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Experimental study on effective range of miniature oscillating heat pipes

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ABSTRACT

A series of experiments were performed to investigate the effect of heat transfer length and inner diameter on the heat transport capability of miniature oscillating heat pipes (MOHPs). In the experiments, MOHPs with heat transfer length (L) of 100, 150 and 200 mm, consisting of 4 meandering turns and inner diameter of 0.4, 0.8, 1.3 and 1.8 mm were adopted, and pure water was used as the working fluid. The results show that increasing inner diameter or decreasing heat transfer length is beneficial to MOHPs startup. An effective range of MOHPs has been identified. The recommended inner diameter of MOHPs should be bigger than 0.8 mm in vertical bottom heating mode, while the heat transfer length should be controlled less than approximately 100 mm in horizontal heating mode. For high heating power, the thermal performance of MOHPs can only approach that of sintered heat pipes in horizontal heating mode, while exceed it in vertical bottom heating mode. Finally, the dominating dimensionless parameters, including Di/L, Ja, Bo and Wa, are used to predict the heat transport capability of MOHPs. The correlation prediction agrees with the experimental results fairly well.

1. Introduction

Oscillating heat pipe (OHP) is a new type of efficient heat transfer device which was introduced in the mid-1990s by Akachi [1,2]. It is getting a great deal of attention due to its simple design, small size and excellent thermal performance. It is predicted as one of the most promising solution for higher heat dissipation compact cooling. The heat transfer characteristics of OHPs have become a hot research. Lee [3], Hosoda [4], Tong [5], Khandekar [6] and Zhang [7] et al. studied the operation mechanism of an OHP through the visualization experiments. Miyazaki [8,9] et al. discussed the relationship between the best liquid filling ratios (FRs) and operating directions. Rittidech [10,11], Qu [12], Wang [13,14] et al. explored the interaction between different working fluids and different inner diameters. Wang and Nishio [15] investigated the effect of length ratio of heating section to cooling section on the ultimate heat transport capability of OHPs. Ma [16–18], Chiang [19], Lin [20] and Wang [21,22] et al. found that functional thermal fluids (such as nano-fluid and microcapsule fluid) can enhance the heat transport capability of an OHP. In summary, the studies mainly focused on parametric experimental investigations and in which conditions OHPs could operate better. The main conclusions in previous studies were as follows: (1) OHPs were hard to operate in horizontal heating mode; the situation would be improved with the increase of the number of turns. There were a certain critical number of turns to reduce the performance gap between horizontal and vertical bottom heating mode. (2) The thermal performance of OHPs was improved with increase of inner diameter. (3) The best liquid filling ratio was around 50% and slightly varied according to gravity orientations. (4) Working fluid had a great influence on the thermal performance of OHPs and should be chosen according to the actual conditions. In fact, an effective range of OHPs is still not clear although many studies have been carried out, such as effective heat transfer length; superiority to conventional heat pipes and a predicting correlation for the heat transport capability of OHPs. In this study, a series of experiments were performed to investigate the questions mentioned above.

Generally, compared to conventional heat pipes which are one of the proven technologies, OHPs have few advantages in conventional sizes (outer diameter larger than 3 mm). Conventional heat pipes have a more extensive range of applications due to wick structures to assist working fluid cycle. Therefore, the research range of OHPs should be focused on miniature sizes which conventional heat pipes are hard to reach. In fact, the difficulties of manufacturing greatly increase when outer diameter of conventional heat pipes is less than 3 mm. How to add a capillary wick layer and meanwhile ensure a sufficient vapor channel is a key problem for manufacturing miniature heat pipe. In contrast, OHPs technology will greatly reduced the difficulties of manufacturing due to its small size and no

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Nomenclature

Bo	bond number ($=Di\ [g(\rho_{tl}-\rho_v)/\sigma]^{0.5}$)
Cp	constant pressure specific heat (J/kg °C)
Di	inner diameter (mm)
Do	outer diameter (mm)
g	gravitational acceleration (m/s^2)
h_{fg}	latent heat of vaporization (J/kg)
ΔT	temperature difference between outlet and inlet ($=T_{18}-T_{17}$)
Ja	Jakob number ($=Cp\Delta T/h_{fg}$)
L	heat transfer length (mm)
L_e	length of evaporation section (mm)
L_c	length of condensation section (mm)
L_a	length of adiabatic section (mm)
q_c	heat flux output (W/m^2)
S	heat transfer area (m^2)
q_h	heat flux input (W/m^2)
Wa	Wallis number ($=1+(\rho_v/\rho_l))^{0.25}$)
Q_h	heating power (W)

Greek symbols

ρ	Density (kg/m^3)
σ	surface tension (N/m)

Subscripts

c	condensation section
e	evaporation section
l	liquid
v	vapor

wick structure. In particular, in some cases such as for cooling LED (Light Emitting Diode), CPUs (Central Processing Units) of notebooks and IGBT (Insulated Gate Bipolar Transistor) modules, MOHPs may be the most promising solution in the small space.

2. Experiment setup

Based on the issues discussed above, copper tubes with outer diameter (Do) of 1.6, 2, 2.5 and 3 mm, inner diameter (Di) of 0.4, 0.8, 1.3 and 1.8 mm were used as manufacturing material, and they were welded into the four-turn MOHPs separately. After welding, oxides in MOHPs needed to be restored. The four-turn MOHP was selected as a typical shape. If a four-turn MOHP operated well; increasing turns would gain better performance [23]. Wall thickness was 0.6 mm in order to avoid serious fold for blocking flow channel. Pure water was used as working fluid. The heat transfer length (L) of 100, 150 and 200 mm were adopted for comparative experiments. In the liquid filling process, internal channels of copper tubes were first evacuated and the working fluid was inhaled fully into the tube under the pressure difference. Liquid filling ratio was controlled around 50 ± 5% by the second vacuum, which discharged the excess liquid.

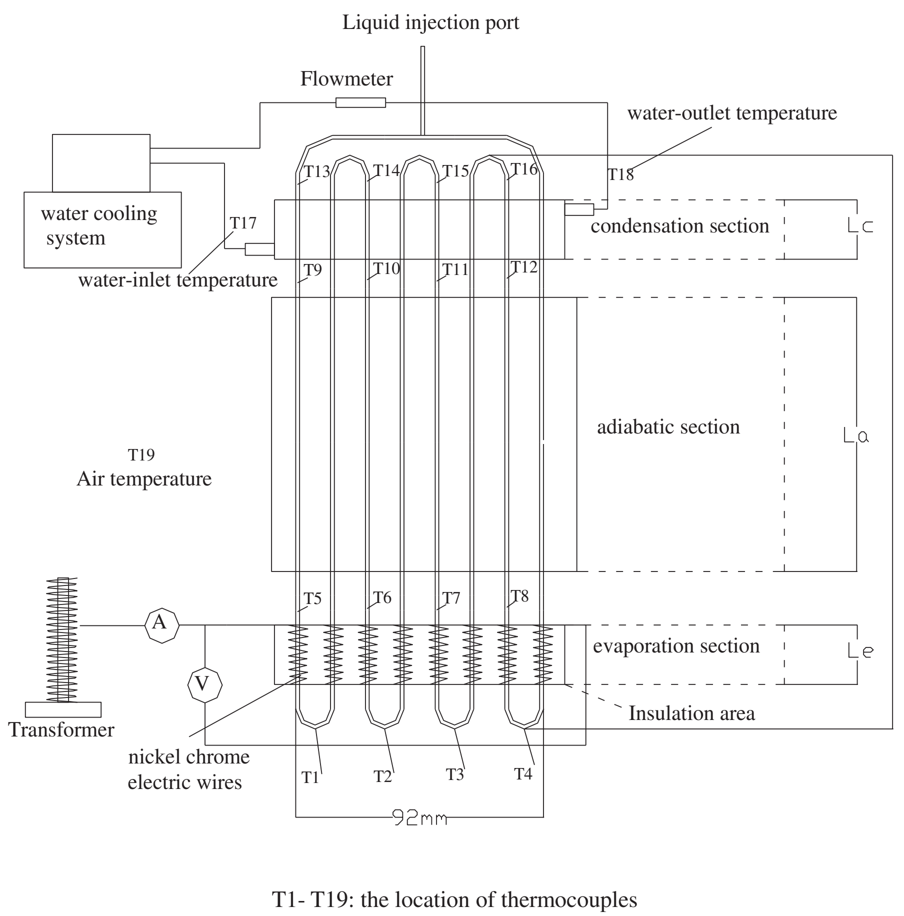

Fig. 1. Experimental apparatus of MOHP.