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Experimental Study on Enhanced Heat Transfer Characteristis of Synergistic Coupling between the Pulsating Heat Pipes

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Abstract

Using a constant temperature water bath as heat source, experiments are performed to investigate the heat transfer characteristies of the coupled pulsating heat pipe (PHP), which consists of the main PHP filled with distilled water and the synergistic oscillating PHP filled with ethanol. The heat transfer characteristies and the wall temperatures of the coupled PHP are analyzed and compared with the single PHP only made of the main PHP under the same condition. The results shows that: in the same heat source temperature, the heat absorption and the heat release of the coupled PHP are both greater than the single PHP's, and the heat transfer is better in the case of small temperature difference. From 50℃, the condenser section of the synergistic oscillating PHP occures oscillating, the pulsating working fluid flow and the oscillating heat transfer characteristics can effect the main PHP, an optimal effect of enhanced heat transfer can been obtained by the two mutual incentive PHPs.

Keywords: enhanced heat transfer; pulsating heat pipe; synergistic coupling; incentive

1. Introduction

The heat exchanger was improved on by using a pulsating heat pipe (PHP) applied in the system of a heat exchanger (e.g., CPU cooling and air pre-heaters [1-3]. The concept of a PHP was first proposed by Akachi [4]. A typical PHP is a small meandering tube that is partially filled with a working fluid. The PHP can be divided into three main types, as seen in Figure 1(a-c): a closed-end pulsating heat pipe (CEPHP), where both ends of the tube are closed; a closed-loop pulsating heat pipe (CLPHP), where the ends of the tube are connected together to form a closed loop; and a closed-loop pulsating heat pipe with a check valve (CLPHPW/CV), which incorporates one or more check valves in the loop.

The pulsating heat pipe is evacuated and then partially filled with a working fluid, a PHP must be

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heated in at least one section and cooled in another. Often the evaporators and condensers are located at the bends of the capillary tube, the liquid and its vapor will become distributed throughout the pipe as liquid slugs and vapor bubbles, as shown in Figure 1(d). As the evaporator section of the PHP is heated, the vapor pressure of the bubbles located in that section will increase. This forces the liquid slug toward the condenser section of the heat pipe. When the vapor bubbles reach the condenser, it will begin to condense. As the vapor changes phase, the vapor pressure decreases, and the liquid flows back toward the condenser end. In this way, a steady oscillating flow is set up in the PHP. Compared to the traditional heat pipe, the pulsating heat pipe presents a number of new features: lower pressure drop, higher thermal response, lower weight, smaller size, higher heat transfer capability, ease of construction, rapid response to high heat load, and an operation almost independentof orientation [5, 6].

Based on the works of the past two years [7-11], we present detailed thermal oscillation measurements of the thin wall surface of PHP. The main objective of this article is to develop a coupled PHP with the aid of enhanced heat transfer. Experiments are performed to investigate the heat transfer characteristies of the coupled PHP and the single heat pipe, through comparing the wall temperatures of the two kinds of PHPs, to study an optimal effect of enhanced heat transfer could been obtained by the two mutual incentive PHPs, the results of this work may become a guide for the design and knowledge of the operating cycle and heat transfer of a PHP.

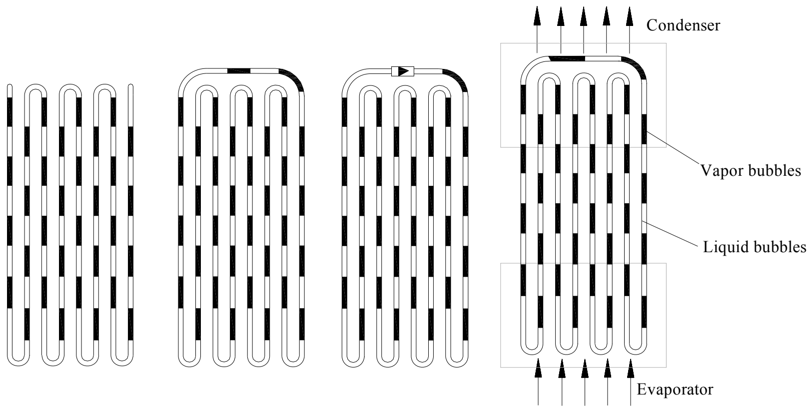


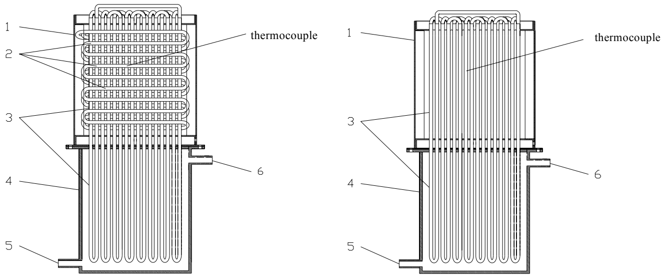
Figure 1. PHPs: (a) closed-end, (b) closed-loop, (c)closed-loop with check valve, (d) principle of work

2. Description of experiments

2.1. Description of Experimental Setups

Two different setups are built for the experiments, the setup one (Figure 2 (a)) consists of a main PHP and a synergistic oscillating PHP, which are orthogonal to layout for point - point contacted, the contacted sites are named as the coupling sites, the non-contacted sites are named as the non-coupling sites. The main PHP is meandering-tube PHP in the water tank, are all made of 24 parallel copper tubes(ID 2.0mm) interconnected alternately by 23 copper U-turns connected together to form a closed loop, the synergistic oscillating PHP which are fabricated in the box, using 6×8 capillary tubes, with an inside diameter of 2 mm, the ends of the tubes are connected together to form a closed loop.

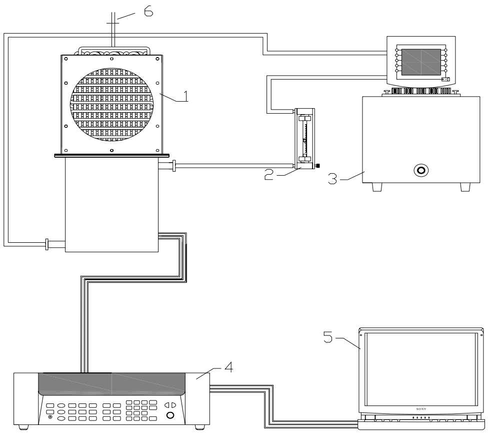
The setup two (Figure 2 (b)) is very simmilar to the setup one with regard to the test PHP structure, the heater source, the cooling technique and the common frame, the main difference is the setup two is only made of the main PHP.



（a） Setup one: the coupled PHP（b） Setup two: the single PHP
1- box 2- synergistic oscillating PHP 3- main PHP 4- water tank 5- water tank inlet 6- water tank oulet

Figure 2. The PHP Schematic

The experimental setup, as shown in Figure 3, consists of the power supply unit, the PHP unit, and the high-speed data acquisition system. An constant temperature water bath is employed to heat source outside the copper tubes at the evaporator section through a water tank for heat transfer, using a cooling fan installs in the outside box at the condenser section. The surface temperatures of the PHP are measured by eight thermocouples located on the surface of the copper tubes, three thermocouples are at the evaporator section, five are at the condenser section. For tempertuare measuremens, Agilent 34980A is employed with a scan time interval of 1s, coupled with ungrounded K-type thermocouples (Thermocoas) of 1mm diameter. The vacuum and filling fluid device Installs above the PHP, which can been evacuated and then partially filled with a some kind of working fluid.



1- PHP 2- suspended body flowmeter 3- constant temperature water bath 4-Agilent 34980A 5-computer 6- vacuum and fluid-filled device

Figure 3. Experimental Setup

2.2. Measurement Procedure

The PHPs are evacuated and then filled partially working fluids, using the vacuum and fluid-filled device. The main PHP is filled with distilled, deionized, and degassed water, the filling rate is 62.254%; the synergistic oscillating PHP is filled with 59.823% ethanol.

The water bath temperature are 50℃, 55℃, 60℃, 70℃, 90℃, respectively, experimental are performed to investigate the heat transfer characteristics of the coupled PHP and a single PHP, respectively. The evaporator section temperature, the condenser section temperature, the water tank inlet temperature, the water tank outlet temperature, the air duct outlet temperature and the ambient temperature are measured to study the heat transmission performance.

3. Experimental results and discussion

3.1 Wall Temperature Comparison Between the Coupled PHP and the Single PHP

Figure 4 is the comparisons of the temperature profiles between the coupled PHP and the single PHP in the condenser section, under the water bath temperature are 50℃, 55℃, 60℃, 70℃, 90℃, respectively. It is seen that: the thermal oscillations is also detected for all cases. However, under the same constant temperature water bath temperature, the oscillation amplitud of wall temperature of the coupled PHP is significantly lower than the single PHP's, while the oscillation frequency is significantly increased, this is another reflection that the coupled PHP enhanced the process of alternating phase transition, which are liquid-phase evaporation and gas-phase condensation, increases the cycle power, so the coupled PHP enhances heat transfer effect.

3.2 Heat Transfer Performance Comparison Between the Coupled PHP and the Single PHP

In this experiment, the heat transfer performance is evaluated by comparing the transmission power Q_1 and Q_2 under different constant temperature water bath conditions. The transmission power Q_1 in the evaporator section is given by the following equation,

$$Q_1 = G_1 c_{p1} (T_2 - T_1) \quad [\mathrm{W}] \tag{1}$$

Where, G_1 denotes the water mass flow rate in the water tank, kg/s, c_{p1} is the specific heat of water under constant pressure, J/(kg·K), T_2 and T_1 denote the inlet and outlet water temperature in the water tank, respectively, ℃.

The transmission power Q_2 in the condenser section is given by the following equation,

$$Q_2 = G_1 c_{p1} (T_4 - T_3) \quad [\mathrm{W}] \tag{2}$$

Where, G_2 denotes the cooling air mass flow rate, kg/s, c_{p2} is the specific heat of air under constant pressure, J/(kg·K), T_3 is the ambient temperature , ℃, T_4 is the air duct outlet temperature, ℃.

Table 1 shows the main reults of the heat transfer comparsion of the coupled PHP and the single PHP in the evaporator and condenser section, the constant temperature water bath are 50 ℃, 55℃, 60℃, 70℃, 90℃, respectively. The result shows that: for the same water bath temperature, the heat absorption and heat release ratios all are > 1, indicating that at the same heat source temperature, relative to the single PHP, the heat absorption of the coupled PHP is more, and the heat release of coupled PHP is also more. So it can be concluded that the coupled PHP can play the role of enhanced heat transfer, from the Figure 2, the coupled PHP is made of two PHP, but the single PHP is only made of one PHP, to some extent, the coupled PHP enhance heat transfer as increasing the heat transfer area.

Table 1 ComParison of heat transfer performance between the coupled PHP and the single PHP in the some constant water bath temperature

Temperature (℃)	The heat absorption of coupled PHP / The heat absorption of single PHP	Increase rate %	The heat release of coupled PHP / The heat release of single PHP	Increase rate %
50.00	1.44	43.80	1.66	66.40
55.00	1.33	33.09	1.36	35.79
60.00	1.62	61.76	1.22	21.60
70.00	1.04	4.41	1.24	23.58
90.00	1.17	16.70	1.03	3.44

From Table 1 it can also be seen that: comparing the single PHP, the lower heat source temperature is, the more obvious of heat transfer enhancement effect of the coupled PHP is, with the constant temperature water bath temperature increasing, the heat transfer enhancement effect of the coupled PHP will be less and less obvious, but such situation is at a very high heat load condition, because when the heat source temperature is very high, the ethanol inside the coupled PHP is close to evaporation, the mass of gas phase is more and more, the flow resistance and pressure drop will rise, impedes the fluid flow inside the heat pipe, leads to decrease the heat transfer performance. It can be concluded that the coupled PHP heat exchanger dominate for a small temperature difference, with the heat source temperature rises, the enhanced heat transfer characteristic of the coupled PHP is dropped.

3. 3 Experimental Results Discussions

Experiments ara performed to investigate the heat transfer characteristies of the coupled PHP and the single PHP, comparing wall temperatures, it is found that: in the same water bath temperature, the heat absorption of the coupled PHP is more than the single PHP's in the evaporator section, and in the condenser section the heat released is also more. The experimental measurements shows that: for the same high height, the wall temperature of the main PHP is higher than the synergistic oscillating PHP wall temperature at the coupling sites, the main PHP on the coupling sites are considered as the heat source of the synergistic oscillating PHP, the ambience air are considered as the cooling source, the main heat pipes and the air establish an unique alternative multi- heat source and multi- cold source form for the synergistic oscillating PHP. Because the fluid occures oscillating volatility inside the main PHP, the effects of the heat input are equivalent to pulse heating for the synergistic oscillating PHP, studies [11,12] showed that: replacing the conventional continuous heat source, the pulse heating could enhance oscillating state, accelerated the circulatory power, improve the heat transfer. At the same time, the oscillation characteristic of the main PHP can provide change-load, induces the synergistic oscillating PHP to oscillate, in this way, under multi- heat source and multi- cold source form, the synergistic oscillating PHP run oscillatory operation, to some extent, the working fluid inside the coupled PHP forms oscillation flow more stabile, the oscillation characteristics can effect the main PHP as the another pulsating outfield. As the oscillation characteristics strengthen each other heat transfer between two PHPs, an optimal effect of enhanced heat transfer could been obtained by the two mutual incentive pulsating heat pipes.

4. Conclusion

Experiments are performed to investigate the heat transfer characteristies of the coupled PHP, using a constant temperature water bath as heat source. The heat transfer characteristies and the wall temperature of the coupled PHP are analyzed and compared with the single pulsating heat pipe with the main PHP filled the same substance under the same heat source conditions. The results shows that: in the same heat source temperature, the heat absorption and the heat release of the coupled PHP are both greater than the single PHP's, and the heat transfer is better in the case of small temperature difference. From 50℃, the condensiong section of the synergistic oscillating PHP occures oscillating, the oscillating working fluid flow and the oscillating heat transfer characteristics can effect the main heat pipe, an optimal effect of enhanced heat transfer can been obtained by the two mutual incentive PHP.

Acknowledgment

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References

[1] Maezawa, S., and Gi, K., CPU Cooling of Notebook PC by Oscillating Heat Pipe in Heat Pipe Science and Technology, Proc. 11th International Heat Pipe Conference, Tokyo, Japan, pp. 469–472, 1999.

[2] Rittidech, S., Dangeton, W., and Soponronnarit, S., Closed- Ended Oscillating Heat-Pipe (CEOHP) Air-Preheater for Energy Thrift in a Dryer, Applied Energy, vol. 81, pp. 198–208, 2005.

[3] Rittidech, S.,Wannapakhe, S., Suwannatip, L., and Buranapithuk, R., Closed-End Oscillating Heat-Pipe for Conversion of Electrical Bakery Ovens to Gas, Proc. 1st International Seminar on Heat Pipe and Heat Recovery Systems, pp. 76–82, 2004.

[4] Akachi, H., Structure of a Heat Pipe, United States Patent 4, 921, 041, 1990.

[5] Vasiliev, L. L., Heat Pipe in Modern Heat Exchangers, Applied Thermal Engineering, vol. 25, pp. 1–19, 2005.

[6] Rittidech, S., Heat Transfer Characteristics of Closed-End Oscillating Heat Pipe, Ph.D. thesis, Chiang Mai University, Thailand, 2002.

[7] Fumim Shang, Haizhen Xian, Dengying Liu, et al. Experimental investigation of enhanced heattransfer of self-Excitingmode oscillating-flow heat pipe with non-uniform profile under laser heating // WIT Transaction on Engineering Sciences: Advanced Computational Methods In Heat TransferⅨ[C]. Southampton: WIP Press, 2006.241-248.

[8] Haizhen Xian, Fumim Shang, Dengying Liu, et al. Experimental investigation on heat transfer enhancement of SEMOS heat Pipe // Proceedings of the 13thInternational Heat Transfer Conference [C]. Sydney: Begell House, 2006, pp.266-269.

[9] Fumim Shang, Haizhen Xian, Dengying Liu, Xiaoze Du. The Heat Transfer Reinforcement Experiment Research of non-Uniform Profile Channel SEMOS Heat Pipe, Journal of Engineering Thermo physics.27(4), 2006, pp.656-658

[10] Shang Fumin, Xian Haizhen, Liu Dengying, et al. The Feasibility Analysis of Self-Exciting Enhaneed Heat transfer of Oseillating-Flow Heat PIPe. Journal of Engineering for Thermal Energy and Power. 21(2) , 2006, pp.161-164

[11] Haizhen Xian, Fumin Shang, Dengying Liu, Xiaoze Du. The Heat Transfer Reinforcement Experiment Research of pulse heating SEMOS Heat Pipe, Journal of Engineering Thermo physics.27(3),2006,,pp. 457-458.

[12] Haizhen Xian, Dengying Liu, Fumin Shang, et al. Study on Heat Transfer Enhancement of Oscillating-Flow Heat Pipe for Drying. Drying Technology, 2007, 25: 723-729.

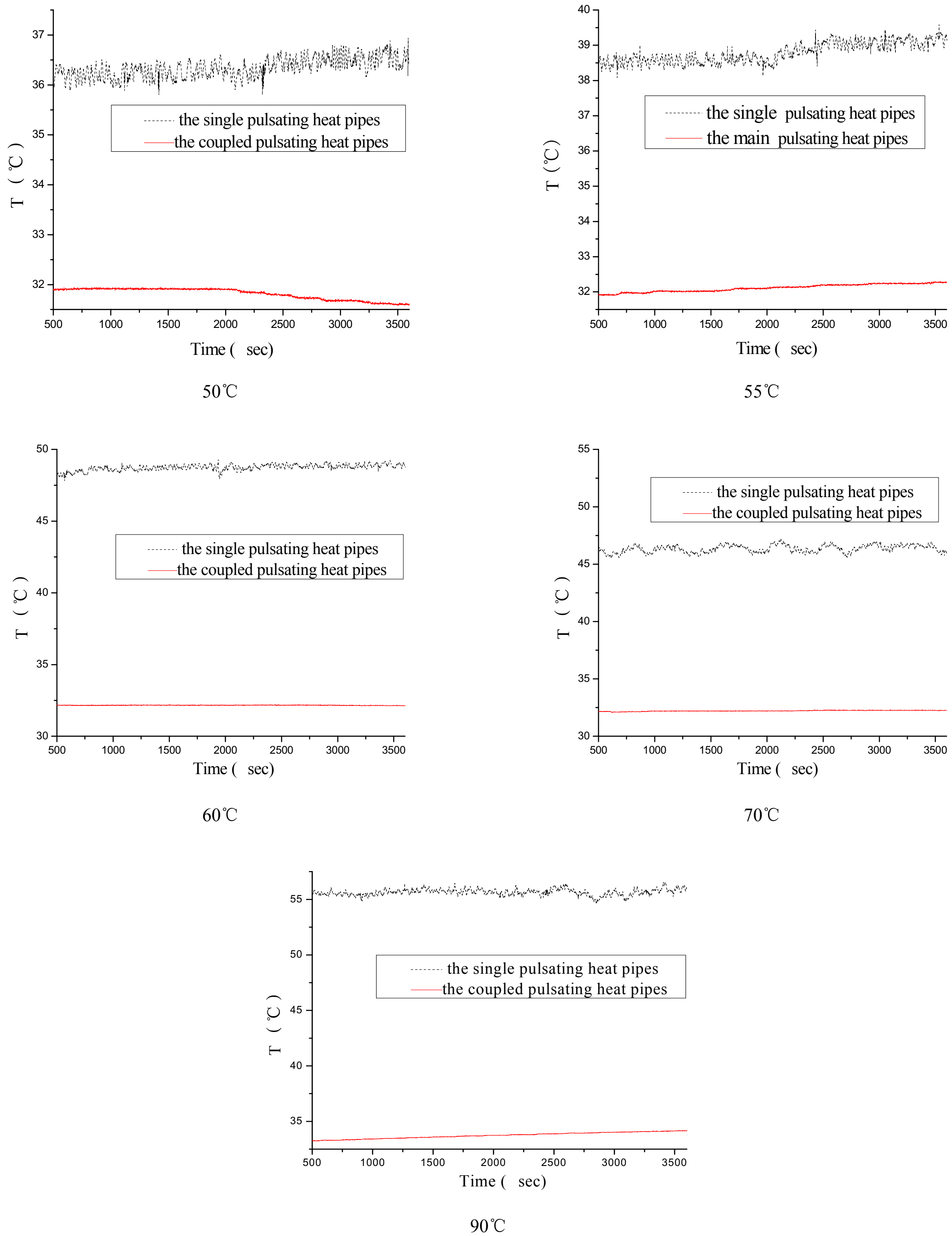

Figure 4. Comparison of the temperature profiles between the coupled PHP and the single PHP in different temperature constant water bath