Experimental Thermal and Fluid Science 98 (2018) 137–145

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Operational characteristics of oscillating heat pipe with long heat transport distance for solar energy application

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ARTICLE INFO

Keywords:
Oscillating heat pipe
Thermal performance
Long-distance heat transport
Pressure spectrum

ABSTRACT

In order to further understand the operational characteristic of long heat transport distance oscillation heat pipe (OHP) for solar energy application, an experimental investigation on the thermal performance of OHP with higher initial vacuum and pressure fluctuation behavior inside under two kinds of inner diameters, two kinds of working media, and different inclination angles and filling ratios (FR) were carried out. The main result shows that the OHPs exhibit excellent heat transfer performance. The effective thermal conductivity is about two orders of magnitude larger than that in the previous work and some other researchers' work. The start-up temperature of the OHP with 3 mm inner diameter increases from 45 °C to 58 °C with the growing of *FR* from 30% to 70% when injected with SRWF and placed vertically. The start-up temperature is inversely related to the inclination angle under the same condition. The working status of the OHP with 3 mm inner diameter and SRWF is hardly effected by the inner pressure. However, the effect is contrary for OHP with critical inner diameter. It can be inferred that the movement law of the liquid medium in the OHP is random and chaotic through the pressure frequency spectrum analysis.

1. Introduction

Oscillation or pulsation heat pipe (OHP or PHP) is being widely investigated by many researchers all over the world since it was first introduced in the 1990s [1,2]. Like other types of heat pipes, it has been studied in many application fields, such as the electronic device cooling [3–5], industrial heat exchange [6,7] and other areas [8,9]. Solar energy is clean and abundant and can play a significant role in the battle of energy-saving and emission-reduction if it can be well developed [10–12]. The application investigation of OHP in the solar thermal energy field has been explored by some researchers due to its great potential for heat transfer and structural flexibility. Rittidech et al. [13,14] designed two kinds of solar collector based on closed-loop OHP with check valve and closed-end OHP, respectively. In the both works, the detailed dimension of the solar collectors were given and the focus is on the thermal efficiency of the collectors. The heat transfer performance characteristic and potential of those OHPs is not presented. Kargarsharifabad et al. [15] proposed a flat plate solar collector based on closed-loop OHP, the structure of which is similar to the former. Many parameters were investigated and the results indicated that the optimal filling ratio and inclination angle was 0.3 and 20°, respectively. Similarly, the detailed thermal performance of OHPs is not provided. Xian et al. [16] also designed two kinds of solar collector respectively based on tube OHP and flat plate OHP. The heat transfer rate and thermal conductivity for those two types were compared under different filling ratios and inclination angles. The OHPs show good heat transfer performance and the largest effective thermal conductivity is above 35,000 W/(m °C). However, the movement law of the internal working fluids was not investigated to further understand the working mechanism of OHP. Xu et al. [17] proposed a newly solar collector that combines the OHP with compound parabolic concentrator and their research view is mainly concerned on the performance of collectors in actual conditions. The results implies that the absorber can work well with a thermal resistance of about 0.26 °C/W.

In the previous work [18], aiming to face large-scale heat transfer applications, such as solar energy utilization and industrial waste heat recovery, the thermal performance of a OHP with 4 mm inner diameter (DI) at critical range and long heat transport distance under different conditions including different working medium, condensation capability and filling ratios were investigated experimentally. As a continuation of the previous work, the further study on thermal performance and potential of long heat transport distance OHP with different *DI*s under different inclination angles, filling ratios (*FRs*) heat inputs and higher initial vacuum were carried out. The start-up characteristic, pressure fluctuation behavior, pressure frequency spectrum under different operation conditions were analyzed in this paper.

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https://doi.org/10.1016/j.expthermflusci.2018.05.026
Received 12 February 2018; Received in revised form 23 April 2018; Accepted 28 May 2018

Nomenclature

R	thermal resistance [°C W^{-1}]
$\dot{m}$	flow rate[kg/s]
ΔT	temperature difference [°C]
$\dot{Q}$	heat transport [W]
k	thermal conductivity [W m^{-1} °C^{-1}]
α	inclination angle[°]
p	pressure [Pa]

Subscripts

ave	average
adia	adiabatic
s	substrate material
e	evaporation
c	condensation
w	water
eff	effective

Acronyms

EF	enhancement factor
DI	inner diameter
FR	filling ratio
SRWF	self-rewetting fluid
OHP	oscillating heat pipe

2. Experiment set up and procedure

Two long heat transport distance oscillating heat pipes with the *DI* of 3 mm and 4 mm were fabricated and the corresponding testing platforms were established, respectively. Fig. 1 shows the photograph of experimental platform configuration, relevant parameters and operational conditions. The structure and dimension of the OHPs can be found clearly. The heating system, cooling system and data acquisition system are similar to those in the previous work. The measuring frequency of the data acquisition instrument is 0.333 Hz. Fig. 2 presents the schematic of temperature measuring points, which includes eight measuring points in the evaporation section ($T_1 \sim T_8$), eight in the condensation section ($T_9 \sim T_{16}$), and each one in the entrance and exit of circulating water box (T_{17}, T_{18}), respectively. Deionized Water (DW) and Hept. DW Sol. 0.1 w% (a kind of self-rewetting fluid, SRWF) are employed as working medium, and the *FR* varies among 30%, 40%, 50%, 60% and 70%. The inclination angles (α) varies among 0°, 30°, 60° and 90°. All the experiments under different conditions were performed long enough to obtain suitable data in the period of thermal equilibrium.

In order to evaluate to thermal performance of the OHP from different views, different evaluation parameters were derived from the original data, including the time-averaged temperature difference between the evaporation and condensation section (considering the temperature only), the thermal resistance (considering the heat transported further), the effective thermal conductivity (considering the heat transport distance further) and the enhanced factor (for direct comparison).

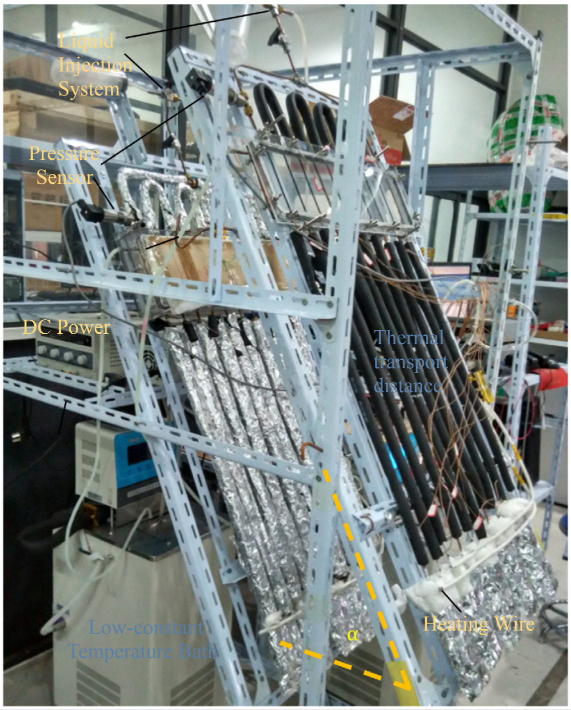
The heat ($\dot{Q}$) transferred by OHP can be calculated through formula (1) and (2), respectively.

$$\dot{Q} = Cp\dot{m}\Delta T_w \tag{1}$$

$$\Delta T_w = \frac{\int_{t_1}^{t_2}(T_{18}(t) - T_{17}(t))dt}{(t_2 - t_1)} \tag{2}$$

where $\dot{m}$ and ΔT_w are the mass flow rate and the time-averaged temperature difference of the circulating water for a thermal equilibrium period of time, respectively. The thermal resistance (R_{OHP}) could be calculated using the following formulas (3)–(5) [19,20]:

$$R_{OHP} = \Delta T_{ohp}/\dot{Q} = (\overline{T_e} - \overline{T_c})/\dot{Q} \tag{3}$$



Relevant Parameters and conditions	
Working fluid	Deionized Water (DW), Hept. DW Sol. 0.1w%
Tube material	Copper
Inner Diameter (*DI*)	3, 4[mm]
Evaporator Height	200[mm]
Condenser Height	150[mm]
Adiabatic Height	640[mm]
Width	480[mm]
Filling ratio (*FR*)	30%, 40%, 50%, 60%, 70%
Inclination angle (α)	0°, 30°, 60°, 90°
Temperature/rate of cooling Water	15°C, 3.5 mL/s

Fig. 1. The photograph of experimental platform and relevant parameters and conditions.