

Effect of Diameter and Filling Ratio on Performance of Closed Loop Pulsating Heat Pipe

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Abstract

Pulsating heat pipe is an effective method of heat transfer through passive two phase mechanism. In the present research work, experimental studies were performed on pulsating heat pipe made up of copper tube having inner diameters of 1, 1.5, 2 and 2.5 mm respectively. The pulsating heat pipe is charged with acetone as working fluid with different filling ratios of 50%, 60%, 70%, 80%, and 90% of its volume. The evaporator zone is electrically heated by means of mica heater with a range of 20 to 80W and condenser section is cooled by means of constant flow cooling water. The effect of filling ratio and tube diameter on thermal performance of closed loop pulsating heat pipe was investigated and the results shows that, for 2 mm and 1.5 mm inner diameter gives better performance compared to other tube diameters. The thermal resistance obtained have a lower value of 0.40 0K/W and 0.45 0K/W for 2 mm and 1.5 mm diameter respectively. It is also observed that the operation of pulsating heat pipe enhances at a filling ratio of 60% for all the tube diameters considered.

Keywords: Heat pipe, Acetone, Filling ratio, Tube diameter and Heat input.etc

INTRODUCTION

Pulsating heat pipes is a new type and two phase heat transfer device classified in a category of heat pipes. The pulsating heat pipe was introduced in the mid of 1990's by Akachi [1]. The pulsating heat pipe consists of relatively long capillary metallic tubes having no moving parts and no wick structure as compared to conventional heat pipes. The pulsating heat pipe consists of one heat receiving zone and one heat dissipating zone separated by an adiabatic zone as shown in Fig.1.

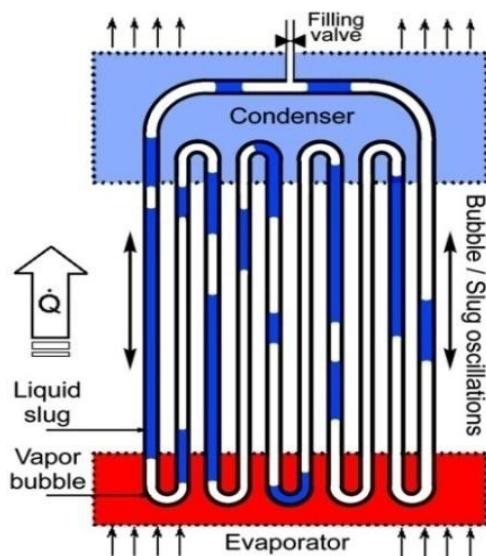


Fig.1. Schematic representation of pulsating heat pipe

Initially the pulsating heat pipe is partially evacuated and then filled with a suitable

quantity of working fluid, which distributes itself naturally in the form of liquid plugs and vapour bubbles that move or oscillate inside the tube. The visualization of vapour bubbles and liquid plugs are carried out by many researchers [2, 7-9]. The several design parameters such as filling ratio, tube diameter, orientation and evaporator length etc plays an important role in efficient operation of pulsating heat pipe [3-6]. When the evaporator section is supplied with a known value of heat flux, a two phase fluid starts moving in the tube and allowing the heat transfer to the condenser section by means of sensible and latent heat. The overall heat transfer rate or performance has been investigated in the literature [10-11]. Also many numerical simulations are carried out to know the heat transfer characteristics in pulsating heat pipe [12-13].

2. EXPERIMENTAL SET UP

The pulsating heat pipe is made from copper tube because of higher thermal conductivity and is fabricated with four multi turns in the condenser and evaporator section. In adiabatic section a straight borosilicate glass tubes are used to view the flow visualization in PHP. The lengths of the condenser, evaporator and adiabatic sections are 640

mm, 512 mm, and 800 mm respectively. The internal diameters of 1 mm, 1.5 mm, 2 mm, and 2.5 mm, and external diameters of 1.5 mm, 2 mm, 3 mm, and 3.5 mm respectively were chosen. In the experimental set up to measure the steady state temperature eight K-type thermocouples were used in which four were employed in the evaporator and four were used in the condenser section.

The evaporator section is exposed to a heat flux by means of a mica heater with a capacity of 150 watt. The voltage and the current were measured by a digital

multimeter. The condenser section is cooled by means of cooling water with constant flow rate of water of about 25 ml in a time of 30 seconds. The experiment is carried out by using Acetone as working fluid and the filling ratio is varied from 50% to 90% of its volume.

During the experiment, the heat input is increased from 20 watt to 80 Watt in a steps of 20Watt. The temperatures is recoded at the evaporator and condenser section when pulsating heat pipe reaches steady state condition.



Fig.2. Experimental setup

3. RESULTS AND DISCUSSIONS

The thermal performance of closed loop pulsating heat pipe at different heating power inputs for different tube diameters and filling ratios will be discussed.

3.1 Effect of thermal resistance on performance of pulsating heat pipe

The thermal resistance of pulsating heat pipe is calculated by using the equation (1).

$$R = \frac{T_e - T_c}{Q} \quad ^\circ\text{K/W} \quad (1)$$

Fig.3.1 (a) to (d) shows the variation of thermal resistance v/s heat input for different inner tube diameters and for different filling ratios. The thermal resistance is defined as the ratio of the temperature difference between the evaporator and the condenser to the net heat input in the system.

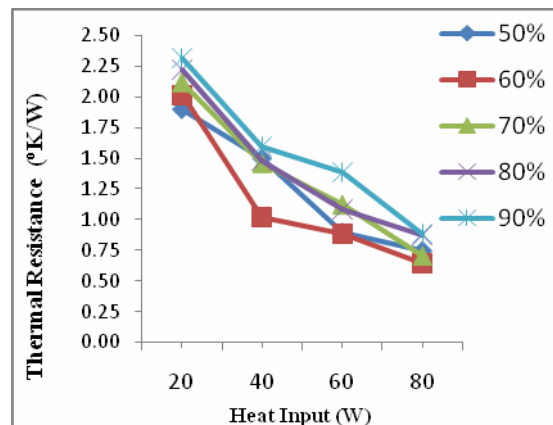


Fig3.1 (a) Thermal resistance v/s heat input for 1 mm diameter

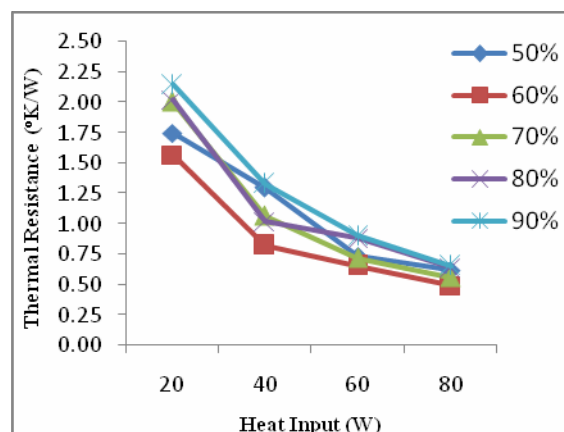


Fig3.1 (b) Thermal resistance v/s heat input for 1.5 mm diameter

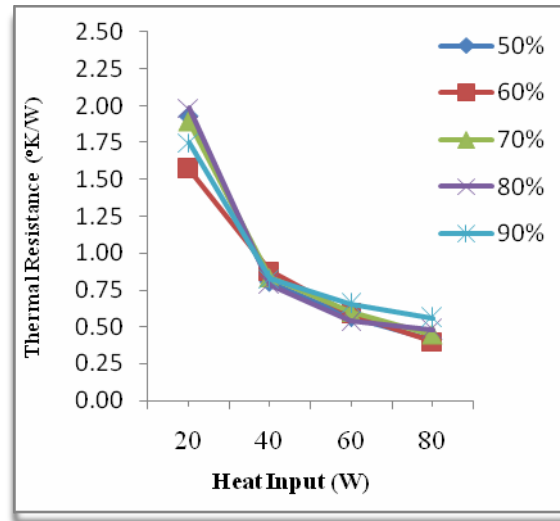


Fig3.1 (c) Thermal resistance v/s heat input for 2 mm diameter

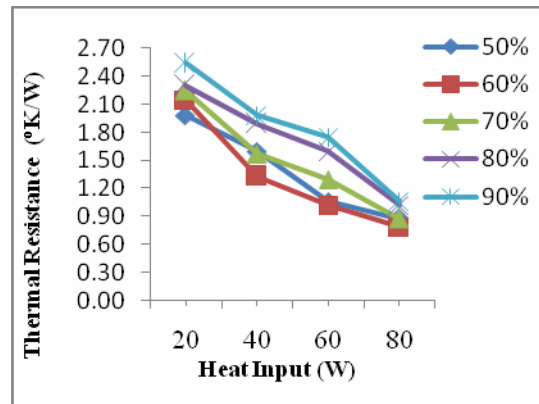


Fig 3.1 (d) Thermal resistance v/s heat input for 2.5 mm diameter

It is clear that the thermal resistance decreases with increase in heat input for all the filling ratios and inner tube diameters considered. At higher heat inputs the pulsating heat pipe operates as a true pulsating mode due to increased in generation of vapour plugs and liquid slugs and thermal resistance is continuously decreased for all filling ratios considered. It

is also observed that at a filling ratio of 80% to 90%, higher value of thermal resistance of 1.02°K/W and 1.06°K/W respectively is observed at 2.5 mm inner diameter as compared to other filling ratios. However lower value of thermal resistance of 0.4°K/W and 0.45°K/W for 2 mm inner diameter at a filling ratio of 60% and 70% is obtained due to more pumping of bubbles

and liquid slugs due to latent heat and sensible heat respectively. Also the lower value of thermal resistance is obtained for 2 mm inner diameter compared to other tube diameters. The optimum filling ratio for pulsating heat pipe charged with acetone is 60% and optimum tube diameter is 2 mm which is close related to critical diameter of pulsating heat pipe.

Effect of heat transfer coefficient on performance of pulsating heat pipe

The heat transfer coefficient of pulsating heat pipe is given by

$$h = \frac{Q}{Ac(T_e - T_c)} \text{ W/m}^2\text{ }^\circ\text{K} \quad (2)$$

Fig.3.2 (a) to (d) shows the effect of heat input on heat transfer coefficient of pulsating heat pipe for 1,1.5 2 and 2.5 mm

diameters. From the Figures, It is clear that the heat transfer coefficient increases with increase in heat input as well as increase in the tube diameters with the filling ratios considered. Increase in heat input increases pumping power of fluid. Further it is seen that in Fig.3.2.(c) exhibits higher value of heat transfer coefficient of 1000.65W/m² 0K compared to other tube diameters considered which is due to the lower value of thermal resistance. Higher value of heat transfer coefficient indicates that pulsating heat pipe has better heat transport capability. It is also observed that the heat transfer coefficient is higher at a filling ratio of 60% in all the tube diameters considered as shown in Fig.3.2.(a) to (d). Hence pulsating heat pipe with acetone can transport better heat at an optimum filling ratio of 60%.

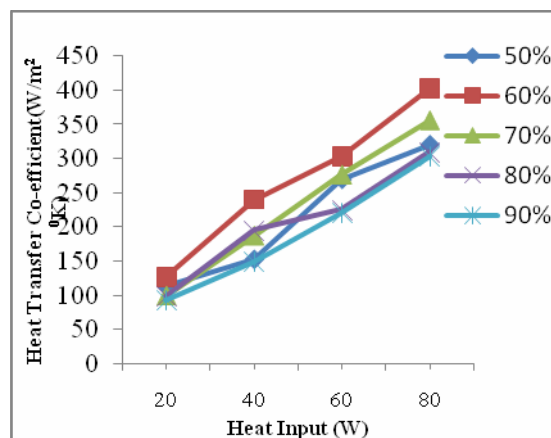


Fig 3.2(a) Heat transfer coefficient v/s heat input for 1 mm diameter

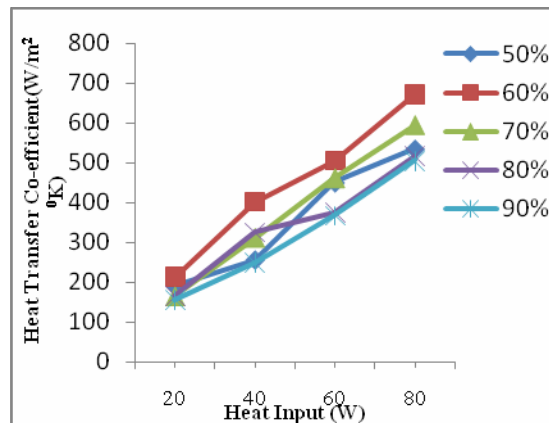
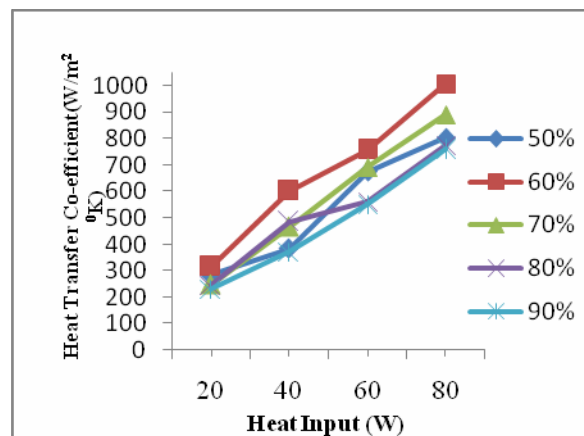


Fig 3.2 (b) Heat transfer coefficient v/s heat input for 1.5 mm diameter



(c) Heat transfer coefficient v/s heat input for 2 mm diameter

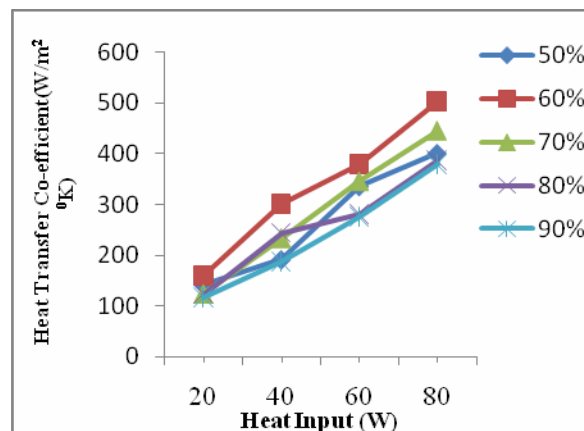


Fig 3.2 (d) Heat transfer coefficient v/s heat input for 2.5 mm diameter

Effect of efficiency on performance of pulsating heat pipe

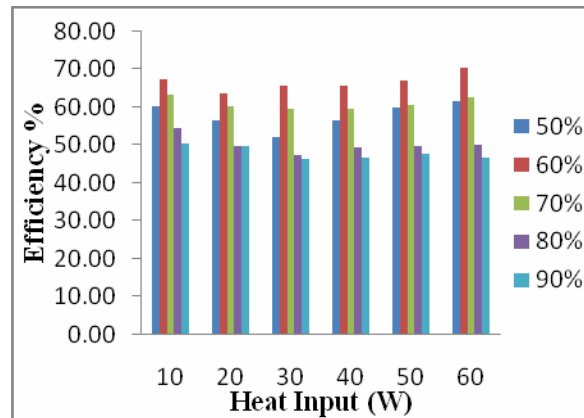


Fig 3.3 Efficiency v/s heat input for 2 mm diameter

Fig.3.3. shows the effect of heat input on the efficiency of pulsating heat pipe for 2 mm diameter. It is observed that efficiency is increased as filling ratio is increased for all heat inputs. It is observed that at 60% filling ratio, the efficiency is more compared to other filling ratio due to more oscillation of fluid in PHP. Also as increase in filling ratio the efficiency drops because of less oscillation of fluid inside the tube. Hence PHP operates better at a filling ratio of 60%.

CONCLUSION

An experimental studies was performed on closed loop pulsating heat pipe with different tube diameters of 1, 1.5, 2, 2.5 mm with a filling ratio of 50%, 60%, 70%, 80%

and 90% of its volume, the following conclusions were drawn as follows.

- Generally, Thermal resistance is reduced and heat transfer coefficient is increased as a result of increasing the heat input power for all the cases considered.
- Closed loop pulsating heat pipe with 1.5 mm and 2 mm inner tube diameter gives excellent performance compared to other tubes. The pulsating heat pipe with 2 mm inner tube diameter gives lower value of thermal resistance of about 0.4 0K/W compared to 1.5 mm tube of 0.45 0K/W, which indicates

that higher thermal performance. Hence the pulsating heat pipe operates efficiently with an inner tube diameter of 2 mm.

- Also it is observed that, the higher value of heat transfer coefficient is obtained at a filling ratio of 60% with all the tube diameters considered, hence the pulsating heat pipe operates efficiently with a filling ratio of 60%.

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