally they do not mix. Exchangers are used in the power, petroleum, transportation, air conditioning, refrigeration, cryogenic, heat recovery, alternate fuels, and other industries [1]. The heat exchanger can be divided into tube-type, plate-type, and extension surface type ones according to their shapes and structure surfaces of the heat exchangers. Tube-type heat exchangers include snake-tube heat exchangers, double tube heat exchanger, and shell and tube heat exchanger. Plate heat exchangers include spiral plate heat exchanger, plate heat exchanger, and plate shell heat exchanger. Extension surface type heat exchangers include tube-fin heat exchanger, plate-fin heat exchanger and so on [2]. Among the many types of heat exchangers in the structure, double tube heat exchangers and tube-fin heat exchangers are widely used in refrigeration and air-conditioning system for heat transfer equipment. The heat exchangers also can be divided into indirect contact heat exchanger and direct contact heat exchanger. The heat exchangers above are all indirect contact heat exchangers. The main form of direct contact heat exchangers are cooling tower. Over the past several decades, with the ever-increasing of the energy-type and the continuing improvement of equipments and systems, the heat exchangers had been rapidly developed. However, the widespread use of the indirect heat exchanger can only achieve the heat exchanger between two kinds of substances; it can not achieve heat exchange of one substance with other two substances at the same time.

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Heat exchanger design

At present, air-conditioning equipment has been widely used in various fields. With the extensive use of air-conditioning, air-conditioned high-energy consumption is gradually concerned by people. There are indications that air-conditioning power consumption of living accounts more than 20% of the total social energy consumption, and the quantity is rising year by year [3]. Air-conditioning system energy conservation has become the priority of air-conditioning system design and research. The air conditioning systems which use the solar energy, geothermal energy, and waste heat as heat source has become a new direction of the research and apply, and even appeared air conditioning systems with a variety composite energy sources. In order to achieve a variety of heat sources, usually are installed two or more forms of heat exchangers in the air-conditioning system [4]. The result is the increased complexity of the air-conditioning system and equipment, covering more area, and other related issues.

Air-conditioning systems usually use air heat source by tube-fin heat exchanger or use liquid heat source by double tube heat exchanger. So the coupled heat exchanger which is able to achieve the function of the tube-fin heat exchanger and double tube heat exchanger at the same time is the best option for composite heat source air-conditioning system.

Structure design

Double tube heat exchanger is made by installing one or more tube inside a package or root tube, and form inner channel and ring channel between the inside and outside tube. The substance in the two channel exchange heat through the inner tube wall. In the air-conditioning systems with liquid heat source, the double tube heat exchangers are main equipment.

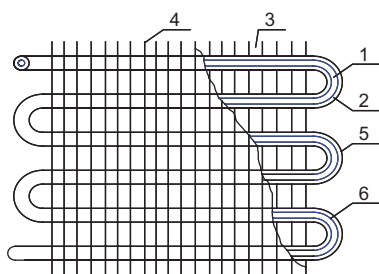


Figure 1. Schematic diagram of coupled heat exchanger; 1 - liquid heat source channel; 2 - refrigerant channel; 3 - air channel; 4 - fin; 5 - outside tube; 6 - inside tube
(for color image see journal web site)

Tube-fin heat exchanger is made by tubes with the external fins on the outside surface. External fins can expand the exchange surface area and promote air perturbation, reduce the heat transfer resistance, effectively increase the coefficient of heat transfer, thus increasing the heating capacity, and achieve full heat transfer of the substance inner and outside [2]; they are widely used in air source air-conditioning system.

The coupled heat exchanger based on the tube-fin heat exchanger, and it was made by installing a tube inside the tube of the tube-fin, as shown in fig. 1. The coupled heat exchanger has the characteristics of the double tube's and tube-fin, and refrigerant can achieve heat transfer with the liquid and air heat source at the same time.

We can see from fig. 1, the coupled heat exchanger is made of fin, outside tube and inside tube, and form liquid heat source channel, refrigerant channel and air heat source channel. When the coupled heat exchanger used in the composite heat source air-conditioning system (CHSACS), it can achieve in three different heat source heating mode based on the demand:

- air heat source alone: close the liquid heat source channel; open the fan of the coupled heat exchanger, the heat source of the CHSACS is air only,
- liquid heat source alone: open the liquid heat source channel; close the fan of the coupled heat exchanger, the heat source of the CHSACS is liquid only, and

- liquid and air: open the liquid heat source channel; open the fan of the coupled heat exchanger, the heat source of the CHSACS is liquid and air.

Performance test

As a new type of composite heat transfer equipment, when the coupled heat exchanger is used in CHSACS, if the heat source is air alone or liquid alone, the CHSACS has no essential difference with tube-fin system or double tube system. When the CHSACS use air and liquid as heat sources at the same time, the temperature difference between the two heat sources, namely two heat sources effectively composite heat transfer temperature difference (TSECHTTD) should be reasonable choice. The temperature difference of the two kinds of heat source cannot higher than the largest TSECHTTD, or they would lead to indirect heat transfer of the two heat sources through, and result heat loss.

The largest TSECHTTD is the maximum allowed temperature difference of the two heat source when they provide heat to the CHSACS at the same time. When the temperature difference of the two heat source is less than the largest TSECHTTD, the temperature of the refrigerant of the CHSACS is lower (or higher) than both the air and liquid heat source and they can both provide heat to the CHSACS. Or else, if the temperature difference of the two heat source is higher than the largest TSECHTTD, the temperature of the refrigerant of the CHSACS would in the middle of the two sources, the high and low temperature heat source will have heat transfer by refrigerant when they provide heat to the CHSACS and result heat loss. The CHSACS can get heat from one heat source only.

In order to fully grasp the performance characteristics of the coupled heat exchanger, a CHSACS test bed was built to test the largest TSECHTTD of the heating conditions, and then test the thermal system of the CHSACS.

The CHSACS test bed, composed of compressor, coupled heat exchanger, user heat exchanger, throttle valve, fan, water tanks, water pump, valves, and pipe, is shown in fig. 2. The system heating capacity is ~ 1 kW.

The coupled heat exchanger is made of copper tubes and hydrophilic Al foils. The diameter of outside copper is 15.6 mm, the inside diameter is 9.52 mm; the thick of the Al foils is 0.2 mm. For enhanced heat transfer, the fin is corrugated [5]. Figure 3 is the photo of the coupled heat exchanger.

In this test, the air side wind speed is 2.5 m/s [6], in order to obtain the largest TSECHTTD at different conditions; the test was done at different air temperature with liquid flux of 0.2 m³/s, 0.4 m³/s, and 0.6 m³/s. then, the heating capacity of the CHSACS with the coupled heat exchanger at different air temperature with liquid flux of 0.6 m³/s. In order to prevent freezing of the liquid heat source, the 33.6% aqueous solution of ethylene glycol was selected as the liquid heat source.

Results

Figure 4 is the largest TSECHTTD with different liquid flux at different temperature. As we can see, with the different air temperature, the largest TSECHTTD is from 11 to 13 °C at liquid flux 0.2 m³/s, the largest TSECHTTD is from 8 to 10 °C at liquid flux 0.4 m³/s

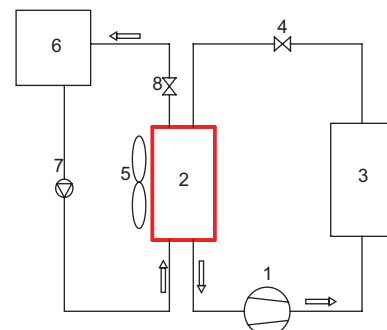


Figure 2 .Test system; 1 - compressor; 2 - coupled heat exchanger; 3 - user heat exchanger; 4 - throttle valve; 5 - fan; 6 - water tanks; 7 - water pump; 8 - valve

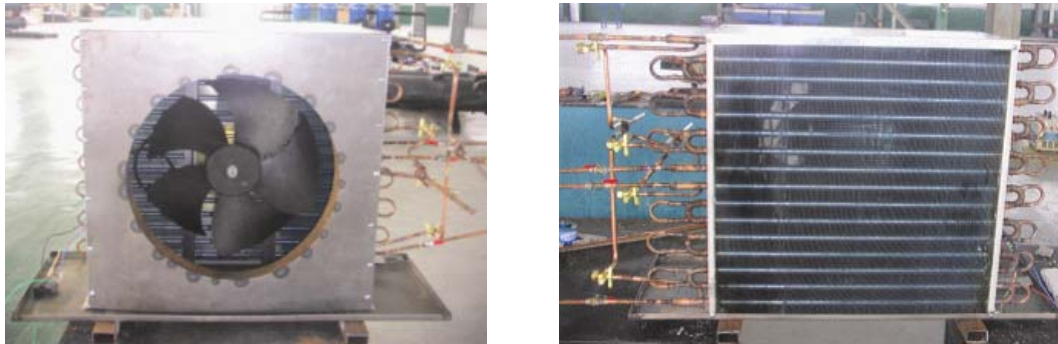


Figure 3. Coupled heat exchanger

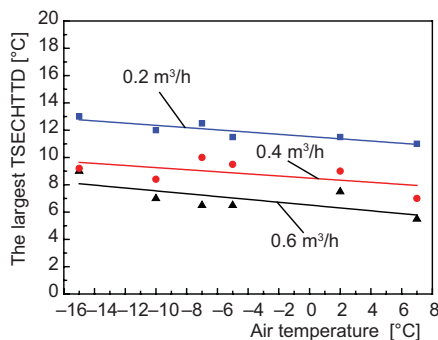
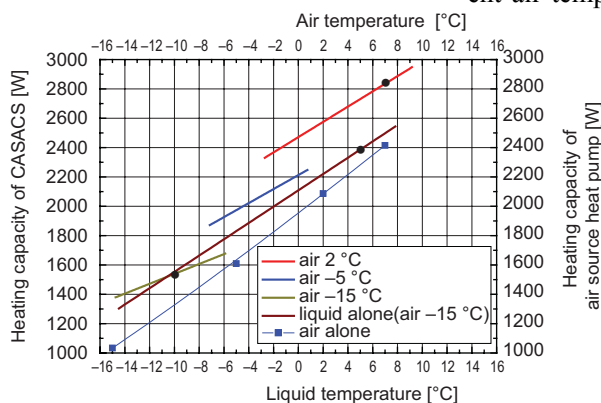


Figure 4. Curve of the largest TSECHTTD

Figure 5. Heating capacity
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equal heat energy of the single air-source heat pump systems at 7 °C by single liquid heat source at 5 °C.

Figure 6 is comparison of coefficient of performance (COP) between the CHSACS and the air source heat pump at different air temperature and liquid flux. As can be seen, the COP of the CHSACS is improved markedly than the single air-source heat pump systems in a

and the largest TSECHTTD is from 6 to 8 °C at liquid flux 0.6 m³/s. The largest TSECHTTD increased in evidence with the reducing of the liquid flux. The main reason is reduction of heat transfer when the liquid flux is reduced. At the same time, the largest TSECHTTD has little fall with the increase of the air temperature, and it is caused by the increase of the air specific volume with the air temperature increase. Therefore, the air temperature and the liquid flux should be designed right to ensure the coupled heat exchanger.

Figure 5 is heating capacity compared between the CHSACS and the air source heat pump at different air temperature and liquid flux. As can be seen, the heating capacity of the CHSACS is improved markedly than the single air-source heat pump systems in a variety of conditions within the TSECHTTD. If selected the TSECHTTD at 5 °C, the heating capacity of the CHSACS is about 35% more than the single air-source heat pump systems when the air temperature was 2 °C; and the heating capacity of the CHSACS is about 45% more than the single air-source heat pump systems when the air temperature was -15 °C. If user needs more heat energy when the air temperature is very low, the CHSACS can make the

variety of conditions within the TSECHTTD. If selected the TSECHTTD at 5 °C, the COP of the CHSACS is about 20% more than the single air-source heat pump systems when the air temperature was 2 °C; and the COP of the CHSACS is about 53% more than the single air-source heat pump systems when the air temperature was -15 °C. If user needs more heat energy when the air temperature is very low, the CHSACS can make the equal heat energy of the single air-source heat pump systems at 7 °C by single liquid heat source at 5 °C, at that time, the COP of the CHSACS is 2 times of the single air-source heat pump systems.

Conclusions

The coupled heat exchanger can achieve the heat transfer of three substances at the same time. By using the coupled heat exchanger, the CHSACS can use the air-type heat source and liquid-type heat source at the same time and the heat capacity can be raised in the TSECHTTD. Furthermore, it simplifies the system, reduces the system investment and reduces the area of equipments need. The coupled heat exchanger also can be widely used in the need of one liquid substance exchange heat with the other liquid substance and gas substance at the same time.

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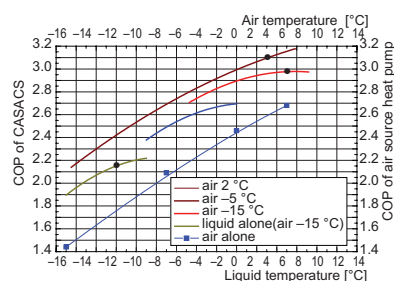


Figure 6. Coefficient of performance
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