Experimental Study on Heat Dissipation Performance of Enclosed Space with Envelope Embedded Flat Heat Pipe

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Abstract. A lot of heat source equipment must work in enclosed space for noise controlling, electromagnetic shielding or three proofings requirement, the heat dissipation is an important problem for being restricted by the enclosed space. In order to solve the heat dissipation problem, the technology scheme was proposed that quantity of heat in enclosed space is conducted out by the flat heat pipe embedding in envelope. Furthermore, the flat heat pipe was designed and fabricated, and the heat dissipation performance of enclosed space with envelope embedded flat heat pipe was studied experimentally. It was found that the convective heat transfer on evaporation fins of heat pipe is the most important section influencing the heat dissipation performance of enclosed space. The temperature in enclosed space decreases greatly with increasing the disturbance air quantity in enclosed space. The temperature difference between inside and outside increases linearly with increasing heat source intensity. It is a novel method to solve effectively the heat dissipation problem of heat source equipment in enclosed space by embedding the flat heat pipe in the envelope.

Keywords. Heat source equipment; Flat heat pipe; Enclosed space; Heat dissipation.

1. Introduction

As the common back-up power supply, the fuel generator set is applied widely in civil and military fields for ensuring power supply normally without city electric supply [1,2]. Not only a large amount of heat but also large noise are brought by working fuel generator set. For ensuring the normal work and environmental friendliness, the heat dissipation and noise reduction must be handled. For most of generator sets, the wind cooling and liquid cooling are used respectively or concurrently for heat dissipation. Meanwhile the generator set is placed in a enclosed box for reducing noise [3,4]. The ventilation hole needs to be set up on box for adopting wind cooling, it exists contradiction with close requirement of noise controlling. Moreover, some generator sets with electromagnetic shielding or three proofings requirement need working in enclosed box [5,6], it is disadvantage to heat dissipation. So the heat dissipation technology has been an important research direction.

Xu et al. [7] designed the water cooling device and enclosed box structure to maximize noise reduction, but it was not adapt to wind cooling generator set. Xu et al. [8] studied numerically the temperature and flow fields in enclosed space, and presented three heat dissipation projects. Miroshnichenko et al. [9] simulated numerically composite heat transfer performance in enclosed space with heat source. Wang [10] and Yang [11] adopted radiator with different structure to absorb the heat from electronic device in enclosed space, and dissipate heat to outside by the connected basilar plate or wall of close space. Xiao [12] used L-style heat dissipation apparatus connected directly with chip bottom to dissipate heat to outside.

The heat pipe is applied usually to heat dissipation of electronic device for its excellent heat transfer performance [13-16]. Zeghari et al. [17] investigated the heat dissipation of the television box by using
conventional fans cooling and passive flat heat pipe cooling, the results show the heat pipe can be more effective to cooling electronic components of the television box than conventional fans. Sulaiman et al. [18] investigated experimentally and theoretically the thermal performance of the radiation-absorbing heat pipe heat exchanger at different temperatures of a hot source. Xiahou et al. [19] adopted the flat heat pipe to cool IGBT, and a new-type of heat pipe was designed by combining the cold end of array with the hot end of public plane, the results shows the designed heat pipe has more obvious advantages to cool IGBT compared with traditional gravity heat pipes. Li et al. [20] developed a new superhydrophilic treatment method for wick capillarity enhancement and studied the mechanism of the superwettability, the microscale flat flat heat pipe has a maximum equivalent thermal conductivity up to 2.88×10^4 W/(m.K). Chen et al. [21] experimentally conducted temperature distribution, maximum heat transfer capability, and thermal resistance of MFPHPs, the experimental results reveal that inner surface treatment has important influence to enhance effectually thermal performance of MFPHPs, and difference enhancement of thermal performance can be achieved by different treatment morphologies of inner surfaces.

The studies of the above show the heat pipe has excellent heat transfer performance by directly contact with generate heat parts. For some heat source devices in enclosed space which are not adapted to contact directly with heat pipe, the traditional heat pipe configuration can not meet the heat dissipation requirements. The new heat dissipation methods by using heat pipe need to be developed and cooling effects should be investigated furthermore. In this paper, in order to solve the heat dissipation problem of heat source device in enclosed space, a novel heat dissipation method is proposed that the flat heat pipes are embedded in envelope, and the heat in enclosed space is removed outside by heat pipe. Based on the designing of the flat heat pipe, the heat dissipation performance of enclosed space with envelope embedded flat heat pipe was studied experimentally.

2. Design of Flat Heat Pipe

In order to acquire better heat transfer performance, the flat heat pipe is manufactured by copper, and embedded in envelope of enclosed space. For enhancing the convective heat transfer on the evaporation and condensation sides of heat pipe, the fins are set up as extended surface. The flat heat pipes are designed horizontal and vertical style respectively for corresponding horizontal top surface and vertical side surface, the size of heat transfer cross section is 280 mm×120 mm and 280 mm×60 mm respectively, as shown in Fig. 1.

![Figure 1. Design of the flat heat pipes.](image)

According to the work principle of flat heat pipe, for the horizontal flat heat pipe, the condensation liquid can automatically flow back to evaporation surface by gravity role because of its horizontal evaporation and condensation surfaces, and circulate work continuously. But for the vertical flat heat pipe, due to its vertical horizontal evaporation and condensation surfaces, the condensation liquid can flow back to the bottom of heat pipe cavity by gravity role, and cannot overspread the whole evaporation surface, the heat transfer performance decreases greatly. Therefore, the foam copper as shown in Fig. 2(a) is used as capillary wick interposed on evaporation surface, the condensation liquid at bottom of cavity can be elevated to infiltrate the whole evaporation surface, thus the working continuously and higher heat transfer performance of the vertical flat heat pipe can be ensured. In order to enhance further the heat transfer performance of the horizontal flat heat pipe, the pin-fin enhance structure is used in the cavity inside as shown in Fig. 2(b). For the devices in the close space
work under 100℃, and the heat pipe has good start-up performance, the absolute alcohol is chosen to be working medium and liquid filling rations of two kinds of flat heat pipe are 50%.

(a) Foam copper capillary wick                                 (b) Pin-fin enhance structure

Figure 2. Inside enhances structure of two flat heat pipes.

3. Heat Dissipation Experiment of Enclosed Space

3.1. Experimental System
The epoxy resin plate with 10 mm thickness was used as envelope of enclosed space, the boundary dimension of enclosed space is 350 mm × 350 mm × 350 mm and its inner volume is 0.0429 m³. The electric stove with 1000 W power was used as simulative heat source, the power can be adjusted by AC voltage regulator and the maximal heating intensity is about 23300 W/m³. Two horizontal flat heat pipes were embedded in top plate of envelope, while a vertical flat heat pipe was embedded in each side plate of envelope (the total heat transfer cross section is 0.0429 m²). The cool fans were installed on condensation side fins of heat pipe. Furthermore, in order to improve temperature uniformity in enclosed space and enhance the convective heat transfer of condensation side fins with inner air, the cycle fans were installed inside of enclosed space to disturb air flow. The envelope of enclosed space was handled with heat insulation for investigating correctly heat transfer capability of heat pipe.

Figure 3. Schematic diagram of experimental system.

The experimental system is shown in Fig. 3, the temperatures of enclosed space, environment, evaporation and condensation sides of heat pipe were measured by E-type thermocouples. Because of uneven temperature distribution in enclosed space, several thermocouples were fixed in enclosed space, and the average value of these measure temperatures is looked as temperature of enclosed space. In order to reduce the temperature measure deviation by thermal radiation of electric stove, one sheet metal for heat shielding was put above electric stove. All signals of thermocouples, current and voltage of electric stove were gathered and recorded by Agilent 34970A data acquisition instrument.

3.2. Data Reduction
The heat power of simulative heat source Q can be calculated as follows:

\[ Q = UI \]
where \( U \) and \( I \) are the voltage and current of the simulative heat source, respectively. The heat dissipation intensity of enclosed space \( q_v \) can be calculated as follows:

\[
q_v = \frac{Q}{V}
\]  

(2)

Where \( V \) is the volume of enclosed space. The heat flux of flat heat pipe \( q \) can be calculated as follows:

\[
q = \frac{Q}{S}
\]  

(3)

Where \( S \) is the total cross section of the flat heat pipes on envelope. For top horizontal flat heat pipe, the convective heat transfer thermal resistance \( R_{i,i} \) on the evaporation side fins, the heat conduction thermal resistance \( R_{i,HP} \), and the convective heat transfer thermal resistance \( R_{i,o} \) on the condensation side fins can be expressed as follows:

\[
R_{i,i} = \frac{(t_{f,i} - t_{HP,i})}{q}, \quad R_{i,HP} = \frac{(t_{HP,i} - t_{HP,o})}{q}, \quad R_{i,o} = \frac{(t_{HP,o} - t_{f,o})}{q}
\]  

(4)

Where \( t_{f,i}, t_{HP,i}, t_{HP,o}, t_{f,o} \) are temperature of the air in enclosed space, evaporation surface, condensation surface and environment, respectively.

4. Results and Discussion

4.1. Thermal Resistance of Heat Transfer

The 8 cycle fans (9 V input voltage) were installed in enclosed space, three heat conditions are shown in Table 1. The Fig. 4 shows temperature measure results of each heat transfer segment.

| NO. | Heat power/(W) | Heat intensity of heat source (W/m³) | Heat flux of flat heat pipe (W/m²) | Environment temperature (°C) |
|-----|----------------|-------------------------------------|-----------------------------------|-------------------------------|
| 1   | 299            | 6980                                | 2228                              | 19.7                          |
| 2   | 439            | 10229                               | 3265                              | 19.5                          |
| 3   | 494            | 11507                               | 3673                              | 20.2                          |

According to Fig. 4, the temperature of enclosed space increases with increasing heat power. With higher heat intensity 11507 W/m³, the temperature in enclosed space is 54.8 °C, and the temperature difference still is to be 34.6 °C, so it can be proved that the heat dissipation performance of the system can be improved further.

For the top horizontal flat heat pipe, the temperature distribution from inside to outside of enclosed space and thermal resistance of each heat transfer segment with \( q_v = 6980 \) W/m³ were shown in Fig. 5. Fig. 5 shows the temperature gradient between inner air and evaporation surface of heat pipe is higher greatly than other two segments, that is to say, its thermal resistance is largest. The heat conduction thermal resistance of heat pipe is smallest in the whole heat transfer process. Due to better heat convective capability of condensation surface with cool fan, its thermal resistance is small relatively. The three thermal resistances of three segments is 73.21 %, 9.65 %, 17.14 % of the total thermal resistance respectively. It can be found that the maximum thermal resistance comes from the convective heat transfer between inner air and evaporation surface of heat pipe. Therefore, The enhancing convective heat transfer on evaporation surface of heat pipe is key to improve the heat dissipation capability of the total system.
4.2. Effects of Air Quantity of Cycle Fans on Heat Dissipation Performance

For investigating the effects of air quantity of cycle fans on heat dissipation performance, the 4 fans with 6V input voltage, 8 fans with 9V input voltage and 8 fans with 24V input voltage were used as inner cycle fan respectively. The heat dissipation performance of system with $q_v = 6980 \text{ W/m}^3$ was studied experimentally. The experimental results of temperature distribution from inside to outside of enclosed space for the top horizontal flat heat pipe were shown in Fig. 6.

Fig. 6 shows that the temperature gradient between inner air and evaporation surface of heat pipe decreases with increasing the air quantity of cycle fans. It can be inferred the thermal resistance decreases and convective heat transfer capability increases. With three kinds of fan design conditions, the temperature difference between inside and outside of enclosed space is 24.1 °C, 19.6 °C and 17 °C.
respectively. Therefore, the effect of enhancing heat dissipation decreases gradually with increasing air quantity. While not to change fundamentally the inner air flow field, the excessive air quantity is not advantage for increasing power consumption and noise of fans.

![Figure 6. Effects of air quantity of cycle fans on heat dissipation performance.](image)

4.3. Effects of Heat Intensity of Heat Source on Heat Dissipation Performance

When the 8 fan with 24 V input voltage were installed in enclosed space, the heat transfer capability of system was investigated experimentally with $q_v = 6980, 7672, 9590, 11510, 13427$ W/m$^3$. The experimental results of temperature distribution from inside to outside of enclosed space for the top horizontal flat heat pipe were shown in Fig. 7.

![Figure 7. Effects of heat intensity of heat source on heat dissipation performance.](image)

Fig. 7 shows the heat transfer intensity of evaporation surface decreases, and average temperature of air in enclosed space increases with increasing the heat intensity of heat source under the condition of
invariant air quantity of cycle fan. The variation of temperature difference between inside and outside of enclosed space with heat intensity of heat source and heat flux of flat heat pipe was shown in Fig. 8.

**Figure 8.** The variation of temperature difference with heat intensity of heat source.

Fig. 8 shows that the temperature difference between inside and outside of enclosed space increases linearly with increasing heat intensity of heat source. The experimental maximum relative error is about 7.3% for ignoring air physical properties variation and measure error. According to Fig. 8, The temperature difference is about 30 °C when the average heat flux of flat heat pipe is 4286 W/m² at \( q_v = 13427 \text{ W/m}^3 \). The effect of temperature change on air physical properties is ignored, thus it can be inferred the temperature difference is still 30 °C, and the average temperature of inner air is 65 °C at environment temperature rises to 35 °C and the same heat intensity of heat source. If temperature difference needs to be 20 °C, then the corresponding heat intensity of heat source can be about 8500 W/m³, and the average heat flux of flat heat pipe is 2713 W/m². Therefore, the needful area of flat heat pipe can be inferred according to actual apply requirement from the linearly law in Fig. 8.

5. Conclusions

According to the excellent heat transfer performance of heat pipe, it is proposed that the flat heat pipes are embedded in envelope, and the heat in enclosed space is removed outside by heat pipe. Based on the designing of the flat heat pipe, the heat dissipation performance of enclosed space with envelope embedded flat heat pipe was studied experimentally. The following conclusions can be arrived:

1. The convective heat transfer between inner air and evaporation surface of heat pipe is main segment influencing heat dissipation performance of enclosed space because its thermal resistance is largest. The temperature of enclosed space can decreased greatly by increasing the air quantity of cycle fan.
2. The temperature difference between inside and outside of enclosed space increases linearly with increasing heat intensity of heat source, thus, the needful area of flat heat pipe can be inferred at different requirement of temperature difference.
3. The heat dissipation problem of the device with heat source in enclosed space can be solved effectively by the way of embedding the flat heat pipe in envelope of enclosed space, and it has advantage of heat transfer but not mass transfer.
4. It is recommended in future work to focus on enhancing heat dissipation performance by using the flat heat pipe with better heat transfer capacity and optimizing the air flow inner enclosed space.
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