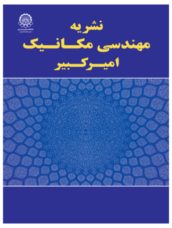

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Experimental Investigation of Thermal Performance of Pulsating Heat Pipe at Angles Close To the Horizon

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ABSTRACT: Pulsating heat pipes can transfer a considerable amount of heat during their simple structure and low cost. In industrial applications, one of the significant weaknesses of pulsating heat pipes is their poor performance at angles close to the horizon. Previous studies have mostly been at 90, 60, 30, and 0-degree angles and have reported the weakness of pulsating heat pipes in the 30 to zero angle range, but detailed studies have not been performed in this range. Therefore, the primary purpose of this study is to experimentally investigate the performance of pulsating heat pipes at angles of deviation close to the horizon and provide a more accurate critical inclination angle. The performance of pulsating heat pipe was evaluated for the best filling percentage (60%) at different angles 0 to 90 degrees. The results showed that by reducing the pulsating heat pipe angle from 90 degrees to 15 degrees, the difference in thermal resistance for different heat input powers was very small, but this difference increased from an angle of 10 to 0 degrees. Further studies showed that the percentage of difference in thermal resistance between angles 15, 10, and 5 with the average value of thermal resistance is 3%, 12%, and 36%, respectively. Thus, it was found that the main weakness of pulsating heat pipes is from an angle of about 10 to 0 degrees.

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1- Introduction

The development of new technologies, including electronic equipment and their size reduction, causes increasing heat flux [1]. Heat pipes are high-efficiency two-phase heat transfer devices [2] that are simple and inexpensive and have extremely high thermal conductivity compared to solids without any moving parts [3, 4] and can transfer significant amounts of heat at low-temperature difference Pulsating Heat Pipes (PHPs) are a type of two-phase heat transfer devices that transfer heat between the evaporator and the condenser through pulsating and continuous motion. PHPs are particularly advantageous over conventional heat pipes due to the simultaneous latent and sensible heat transfer [5]. PHPs are used for different angles, and gravity is an influential factor in their thermal performance. Many researchers have examined the performance of PHPs from different angles. Ji et al. [6] found that by changing the PHP angle from vertical (90°) to horizontal (0°), thermal resistance increased. Also, the results showed that there is an effective relationship between the number of PHP turn and the inclination angle so that the thermal performance of PHP with more turn at equal inclination angles is better than the PHP with less turn [7, 8]. Experimental study of the effect of the inclination angle showed that reducing the inclination angle from vertical to a horizontal position is associated with an increase in thermal resistance and negatively affects the performance of the device and at an angle of 60 to 75 degrees has the highest coefficient heat transfer [9, 10]. Previous studies have typically been performed at angles of 60, 90, 30, and zero degrees and showed that the thermal performance of PHP is poor in the 30 to zero degrees. Given that PHPs in the industry can be used for all angles. Therefore, this study aims to experimentally evaluate the performance of PHP at angles of zero, 5, 10, 15, 30, 50, 70, and 90 degrees, Until the exact range of poor performance of PHP is determined.

2- Methodology

PHPs consist of three main parts: evaporator, adiabatic, and condenser. For the PHP setup, the length of each part is 105 mm, 85 mm, and 110 mm, respectively. the copper pipe with four turns and with external and internal diameters of 4.76 mm and 3.86 mm, respectively, is used. A PHP must be designed so that the working fluid is pumped automatically. Considering the critical value of the Eötvös number≤4, the critical diameter is obtained from Eq. (1) [31].

$$Eo_{crit} = \frac{D_{crit}^2 \cdot g\,(\rho_{liq} - \rho_{vap})}{\sigma} \le 4 \qquad (1)$$

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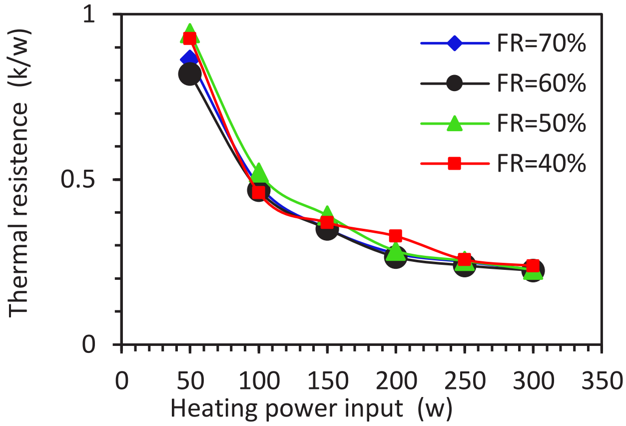

Fig. 1. Thermal resistance vs input heating power for various filling ratios in the vertical position

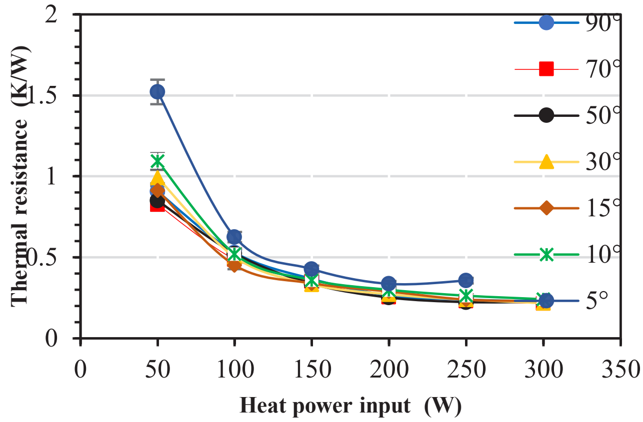

Fig. 2. Thermal resistance vs input heating power for various inclination angles of PHP

where Dcrit is the maximum internal diameter, σ is the surface tension, ρliq and ρvap are the liquid and vapor phase density of the operating fluid, respectively, and g is the gravitational acceleration. based on the properties of the distilled water, the critical diameter is about 5 mm, which is more than the inner diameter of the tube used in this study. In PHPs, the thermal resistance is used to compare and analyze the thermal resistance of the device; this is obtained from Eq. (2):

$$R_t = \frac{T_e - T_c}{Q} \quad (2)$$

In Eq. (2), Te and Tc are the evaporator and the condenser average external wall temperatures, respectively, and Q is the heat input. Along with the thermal resistance, the effective thermal conductivity is used as a criterion for the thermal performance of a PHP system, which is determined by Eq. (3) [32]:

$$K_{eff} = \frac{Q}{A}\frac{L_{eff}}{T_e - T_c} = \frac{1}{R_t}\frac{L_{eff}}{A} \quad (3)$$

where A is the cross-sectional area of the pipe based on the outside diameter and Leff, the effective length between the evaporator and the condenser.

The maximum value of uncertainty for the main parameters such as thermal resistance and effective thermal conductivity is respectively 4.80% 4.75%.

3- Results and Discussion

We performed the experiments in the vertical position for 40%, 50%, 60%, and 70% Filling Ratios (FR) to select the best filling ratio. The results of Fig. 1 show that the filling ratio of 60% shows lower thermal resistance compared to other filling ratios Fig. 1.

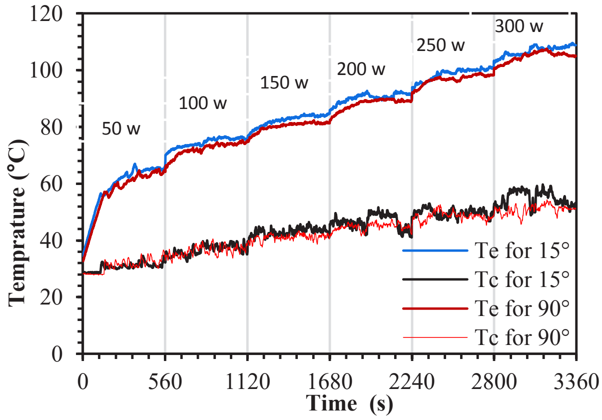

Fig. 3. Comparison of the transient evaporator and condenser temperature in inclination angle 15 and 90 degrees

A range of experiments was conducted to compare the thermal resistance for PHP, with the inclination angles of 0, 5, 10, 15, 30, 50, 70, and 90 degrees, and the input heating powers of 50W-300W.

Fig. 2 shows that the best performance of pulsating heat pipes occurs at high heat power, and more importantly, from an angle of 90 to 15 degrees, the amount of thermal resistance in all heat powers (except thermal power of 50 Watts) is almost equal and the same thermal performance. They have a hopeful result.

Fig. 2 shows that PHP has better thermal performance in the range of 50 to 70 degrees. On the other hand, in PHP, the main difference between thermal resistance occurs at angles from 15 degrees to zero degrees. Then the thermal resistance increases as it approaches the horizon.

Fig. 3 shows the temperature difference between the condenser and the evaporator at two angles of 15 and 90. As shown in the figure, with increasing heat power, the evaporator's temperature difference and the condenser have increased. The average temperature difference between the evaporator and the condenser at an angle of 15 degrees is close to 90 degrees, indicating that the thermal performance of PHP at an angle of 15 degrees is close to a 90-degree angle. To examine more precisely the difference in thermal resistance of the three angles of 15, 10, and 5 degrees compared to the average value of thermal resistance for angles of 90, 70, 50, and 30 degrees were calculated. The results showed that the difference in thermal resistance of angles 15, 10, and 5 compared to the average was 3, 12, and 36%, respectively. Thus, it was found that the main weakness of oscillating pipes from an angle of about 10 to zero degrees.

4- Conclusions

1-The results showed that the lowest thermal resistance and the highest effective thermal conductivity occur in a 60% filling ratio.

2- from an angle of 90 to 15 degrees, the amount of thermal resistance in all heat powers is almost equal and the same as thermal performance.

3-PHP has the best thermal performance in the range of 50 to 70 degrees.

4- The results showed that the difference in thermal resistance of angles 15, 10, and 5 compared to the average was 3, 12, and 36%, respectively. Thus, it was found that the main weakness of oscillating pipes from an angle of about 10 to zero degrees.

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