Performance Investigation on the Thermosyphon with Evaporative Condenser for Free Cooling of Data Centers

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Abstract
The microchannel heat exchanger is applied as the heat exchanger of the thermosyphon for data center cooling, and the evaporative cooling experiment is carried out on the side of the microchannel condenser. The influence of evaporative cooling on the microchannel condenser is measured by using the enthalpy different laboratory in the experiment, and the temperature difference between the inlet and outlet air of the microchannel condenser and with different indoor and outdoor temperature and humidity was analyzed. The experimental results show that evaporative cooling can make the condenser inlet air temperature achieve a large temperature drop and increase the temperature drop of the inlet and outlet air, while the spraying can cool the air through the thermosyphon about 0.3-1.9 degrees and increase about 0.1-0.6kW heat transfer of the system. Moreover, the evaporative cooling can improve the heat exchange efficiency of condensers, expand the application area of the loop thermosyphon and extend the annual utilization time.

Keywords: thermosyphon; evaporative cooling; free cooling; data center; microchannel heat exchanger

1. Introduction
Data centers are building sites that provide operating environment for centralized electronic information equipment. In recent years, data centers in China have developed rapidly, with a total number of more than 400,000. The overall energy consumption of the data center in 2015 was close to 100 billion kwh [1]. The cooling load of the computer room is large and it needs to be refrigerated all year round. If simply adopted the steam compression refrigeration, the energy consumption of the air conditioning system accounts for about 50% of the total energy consumption of the data centers [2]. In northern region of China, the outdoor temperature is lower than 20 °C and lower than the indoor temperature in most days in winter and transitional seasons. Natural cooling energy can be both directly and indirectly used to reduce the use of compression refrigeration units and energy consumption.

As a form of natural cooling, the thermosyphon system is an efficient heat transfer unit which has high energy efficiency ratio, fewer running parts and low energy consumption. The natural cooling system of thermosyphon uses sensible heat of air to refrigerate and the refrigeration capacity increases with the increase of indoor and outdoor temperature difference. So in season with high outdoor temperature, the operating time and working region will be limited. In addition, due to the restriction of thermosyphon structure and heat transfer mode, the thermosyphon has evaporation and condensation heat transfer limits [3]. Moreover, the use of microchannel heat exchanger can improve the heat transfer efficiency with light weight, compact structure and less filling. So in this paper, microchannel condenser and microchannel evaporator are used as heat exchanger of the data center thermosyphon system on the experimental platform.
2. Experimental device and method

2.1 Experimental device

In this experiment, the thermosyphon consists of a microchannel evaporator at indoor side, a microchannel condenser at outdoor side, spraying device and matching axial fan as shown in Fig.1. The height between the condenser and the evaporator is set as 1.0 m [4] due to the flow resistance of liquid and vapor in the pipeline. The test platform of heat exchanger is equipped with air duct as samplers separately. The structural parameters of the microchannel evaporator and condenser are shown in Tab.1. The evaporator and condenser are composed of horizontal collector, vertical flat microchannel tube and aluminium fin of louver and are separately equipped with axial flow fans. The evaporative cooling applied for condenser is realized by spraying device, which is composed of micro pump and ultrafine atomizing nozzles with 0.6 mm aperture. The evaporator and the condenser are connected by a 10 mm diameter copper tube, which is about 8 m long.

![Diagram of the thermosyphon with an evaporative condenser](image)

**Figure 1** Experimental setup of the thermosyphon with an evaporative condenser

**Table 1** The structural parameters of the microchannel heat exchangers

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Evaporator</th>
<th>Condenser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size/mm</td>
<td>650×770</td>
<td>650×770</td>
</tr>
<tr>
<td>Thickness/mm</td>
<td>25.4</td>
<td>25.4</td>
</tr>
<tr>
<td>Tube number / -</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Weight/kg</td>
<td>5.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

2.2 Experimental method

In this experiment, the microchannel evaporator and condenser were placed on the indoor side and the outdoor side of the enthalpy different laboratory. The testing method of heat exchanger performance refers to national standard about room air conditioner. The experiment was carried out in refrigeration condition. The refrigerant was R22. The optimum refrigerant filling rate was set at about 80% which was about 4 kg in this experiment, and the air volume of the fan can be adjusted within 0-2000m³/h. According to the national standard about data center design specification, the operating environment parameters of C-level data centers require temperature of 18-27 ℃, relative humidity is not more than 60%. So the dry bulb temperature at indoor side was set at 24 ℃, relative humidity was 50%. The temperature difference in outside and inside room was 5 ℃, 10 ℃, 15 ℃ and the relative humidity outside was set as 30%, 40%, 50%, 60% and 70%. The dry and wet bulb temperatures were set at 9/3.75 ℃, 9/4.69 ℃, 9/5.59 ℃, 14/6.47 ℃, 14/7.66 ℃, 14/8.80 ℃, 14/9.92 ℃, 14/10.99 ℃, 19/11.52 ℃, 19/12.91 ℃ and 19/14.24 ℃, respectively.

Calculation of heat transfer capacity of heat exchanger as follows:

\[ Q = \rho G c_p \Delta T \]

Where,

- \( \rho \) -- air density, kg/m³;
- \( G \) -- air volume, m³/s;
- \( c_p \) -- specific heat capacity of air at constant pressure; kJ/(kg • ℃)
- \( \Delta T \) -- inlet and outlet air temperature difference.

3. Experimental results and analysis

3.1 Outdoor temperature and humidity influence evaporative cooling of thermosyphon

The difference between the dry bulb temperature of outlet and inlet air of the evaporator and the condenser were measured in the temperature difference range of 5-15 ℃, that is 19 ℃, 14 ℃ and 9 ℃ of outdoor air and under the condition of 30%-70% relative humidity, as shown in Fig. 2 to Fig. 5.

It can be seen from the diagram that the temperature difference between intake and exhaust air of the microchannel condenser increases with the increase of the indoor and outdoor temperature difference under different working conditions while the humidity has no obvious effect on the behaviour of heat exchanger. The spray experiment was taken in the same temperature and humidity condition as no spraying. It can be concluded from the results that the spraying cooling the air out of the heat exchanger and bearing the heat load of condenser. The air flowing through the thermosyphon can be cooled by about 0.3-1.9 ℃ by spraying, and the cooling heat transfer coefficient of the heat...
exchanger can be increased. With the increase of relative humidity, the temperature difference between the outlet and inlet air of microchannel condenser has no great application effect which compares to the condition without spraying.

The inlet and outlet temperature difference of microchannel evaporator showed the same increasing trend as condenser with the increase of in and out temperature difference. The evaporative cooling also produces a certain degree of temperature difference under different working conditions. The spraying effect is more obvious under large temperature difference, while the influence of humidity on the air inlet and outlet of evaporator is less obvious.

![Figure 2](image2.png)  
**Figure 2** Air temperature difference at the inlet and outlet of the condenser at different outdoor air temperature and humidity without spray cooling

![Figure 3](image3.png)  
**Figure 3** Air temperature difference at the inlet and outlet of the condenser at different outdoor air temperature and humidity with spray cooling

![Figure 4](image4.png)  
**Figure 4** Air temperature difference at the inlet and outlet of the evaporator at different outdoor air temperature and humidity with spray cooling

![Figure 5](image5.png)  
**Figure 5** Air temperature difference at the inlet and outlet of the condenser at different outdoor air temperature and humidity with spray cooling

### 3.2 Efficiency of evaporative cooling

Before the air enters the condenser, the evaporative cooling can cool the air directly. The limiting temperature is the wet bulb temperature of the air. The wet bulb efficiency is defined as the ratio of the air temperature to the limit temperature of the air cooled by evaporative cooling after spraying at the inlet side of the heat exchanger. The sampler is placed on the inlet side of the condenser to measure the temperature after spraying and the calculated temperature drop is shown in Fig. 6, and the corresponding wet bulb efficiency is shown in Fig. 7.

As can be seen from the above, the inlet air temperature drop of condenser with spraying still increases with the increase of in and out temperature difference, and decreases with the increase of outdoor relative humidity. The inlet air wet bulb efficiency showed a similar change rule, and the highest reached 54%.
3.3 Effects of evaporative cooling for different cities

Statistical analysis was made on the annual working hours of air conditioning units in different climatic zones using thermosyphon system in data center cooling system. The thermosyphon cooling system can operate normally under the condition of minimum 5 °C temperature difference between indoor and outdoor air [5]. Referring to the meteorological database, the evaporative cooling can increase temperature drop at different outdoor climatic conditions under requiring temperature at 24 °C, thus prolonging the annual utilization time of thermosyphon system and expanding the application area. As can be seen from Fig. 9, the annual cooling time of thermosyphon air conditioning units can be increased in most parts of the country, especially in the northern region.

4. CONCLUSIONS

Evaporative cooling is applied to the microchannel condenser of the thermosyphon system for data center cooling, which can improve the heat transfer effect of the heat exchanger and the system. Different spray density and different wind speed have different effects on heat transfer with evaporative cooling. After spraying, the inlet air temperature of the heat exchanger can be reduced by about 0.9-3.5 °C. Further cooling of the air before the intake can effectively reduce the condensation heat, expand the using area of thermosyphon cooling system and prolong the using time. In addition, the evaporative cooling on the side of microchannel condenser can make the air flowing through the thermosyphon cool down about 0.3-1.9 °C, and can bear the load of the condenser side about 0.6 kW under the condition of low humidity. It can reduce the condensation temperature, reduce the heat transfer restriction of the thermosyphon and
increase the heat transfer capacity of the system by about 2-20%. The evaporative cooling capacity of microchannel condenser and evaporator increases with the increase of indoor and outdoor temperature difference, and decreases with the increase of outdoor relative humidity. Compared with single thermosyphon technology, the thermosyphon with evaporative cooling can make better use of natural cooling energy, and prolong the utilization time of air conditioning system in a year, and expand the application area of the system.

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Reference