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A novel double pipe pulsating heat pipe design to tackle inverted heat source arrangement

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HIGHLIGHTS

- A novel pulsating heat pipe (PHP) is proposed for upside down heat source/sink arrangement.
- The PHP features alternative double-pipe and extra opening for more unbalanced forces.
- The PHP is functional properly even when the heat source is placed at the bottom.
- The thermal resistance is 0.0729 W/K and an effective thermal conductivity of 12,603 W/m·K.
- The thermal resistance for the proposed design is only half of the single tube design.

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ABSTRACT

Traditional pulsating heat pipe with fewer turns is functional only when the heat source is placed at the bottom while the heat sink is on top. This study proposes a novel design having alternative double-pipe tube diameter with some extra open connections of these double-pipes. By introducing extra un-balanced pressure force, capillary force and gravity force, the PHP can be easily starting up even for an opposite heat source/sink arrangement while the conventional single tube design fails to start up with this opposite arrangement. The thermal resistance of double pipe PHP can be lowered to 0.0729 W/K with an effective thermal conductivity of 12,603 W/m·K when the heat source is placed on top. Yet the thermal resistance for the proposed double pipe design is only half of the single tube design.

1. Introduction

The pulsating (or) oscillating heat pipe (PHP), featuring a wickless and a comparatively long distance transport ability, was introduced by Akachi [1,2] in early 1990. Typical PHPs are made of small diameter tubes with vertically serpentine configurations, filling with some amount of working fluid. Through this arrangement, the PHPs are able to operate subject to expansion of vapor slug at the evaporator and contraction in the condenser with unevenly distributed liquid slugs and vapor plugs within the whole tube [3]. Unlike the conventional heat pipes that make use the capillary wick structure to complete the flow circulation, the wickless design of PHP significantly ease the capital cost of the manufacturing process. In addition, the PHPs also hold many superior features such as high effective thermal conductivity, flexibility, large maximum heat transfer, and long distance transportation capability. Hence it is especial viable for industrious, military, heat recovery, and aerospace applications. Some related studies like Charoensawan et al. [4] and Khandekar et al. [5] had experimentally studied a wide range parameters of pulsating heat pipes in association with thermal performance.

However, since the introduction of PHPs by Akachi [1,2] at early 1990, very few PHPs had been put into actual product. This is because the original PHP is applicable only when gravity is in assistance [4] (vertically arrangement with heat source being placed at the bottom while heat sink is on top) when the number of turns (N) is less than a threshold value of N_{crit}. This inevitably limits the applications of PHPs. Although using more turns can successfully launch PHPs in the horizontal orientation [6], it will require more space to accommodate PHPs. To tackle this problem, Rittidech et al. [7] added a check valve onto the PHP for providing unilateral flow direction which can improve the startup characteristics for PHP subject to horizontal arrangement. Mohammadi et al. [8] suggested the use of magnetic particle accompanying with a magnetic field control to facilitate the startup of PHP pertaining to horizontal arrangement. The use of check valve or magnetic particle is

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Nomenclature

A	heat transfer surface area (m^2)	Q_{out}	cooling capacity of condenser (W)
C_p	specific heat at constant pressure of water (J/kg·K)	R	total thermal resistance (K/W)
k_{eff}	effective thermal conductivity (W/m·K)	T_c	average temperature of condenser (K)
L_{eff}	length between the thermal couple location of evaporating and condensing (m)	T_e	average temperature of evaporator (K)
$\dot{m}$	mass flow rate (kg/s)	T_{in}	inlet temperature of chilled water (K)
Q_{input}	supplied input power from the heater (W)	T_{out}	outlet temperature of chilled water (K)

effective but it brings out the issues of higher installation cost and system complexity. Chien et al. [9] proposed a novel design of PHP having a non-uniform channel configuration which introduces additional unbalanced capillary force to startup PHPs with fewer turns subject to horizontal configuration. Tseng et al. [10] extended this concept further to a typical PHP with fewer turns and the working fluids include distilled water, methanol and HFE-7100. Yang et al. [11,12] also applied the concept to silicon based micro PHP to resolve the heat dissipation of high power electronics and hot spot in LEDs.

Though some of aforementioned ingenious designs had effectively started up PHPs with horizontal arrangements, they are still not functional when the heat source is being placed at the bottom. Note that the upside arrangement of heat source and heat sink is not uncommon in practical applications. To tailor this difficulty, this study proposes a novel design using combined alternative double-pipe tube diameters with some extra open connections to the double-pipe. By introducing extra un-balanced pressure force along with capillary force and gravity force, the PHP is able to operate even with an opposite heat source/sink arrangement. Further details of the performance of this novel design in comparison with previous studies will be addressed accordingly.

2. Experimental apparatus

Further elaborations of the present apparatus for the experiments can be referred to Tseng et al. [10]. In this study, two PHPs having either single or double pipe configuration were fabricated and tested. Detailed geometries and dimensions of the tested single pipe and double pipe PHP are shown in Figs. 1 and 2, respectively. The single pipe PHP was made of copper tube with an overall size of 200 mm × 210 mm × 3 mm having 8 parallel channels whose details can be found from Tseng et al. [10]. The outer diameter of the single pipe PHP is 3 mm having a wall thickness of 0.3 mm and half of the tubes were compressed to become oval shape with a minor diameter of 1.5 mm as depicted in Fig. 1. For the double pipe PHP, the outer diameters of the PHP are 3 mm and 2 mm, respectively. Yet the corresponding wall thickness is 0.3 mm and 0.2 mm. The two pipes are joined together by soldier as shown as the photo in Fig. 2. The filling ratio of working fluids (methanol) for the single pipe PHP and double pipe PHP in this study are 59.8% and 50.1%, respectively. After filling and sealing, the PHPs were tested with power inputs ranging from 40 W to 220 W with normal vertical arrangement (heat source in the bottom, heat sink on top) and upside down arrangement where the

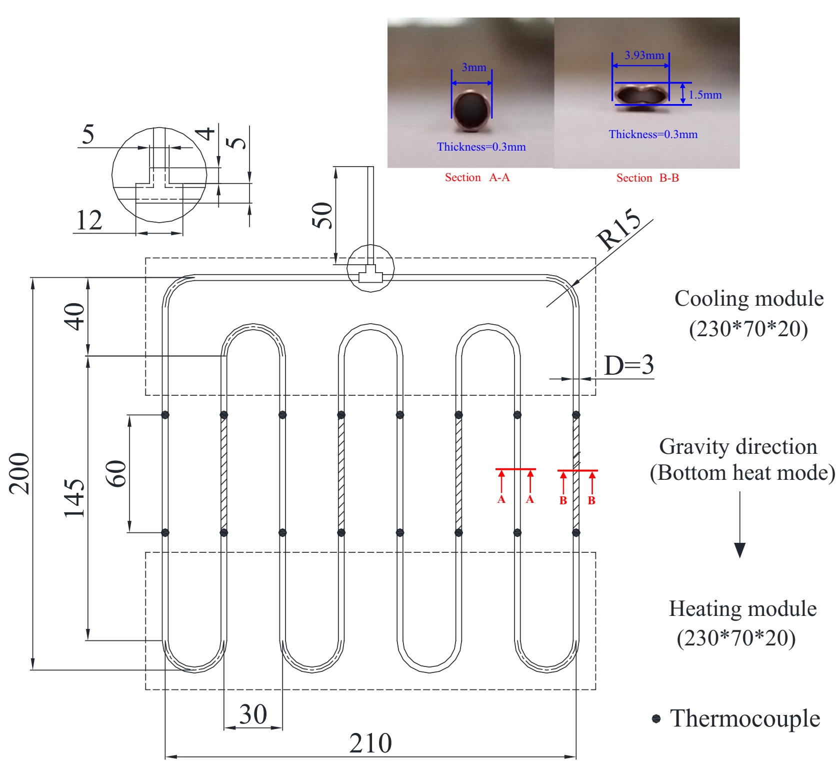

Fig. 1. Schematic of dimensions and the locations of the thermocouples of the test CLPHP. (Unit: mm).