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Experimental Investigation of Gravity Heat Pipe Exchanger Applied in Communication Base Station

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Abstract

This paper proposes a gravity heat pipe exchanger used for cooling the communication base station to replace the air conditioning in winter and transition seasons. Tests were made on the gravity heat pipe exchanger of DHHP 3000 produced by Harbin Dawnhappy Heat Pipe Technology Incorporated. The experiment was performed in order to study the effects of the inlet air flow rate, temperature and the exchanger inclination angle on cooling capacity and efficiency of the heat pipe exchanger. As the indoor and outdoor air flow rate are equal, the cooling capacity of heat pipe exchanger increases with the air flow rate and it also increases with the increase of indoor air temperature and with the decrease of outdoor air temperature; The cooling efficiency decreases with the increase of air flow rate and it gradually reduces with the outdoor air temperature increases from 2°C to 18°C. Among the ratios of indoor to outdoor air flow rate of 0.4kg/s:0.5kg/s, 0.4kg/s:0.6kg/s and 0.5kg/s:0.6kg/s, the cooling efficiency of 0.4kg/s:0.6kg/s achieves the highest value. In addition, as the inclination angle varies from 5° to 50°, the maximum cooling efficiency can be obtained at angle of 20°.

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Keywords: Communication base station; Gravity heat pipe exchanger; Cooling capacity; Cooling efficiency

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1. Introduction

Nomenclature

Q	cooling capacity (kW)
C_p	specific heat of indoor air at constant pressure
t_1	indoor air inlet temperature(°C)
t_2	indoor air outlet temperature(°C)
t_3	outdoor air inlet temperature(°C)
ε	cooling efficiency(%)
Q_{actual}	actual cooling capacity(kW)
Q_{max}	maximum theoretical cooling capacity(kW)
m_s	indoor air flow rate(kg/s)
m_{min}	minimum air flow rate between indoor and outdoor(kg/s)

Communication base station is an important part of communication system. It is of large number, high heat quantity, long-time cooling season and high energy consumption. The internal environment factors, such as temperature, humidity and cleanliness, affect the reliable operation and service life of the communication equipment [1]. The cooling of communication base station has emerged as a significant challenge with the increase of IT equipment. As shown in Fig.1, the consumption of communication base station includes the following four aspects, communication equipment, air conditioning system, distribution system and other auxiliary equipment. We can learn that the consumption of air conditioning system occupies about 43% of the total energy consumption, which is the largest part except the main equipment energy consumption [2]. Reducing the consumption of the main equipment is unlikely, therefore, reducing the energy consumption of air conditioning is the key to saving energy for communication base station.

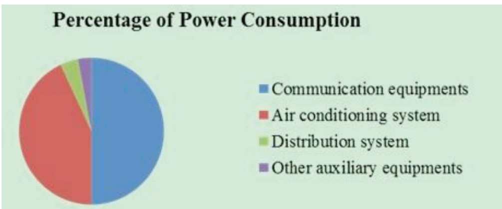


Fig .1. The consumption of communication base station.

Since 1970, heat pipe exchangers have been extensively applied in many industries including HVAC systems. Hayama[3] and Hong-Koo[4] et al. studied the effects of the parameters and the way of supply air on the communication base station. They reported that the change of velocity has more obvious effect than that of temperature on energy saving, and under air supply system could improve the temperature distribution to obtain a good energy saving effect. Al-Rabghi [5] and Wang [6] et al. used outdoor air for cooling, which can decrease 30% energy consumption of air conditioning system. El-Baky and Mohamed [7] stated that the incoming fresh air could be cooled down by the application of heat pipe exchanger between two streams of fresh and return air in an air conditioning system,. Firouzfar [8] et al. established that the application of methanol-silver nanofluid as the working fluid in a two-phase thermosyphon heat exchangers saves energy by 9-31% for cooling and 18-100% for reheating the air supply stream in an air conditioning system.

The gravity heat pipe is a promising heat transfer component with high thermal conductivity [9]. By the evaporation and condensation of the working fluid, it can work effectively. The gravity heat pipe has been proved to have a comparatively high heat transfer capability with a very small temperature difference between the heat source and heat sink. Moreover, it has excellent isothermal property, compact structure and small fluid resistance loss, therefore, it has been widely applied in the thermal industry [10].

The gravity heat pipe can be divided into three sections: the evaporation, the condensation and the adiabatic section [11]. Evaporation is the one end where the working fluid absorbs heat from the heat source to evaporate. Condensation is the other end where the working fluid condenses to release heat to the heat sink. Adiabatic section is heat transmission channel in the middle of the heat pipe.

Compared with standard heat pipe (Fig. 2(a)), the gravity heat pipe does not have the wick, resulting in simple production and low cost. Because of reliable working performance, this kind of heat pipe has been widely used, which is also adopted in this paper. The structure of gravity heat pipe is shown in Fig. 2(b).

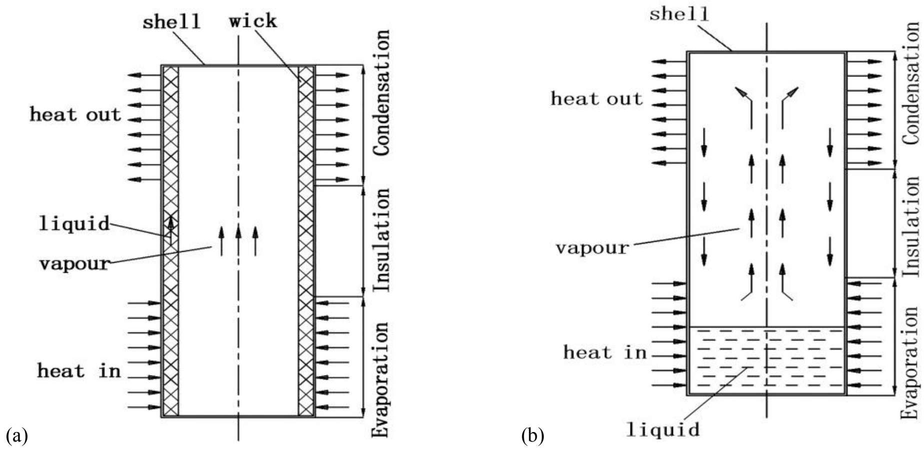


Fig. 2. The structure of heat pipe: (a) standard heat pipe; (b) gravity heat pipe.

In this study, the heat pipe exchanger performance test system is constructed. The effects of the inlet air flow rate, temperature and the exchanger inclination angle on the heat transfer capacity and efficiency of the heat pipe exchanger are investigated.

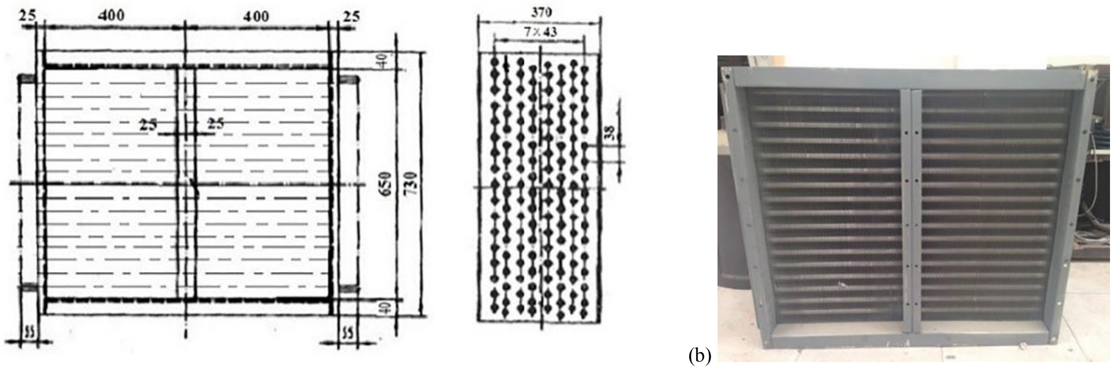
2. Methods

2.1. The configuration of heat pipe exchanger

The DHHP3000 gravity heat pipe chosen in this experiment is produced by Harbin DawnHappy Heat Pipe Technology Incorporated. The main parameters of heat pipe exchanger are shown in Table 1. It can be clearly seen the profile and configuration of heat pipe exchanger from Fig. 3. It is made of pure aluminum finned tube. The diameter of heat pipe is 16 mm. The length of evaporation and condensation is 0.3 m, together with the length of adiabatic section is 0.27 m. There are 17 rows tubes on the windward side and 8 rows tubes on the depth direction. The working liquid in the heat pipe is R-134a with 20% filling ratio and it has an inclination angle of 5°. The evaporation and condensation of heat pipe are sealed by partition and wedge cushion. It can be used at the range of -40 ° C to 80 °C.

Table 1. The main parameters of heat pipe exchanger.

The model of heat exchanger	Air volume m3·h-1	The diameter of heat pipe mm	Resistance Pa	Efficiency %
DHHP3000	3000	16	100	60



(a) (b)

Fig. 3. (a) The profile of heat pipe exchanger; (b) the configuration of heat pipe exchanger.

2.2. The construction of experimental system

This experimental system was set up in enthalpy difference laboratory of Xi'an Jiaotong University, which was used to provide different indoor and outdoor environment to test the performance of heat exchanger. The schematic diagram of experimental unit is shown in Fig. 4.

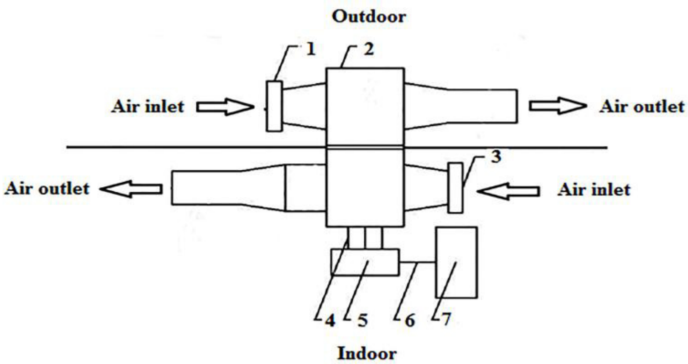


Fig. 4. Schematic diagram of experimental unit. 1 outdoor frequency conversion fan 2 heat pipe exchanger 3 indoor frequency conversion fan 4 wire 5 data acquisition equipment 6 date cable 7 computer

The evaporation and condensation of heat pipe exchanger were separated by a partition, one side provided indoor environment and the other side provided outdoor environment. Frequency conversion fans were connected to their outlet adjusting the air flow rate. At the outlet of condensation and evaporation, there are three thermocouples located on upper, middle and lower of the heat pipe, respectively. According to the experimental data of three different positions, we can obtain indoor and outdoor air outlet temperature by calculating their average value. Mass air flow rate was calculated by the wind speed measured by wind velocity indicator. The cooling capacity and cooling efficiency under different operating conditions can be calculated.

2.3. Experimental data processing

The amount of heat transfer of indoor and outdoor air can be calculated by Eq. (1) as follows:

$$Q = m_s C_\rho (t_1 - t_2) \tag{1}$$

The cooling efficiency of heat exchanger can be determined by the following equation [12]:

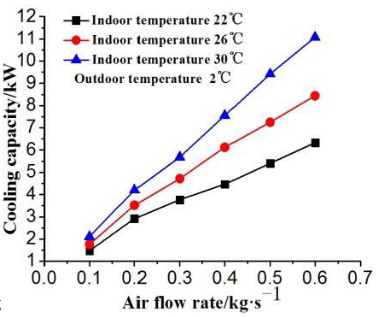
$$\varepsilon = \frac{Q_{actual}}{Q_{max}} = \frac{m_s\left(t_1 - t_2\right)}{m_{min}\left(t_1 - t_3\right)} \tag{2}$$

3. Results and discussion

3.1. The influence of air flow rate and temperature on cooling capacity

In this paper, the amount of heat transfer of heat pipe exchanger refers to the cooling capacity of heat pipe exchanger. From Fig. 5 and Fig. 6, we can see the influence of different air flow rate and temperature on the cooling capacity of heat pipe exchanger. It shows that the cooling capacity of heat pipe exchanger increases with the increase of indoor and outdoor air flow rate when the indoor air temperatures are set to22°C, 26°C, 30°C, respectively. The reason is that the increase of air flow rate accelerates the air speed, which will enhance the heat transfer coefficient between heat pipe and air, so the overall heat transfer increases. Similarly, we can learn that the cooling capacity of heat pipe exchanger increases with the increase of indoor air temperature and with the decrease of outdoor air temperature. This is because higher indoor air temperature results in stronger heat absorption capacity of evaporation and lower outdoor air temperature results in stronger heat release capacity of condensation. So the overall cooling capacity of heat pipe exchanger increases.

From Fig. 7, we can see that, with the increase of temperature difference between indoor and outdoor, the cooling capacity of heat pipe exchanger increases approximate linearly. The lower the outdoor air temperature and the higher the indoor air temperature, the more cooling capacity. When the temperature difference between indoor and outdoor is constant, the cooling capacity of indoor temperature at 26°C is the highest in transition seasons.



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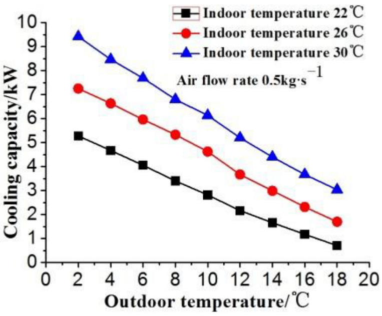

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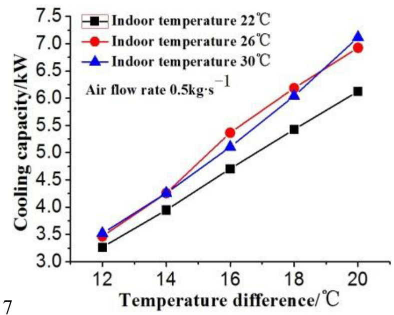

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Fig. 5. Influence of air flow rate on cooling capacity.

Fig. 6. Influence of outdoor temperature on cooling capacity.

Fig. 7. Influence of air temperature difference on cooling capacity.

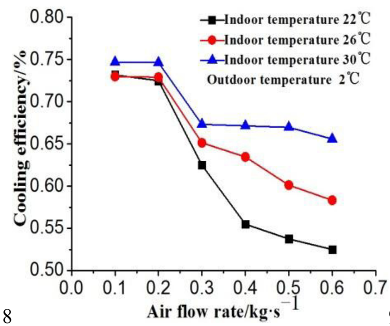
3.2. The influence of air flow rate and temperature on cooling efficiency

In this study, the thermal efficiency of heat exchanger refers to the cooling efficiency of the heat pipe exchanger. Fig. 8 and Fig. 9 show the influence of air flow rate and temperature on cooling efficiency under equal indoor air flow rate and outdoor air flow rate.

From Fig. 8, we can see that, with the increase of indoor and outdoor air inlet flow rate, the cooling efficiency of heat pipe exchanger gradually decreases. When the inlet flow rate increases from 0.1kg/s to 0.2kg/s, the cooling efficiency remains the same. The reason is that heat transfer between cold and hot fluids is sufficient because of small air flow rate and low air speed. So the maximum cooling efficiency of heat pipe exchanger arrives under this condition. When the inlet flow rate increases from 0.2 kg/s to 0.4 kg/s, it can be seen from the figure that the cooling efficiency of the heat pipe exchanger has fallen sharply. In this case, insufficient heat transfer is caused by large air flow rate. With the further increase of air flow rate, the efficiency of heat exchanger decreases slowly, especially as the indoor temperature is 30℃.

In addition, it can be seen from Fig.9, as the air flow rate is constant, the cooling efficiency of heat pipe exchanger gradually reduces with the outdoor air temperature increases from 2°C to 18°C. The increase of outdoor air temperature leads to the decrease of heat transfer, and then the indoor air outlet temperature will increase, so the cooling efficiency decreases.

Fig. 10 shows the influence of air temperature difference on cooling efficiency. Similar to Fig. 7, the cooling efficiency increases with the increase of temperature difference between indoor and outdoor. The lower the outdoor air temperature and the higher the indoor air temperature, the better cooling efficiency.



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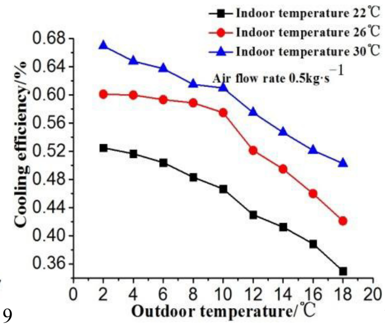

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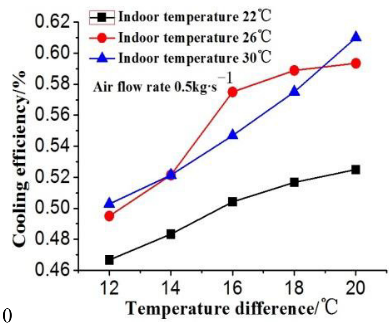

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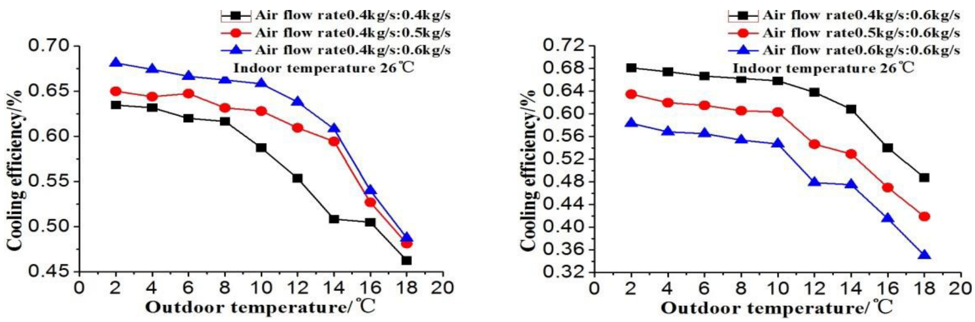
Fig 8. Influence of air flow rate on cooling efficiency.

Fig. 9. Influence of outdoor temperature on cooling efficiency.

Fig. 10. Influence of air temperature difference on cooling efficiency.

From the above, in winter, transition seasons and summer in specific areas, such as northeast in China, using heat pipe exchanger under low outdoor temperature can effectively utilize natural resources to achieve energy saving. The lower the outdoor air temperature is, the better energy saving effect. So the heat pipe exchanger has the good energy saving effect in communication base station in winter and transition seasons.

3.3. The influence of the ratio of indoor to outdoor air flow rate on cooling efficiency



4.

(a) The ratio of indoor to outdoor air flow rate are 0.4kg/s:0.4kg/s, 0.4kg/s:0.5kg/s, 0.4kg/s:0.6kg/s

(b) The ratio of indoor to outdoor air flow rate are 0.4kg/s:0.6kg/s, 0.5kg/s:0.6kg/s, 0.6kg/s:0.6kg/s

Fig. 11. Influence of outdoor air temperature difference on cooling efficiency.

Fig. 11 shows the influence of outdoor air temperature on cooling efficiency as the ratios of indoor to outdoor air flow rate are 0.4kg/s:0.4kg/s, 0.4kg/s:0.5kg/s, 0.4kg/s:0.6kg/s and 0.4kg/s:0.6kg/s, 0.5kg/s:0.6kg/s, 0.6kg/s:0.6kg/s, respectively. We can easily learn that the cooling efficiency of 0.4kg/s:0.6kg/s is the highest among them. As shown in Fig. 11(a), compared with the condition that indoor and outdoor air flow rate are both 0.4kg/s, when indoor air flow rate remains constant, the heat transfer amount increases with the increase of outdoor air flow rate, which leads to an increase of indoor temperature drop, so the cooling efficiency increases correspondingly. Similarly, in Fig. 11(b), when outdoor air flow rate remains in 0.6kg/s and indoor air flow rate increases from 0.4kg/s to 0.6kg/s, indoor air temperature drop decreases due to the increased air speed and insufficient heat transfer, which results in lower cooling efficiency. Based on the above analysis, the cooling efficiency increases with the outdoor air flow rate and decreases with the indoor air flow rate.

4.1. The influence of inclination angle on cooling efficiency

Fig. 12 reflects that, when indoor and outdoor air inlet flow rate is 0.4kg/s and indoor air inlet temperature is 30°C, changing angle from 5° to 50° can lead to different cooling efficiencies.

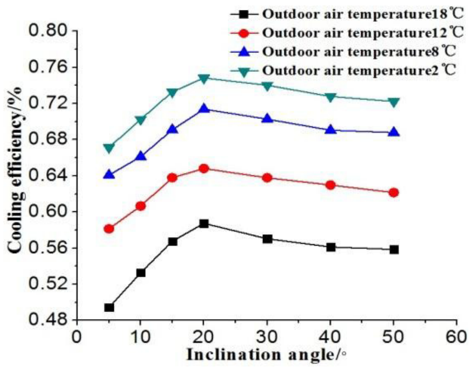


Fig. 12. Influence of inclination angle on heat transfer efficiency.

As inclination angle varies from 5° to 20°, the efficiency of heat exchanger is extremely sensitive to angle. Indoor air outlet temperature falls sharply with the increase of inclination angle. So the cooling efficiency increases sharply. This is because as the inclination angle is 0°, all gravity acts on the liquid film. The refrigerating fluid inside the heat pipe can not return to evaporation. Thus, the thickness of liquid film is thicker, and the thermal resistance is bigger, so the cooling efficiency is lower. As the inclination angle increases to 20°, only part of gravity acting on the liquid film, more and more liquid starts returning to evaporation. The thickness of liquid film becomes thinner, and the thermal resistance becomes smaller, so the cooling efficiency becomes higher. After that, inclination angle continues to increase, the backflow of excess liquid to the evaporation results in insufficient heat transfer, so the cooling efficiency will decline with the increase of inclination angle. And the inclination angle has little effect on thermal efficiency. Therefore, we can learn that, as the inclination angle varies from 5° to 50°, the maximum cooling efficiency can be obtained at angle of 20°.

5. Conclusions

Using gravity heat pipe exchanger for cooling the communication base station to replace the air conditioning has a promising prospect. This paper studies the effects of the inlet air flow rate, temperature and the exchanger inclination angle on cooling capacity and efficiency of the heat pipe exchanger. The main conclusions of this study are as follows:

（1）Under a constant indoor and outdoor air temperature, the cooling capacity of heat pipe exchanger increases with the air flow rate, while the cooling efficiency decreases with it.

（2）The lower the outdoor air temperature and the higher the indoor air temperature , the more energy saving. In cold winter, transition seasons and mild summer such as some areas in northeast China, the natural resources can be utilized effectively by gravity heat pipe exchanger under low outdoor temperature. The lower the outdoor temperature is, the better the energy saving effect. Whereas the outdoor temperature is not low enough in cool winter, transition seasons and hot summer areas, the heat pipe exchanger can not save energy efficiently. Because of expensive equipment investment, using the heat pipe exchanger can lead to a waste of resources.

（3）Under different indoor and outdoor air flow rate, the higher the outdoor air flow rate and the smaller the indoor air flow rate, the higher the cooling efficiency.

（4）When the indoor and outdoor air flow rate are 0.4kg/s and indoor air temperature is 30° C, the cooling efficiency of heat pipe exchanger has a sharp rise firstly and then decrease slowly with the increase of inclination angle. As the inclination angle varies from 5° to 50°, the maximum cooling efficiency can be obtained at angle of 20°.

The heat pipe exchanger can satisfy the cooling requirement of communication base station without air conditioning system in winter and transition seasons. Meanwhile, it can also save energy with combination of air conditioning in summer.

Acknowledgements

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