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Experimental Study on Heat Transfer Performance of Antiseptic Evaporator

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ABSTRACT

Corrosion is the problem which geothermal source heat pump system must face and resolve. Antiseptic dope was spray-painted onto the surface of water channel of the evaporator to help fight corrosion. In this paper, heat transfer characteristic of the antiseptic evaporator was studied. Experiment was carried out, in the condition of different water velocity, heat transfer performance of spray-painted antiseptic U-type double pipe evaporator and unpainted U-type double pipe evaporator were tested and contrasted. Experimental results indicated that when water velocity is less than 1.64m/s, which in laminar flow, heat transfer coefficient of the spray-painted antiseptic evaporator is larger than that of the non-spray-painted evaporator, while when water velocity is large than 1.64 m/s, which in turbulence flow, the enhancement of coating surface roughness is weaken, then the heat transfer coefficient of the spray-painted antiseptic evaporator is less than that of the non-spray-painted evaporator.

1. INTRODUCTION

Heat pump system has the advantage of reducing CO_2 emissions, high efficiency and increasing the total consumption of renewable and clean energy. Geothermal source or ground source heat pump (GSHP) systems is heating and cooling by using shallow geothermal energy. In winter, heat pump extracts low grade heat energy from the underground and transformed that heat and the consumed electricity into higher temperature heat energy to heat the building, at the same time, cold energy can be stored in the underground. In summer, the stored cold energy in winter can be used as the heat sink of the heat pump system to cool the building, meanwhile, heat can be transferred from indoors into underground and stored in the soil for winter use. GSHP system is seasonal energy storage and high efficiency space heating and cooling technology, which have been widely used throughout the world, which are considered as the most efficient, "green" alternative to traditional heating and air conditioning equipment, offering significant, economic environmental and societal benefits. GSHP systems abstract the clean energy of the sun naturally stored in the near-surface of the earth, transferring this free heat to buildings for heating in winter and back to the ground in summer [1]. GSHP systems are rapidly spreading in Europe, China, Canada and USA, and have a great potential for energy, cost and CO_2 emission saving[2].In Europe, there are about 100,000 low-enthalpy geothermal plants installed every year, mainly for new dwellings in Sweden, Germany and France [3-6]. In China, GSHP systems are widely used for space heating and cooling, especially in Tianjin, Shenyang, Beijing, Hebei and Shandong province [7-10].

With the widely use of GSHP system, there are also much study in thermodynamic analysis [11-13], heat balance, underground heat transfer performance [14, 15], loop design and optimal sizing [16-17], coefficient of performance (COP) of the GSHP system, economic analysis, effect on the environment and optimal design in ground source heat pump [18], however little attention has been given to the corrosion of ground water to the heat exchangers. In some areas, especially in the areas by the sea, shallow underground water usually is brine, which component is close to sea water and is corrosive. Also for some heat pump systems which use geothermal water as the heat source or sink, geothermal water usually is caustic. Those underground brine water or geothermal water has serious corrosive on the evaporator or condenser of GSHP system. An additional heat exchanger is usually needed in these conditions, which is arranged between the source water and heat pump system to avoid the corrosion of brine water or geothermal water to evaporator or condenser. It is not only adding the initial equipment investment, but also decreasing evaporating temperature or increasing condensing temperature, and then results in the lower efficiency of heat pump system. So, it is urgent to find ways resolving the corrosion problem of the brine or geothermal water on GSHP system in the coast region.

In order to overcome the erosion of brine water to GSHP, improve the GSHP system efficiency of space heating and cooling, antiseptic dope was sprayed onto the surface of water channel of the evaporator to avoid being corroded. But the spray-painted dope coating will add the conductivity heat resistance, which will decrease the heat transfer coefficient of the evaporator. In this paper, experimental study on the thermal performance of the antiseptic evaporator was carried out. In the condition of different water velocity, heat transfer performance and coefficient of spray-painted antiseptic U-type double pipe evaporator was tested and calculated, which was also contrasted with unsprayed evaporator.

2. EXPERIMENTAL SETUP

For the convenience and easy process to spray, U-type double pipe evaporator was adopted. Inside of the inner tube was the water channel and the annular between the two tubes was flow through refrigerant. In the spraying process, antiseptic material was fed into and passes through the inner tube, and then the dope could adhere to the surface of inner wall and form a continuous corrosion protection coating, which could protect the surface from being eroded. Two U-type double pipe evaporators were matched with the same dimensions. Outer diameter of out-tube and inner-tube were 28 mm and 16 mm respectively, thickness was 1mm, the total length of the evaporator was 3.8m. The only difference between the two evaporators was that one was sprayed with antiseptic dope on the water channel surface and the other wasn’t sprayed. Thickness of the antiseptic dope coating was 260μm.

In order to study the effect of sprayed dope coating on the heat transfer performance of the antiseptic evaporator, Experiment table was set up. The experiment setup consists of two water storage reservoirs, 1# and 2# water tank, circulating pump, flow meter, antiseptic evaporator test section, compressor, condenser, refrigerating system and other accessories. Water tank 1# was connected with the test evaporator and 2# was connected with the condenser. The two water tanks were equipped with three electricity heating tubes in each tank, electricity power were 1kW, 2kW and 3 kW respectively. The 2kW and 3kW electricity heaters were controlled by hand, and the 1kW one was connected with the temperature controller and controlled automatically. The schematic diagram of the experiment system is shown in Fig. 1.

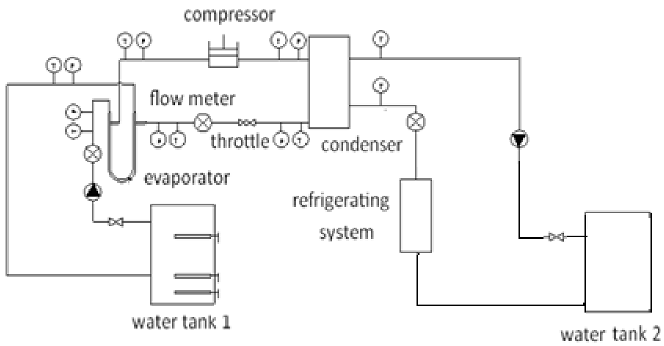

Figure 1: schematic diagram of experiment system

In the 1# water tank, water was heated, and then entered into the antiseptic evaporator trough the circulating water pump. When hot water flowed through the antiseptic evaporator, it discharged heat to refrigerant flowing through the annular, then heat was transferred from water to refrigerant and the water temperature decreased. The low temperature water exited the evaporator and flowed back to the 1# water tank. A glass tube float flow-meter was used to measure the flux of water before entered into the antiseptic evaporator. Copper-constantan thermocouples were installed in the inlet and outlet of antiseptic evaporator to measure the inlet and outlet temperature of water. Inlet and outlet pressure of the water were measured by pressure gauge, which with an accuracy of 0.1MPa.

In the vapor-compression refrigeration cycle, when refrigerant pass through the evaporator, it was heated and exited in a slightly superheated vapor form. Then the refrigerant vapor entered compressor. The compressor compressed the refrigerant vapor to a high pressure, which resulted in it also having a high temperature. The heat increase was due to the energy used in the compression process being transferred to the vapor. The superheated vapor leaved the compressor and entered the condenser where it was cooled with the aid of cooling water. The heat from the vapor was transferred to and carried away by the cooling water in the condenser. The refrigerant exited the condenser as a high-pressure liquid and its pressure was then decreased by flow though the throttle valve. Some of the liquid flashed evaporate due to the sudden reduction in pressure. Low-pressure and temperature refrigerant flow into the evaporator, and the cycle would be all over again. Inlet and outlet temperature and pressure of the refrigerant in the evaporator and condenser were tested in the experiment.

Cooling water abstracted heat from refrigerant and temperature raised, and then high temperature cooling water exited the condenser and entered into the 2#. Water from the 2# water tank then flowed into the refrigerating system. When it flowed through the refrigerating system, cooling water discharged heat and its temperature decreased. Low temperature cooling water entered the condenser to cool the refrigerant gain.

In the evaporator, source heating water flowed through inside tube and refrigerant flowed in annular. Water and refrigerant temperature entered and exited the evaporator were measured with 4 copper-constantan thermocouples, located at the inlet and outlet sections of each element of the water and refrigerant fluid circuits. Copper-constantan thermocouples were calibrated in the lab by using standard glass thermometer and its uncertainty was 0.2%. All thermocouples were connected to Fluke DAQ v2.0 data acquisition system, which was further connected to computer. Data from the thermocouples can be recorded and stored in the computer.

Inlet and outlet pressures of the refrigerant were measured by pressure gauge in ranges of 0~16MPa with an accuracy of 0.1MPa, located at the inlet and outlet of the refrigerant circuits. Water pressures were measured by pressure gauge in ranges of 0~1MPa with an accuracy of 0.1MPa, located at the inlet and outlet of the water circuits. Refrigerant mass flow rate was measured by mass flow-meter with an uncertainty of 0.2%. Water flow rate was measured by glass tube float flow-meter in ranges of 0～3000 L/h, which was arranged in the tube before entered into the antiseptic evaporator. A valve was used to turn on and shut off the water flow to the evaporator, by valve opening could adjust the water flow rate.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Heat transfer coefficient of the evaporator can be calculated according to the heat and heat transfer area of the evaporator. In the experiment, heat transferred in the evaporator was calculated by testing water and refrigerant temperature and flow rate entered and exited evaporator. Heat transfer area was calculated according to the geometry structure of the evaporator. How the antiseptic dope coating affect the heat transfer performance of evaporator can be analyzed by comparing the heat transfer performance of the antiseptic evaporator to that of the un-spraying painted evaporator. In this experiment, in the condition of water temperature was 10 ℃, water flow rate was varied from 0.5 m^3/h to 1.3m^3/h, the heat transfer coefficient of the evaporator was studied.

The relation curve of overall heat-transfer coefficient and water velocity is shown in Fig.2. There is an interesting phenomenon in the experiment that the overall heat-transfer coefficient of the antiseptic evaporator is larger than that of the unpainted evaporator when water velocity is less than 1.64m/s. It was thought that the overall heat transfer coefficient of the evaporator would decrease when painted with anticorrosion dope on the interior wall of the inner tube, because it increased the conductive resistance of corrosion protection coating. But in fact, the corrosion protection coating could enhance the heat transfer preface in the lower water velocity condition. The possible reason was that the interior surface of inner tube became rough surface when painted with anticorrosion dope. Compared to the unpainted evaporator, which was light tube and smooth surface, the surface roughness of antiseptic evaporator enhanced heat transfer when water velocity was less than 1.6 m/s. It can be concluded from Fig.3 that the Re of water is below 10000 when water velocity was less than 1.64m/s, which was in the laminar flow or transferring flow. Heat transfer coefficient was small in laminar and transferring flow, and then the enhancement of surface roughness on the heat transfer is notable in this range.

While as water velocity is larger than 1.64 m/s, Re is greater than 10000 and flow entered into turbulence. Heat transfer enhancement due to water velocity increasing was much more than the surface roughness in turbulence flow. Compared to the unpainted evaporator, the conductive heat resistance increase due to the antiseptic dope coating was larger than the enhancement by surface roughness, so the heat transfer coefficient of the antiseptic evaporator was less than that of unpainted evaporator in turbulence flow. Whether the heat transfer performance of evaporator will be increased or decreased, it depends on which factor, conductive heat resistance increase and the enhancement by surface roughness, was in the dominant.

It is also showed in the Fig.2 that the overall heat-transfer coefficient of evaporator increases with the water velocity increasing, but the amplification is gentle. It is because in the evaporation process, heat resistance in water side and refrigerant side was not comparative. Heat resistance in the refrigerant side was much larger than that of the water side, and it determined the overall heat-transfer coefficient of the evaporator. So the influence of water velocity on overall heat-transfer coefficient was gently.

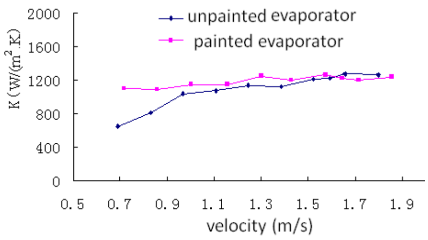

Figure 2: overall heat-transfer coefficient change with water velocity

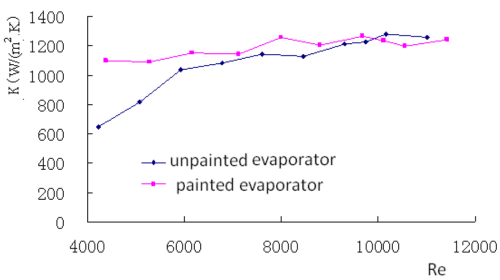

Figure 3: overall heat-transfer coefficient change with Re

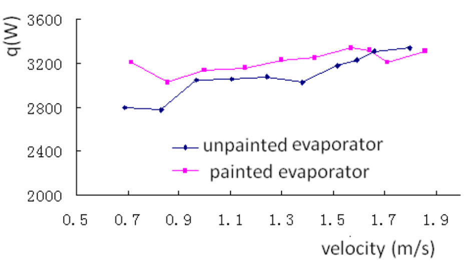

Figure 4: heat flux change with water velocity

Fig.3 shows that the overall heat-transfer coefficient varying with the Re, which has the same tendency with the heat transfer coefficient changing with velocity. When Re is less than 10000, overall heat-transfer coefficient of antiseptic is larger than that of the unpainted evaporator for the enhancement of the surface roughness of anticorrosion dope coating. While the overall heat-transfer coefficient of antiseptic is lower than that of the unpainted evaporator when Re is greater than 10000, it is because the added conductive heat resistance of the antiseptic dope coating.

The relation curve of heat flux and water velocity is shown in Fig.4. It shows that the heat flux of evaporator increased with the water velocity increasing. Compared to the unpainted evaporator, when water velocity is less than 1.64m/s, heat flux of antiseptic evaporator is larger than that of unpainted evaporator, but when water velocity is greater than 1.64m/s, heat flux of antiseptic evaporator is smaller than unpainted evaporator. It was also because the heat transfer enhancement of the surface roughness and the decrease in heat transfer for added conductive heat resistance.

4. CONCLUSION

From the analysis of above, it can get the conclusion that the antiseptic dope coating has duality on the heat transfer performance of antiseptic evaporator. In one hand, it can enhance heat transfer for increasing surface roughness, and on the other hand, it increase conductive heat resistance which decrease the heat transfer performance of the evaporator. Whether the heat transfer performance of evaporator will be increased or decreased, it depends on which factor, conductive heat resistance increase and the enhancement by surface roughness, is in the dominant.

In the experiment, when source water velocity was lower than 1.64 m/s, which was laminar flow, surface roughness enhanced the heat transfer performance; with source water velocity increased larger than 1.64 m/s, water flow become turbulence, heat transfer performance had little decrease for added conductive heat resistance.

On the whole, the antiseptic dope coating with 260μm has little influence on heat transfer coefficient and will not decrease the heat transfer performance largely. Even the anticorrosion dope coating also has role of anti-scaling, so for long term operation, heat transfer performance of evaporator painted with dope would better than that of unpainted evaporator.

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