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EXPERIMENTAL MEASUREMENT OF THE EFFECT OF HIGH FILLING RATIO ON THE PERFORMANCE OF THE PULSATING HEAT PIPE

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Abstract. The objective of this work was to experimentally investigate the influence of high filling ratio on the performance of the pulsating heat pipe in the favorable vertical position. R134a with filling ratios of 95%, 90% and 85% was used as working fluid. The pulsating heat pipe had presented one turn in the adiabatic section, one turn in the condenser and one in the evaporator. The results showed that for all filling ratios the pulsating heat pipe work properly. The measured equivalent thermal conductivity ranged from 10 to 52 kW/m.K which are quite high values.

Keywords: Experimental Measurement, High Filling Ratio, Pulsating Heat Pipes, Favorable Vertical Position

1. INTRODUCTION

The pulsating heat pipes or oscilating heat pipe was proposed by Akachi(1990). Its heat transfer mechanism is based on the oscillatory or pulsating movement of the vapor bubbles and the liquid pistons along the tube. The pulsating heat pipe presents three basic regions: the evaporator, the condenser and the adiabatic region. Fig. 1 shows the typical structure of a pulsating heat pipe.
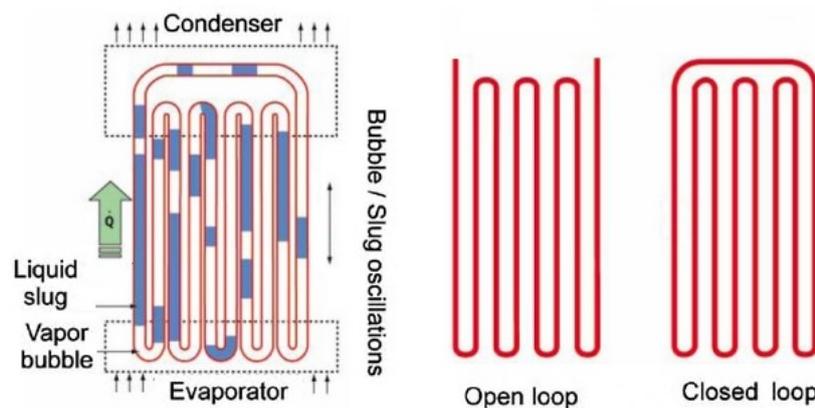

Figure 1. Schematic of a pulsating heat pipe and its design variations, Charoensawan et al. (p. 2011, 2003)

The filling ratio is the ratio of the volume of working fluid to the total volume f the tube. The choice of the proper filling ratio is important to ensure that there is liquid in the heat input region, which enables the start of the pulsating heat pipe to function due to bubble nucleation.

According Groll e Khandekar (2003) the pulsating heat pipes has two operational extremities with respect to the filling ratio and optimum operating range.

- Filling ratio 100%: The bubbles are not sufficient to generate the required pumping action/pertubations of the liquid plug.

- Filling ratio 0%: In this mode, there is insufficient liquid to form enough distint slugs and there is a tendency towards evaporator dry - out.

- Filling ratio in range of the 20% to 80%: The pulsating heat pipe operates as a true pulsating device.

The objective of this work is to investigate if at high filling ratio the pulsating heat pipe works properly.

2. METHODOLOGY

2.1 Experiment description

In experiments presented in the Fig. 2 the water in the evaporator was heated with an electrical resistance heater of 500 W e 220V, up to the desired temperature around $60°$C. In order to avoid stratification of the water in evaporator a 4W pump mixes the flow.

The cold water in the condenser was kept always at $0°$C using ice mixed with water. For data acquisition the readings with type K thermocouples of the water temperature inside the evaporator T_{liquid}, the temperature at input and output of the evaporator $T_{evaporator}$ and the temperature of the input and output of the condenser $T_{condenser}$.

The pulsating heat pipe is made of nylon flexible tube, having 2.4 mm of external diameter and 2.0 mm of internal diameter. This tube is filled with R134a and filling rations of the 95%, 90% e 85%.
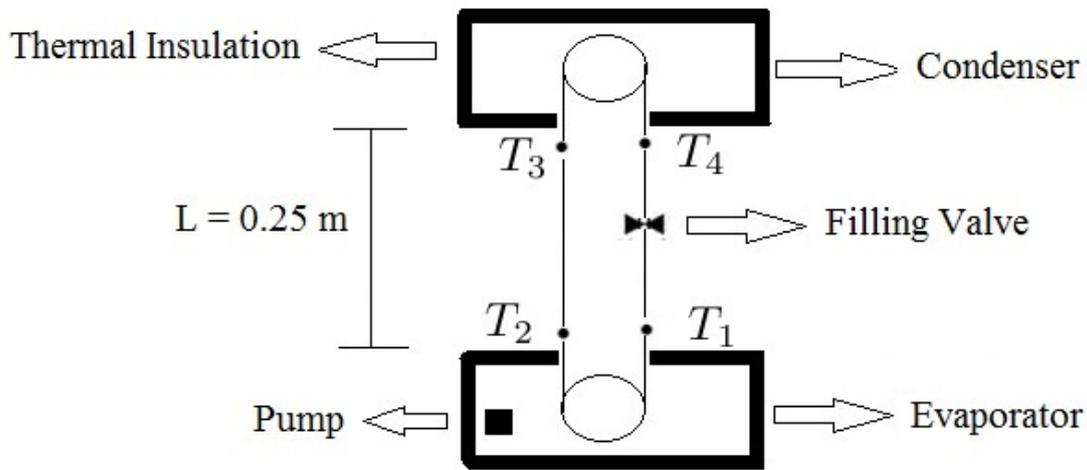

Figure 2. Experimental system

The thermocouples T_1, T_2, T_3 and T_4 were used for reading the temperature at input and output of the evaporator $T_{evaporator}$ and the temperature of the input and output of the condenser $T_{condenser}$ and L the distance between evaporator and condenser.

2.2 Data reduction procedure

- The heat transfer rate transferred $Q_{liquid}(W)$ which occurs in the water inside the evaporator is given by equation 1:

$$Q_{liquid} = m_{water} c_p \frac{\Delta T}{\Delta t_{withTube}} \tag{1}$$

Where:
m_{water}: Water mass in the evaporator - 3 kg.
c_p: Specific heat for the water obtained from the program EES (Engineering Equation Solver) based on the temperatures of the liquid inside the evaporator T_{liquid}.
ΔT: Temperature difference of the liquid inside the evaporator T_{liquid}.
$\Delta t_{outTube}$: Time interval in seconds.

- The loss of heat to the environment $Q_{environment}$ occurs due to the difference in temperature between the water in the evaporator T_{liquid} and the ambient temperature $T_{environment}$. The environmental loss $Q_{environment}$ is given by equation 2.

$$Q_{environment} = (T_{liquid} - T_{environment})/R_{environment} \tag{2}$$

- The thermal resistance of the environment $R_{environment}$ is calculated based on heat loss from the evaporator without the use of pulsating heat pipes, is given by equation 3.

$$R_{environment} = \frac{(T_{liquid} - T_{environment})}{Q_{environment}} \qquad (3)$$

In the calculations an average value is used for the thermal resistance of the environment $R_{environment}$.

- The heat lost due to the temperature difference of the liquid inside the evaporator T_{liquid} and the ambient temperature $T_{environment}$ without the use of pulsating heat pipes Q_{lost} is given by equation 4.

$$Q_{lost} = m_{water} c_p \frac{\Delta T}{\Delta t_{withoutTube}} \qquad (4)$$

Where:
m_{water}: Water mass in the evaporator - 3 kg.
c_p: Specific heat for the water obtained from the program EES (Engineering Equation Solver) based on the temperatures of the liquid inside the evaporator T_{liq}.
ΔT: Temperature difference of the liquid inside the evaporator T_{liquid}.
$\Delta t_{withoutTube}$: Time interval in seconds.
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- In order to avoid stratification of the water inside the evaporator, a pump Alife with flow of 180l/h with 4W e 220V. The average pump power $P_{averagePump}$ is given by equation 5:

$$P_{averagePump} = P_{pump} \frac{\Delta t_{connectedPump}}{\Delta t_{withTube}} \qquad (5)$$

Onde:
P_{pump}: Is pump power of the 4W.
$\Delta t_{connectedPump}$: Time pump is turned on 45 s.

- The energy balance $Q_{inputTube}$ for calculating the power input to the evaporator is given by equation 6

$$Q_{inputTube} = Q_{liquid} + P_{averagePump} - Q_{environment} \qquad (6)$$

- The thermal resistance of the pulsating heat pipe $R_{thermal}$ (K/W) is given by equation 7:

$$R_{thermal} = \frac{T_{evaparator} - T_{condenser}}{Q_{inputTube}} \qquad (7)$$

Where:
$T_{evaparator}$: Temperature of water in output the evaporator, K.
T_{cond}: Temperature of water in output the condenser, K.

- The effective thermal conductivity K_{eff} (kW/m.K) is given by equation 8:

$$K_{eff} = \frac{Q_{inputTube}L}{A_{total}(T_{evaparator} - T_{condenser})} = \frac{Q_{inputTube}L}{2N_{channel}A_{T_{channel}}(T_{evaparator} - T_{condenser})} \qquad (8)$$

Where:
A_{total}: Total tube cross section area in the adiabatic region.
N_{canais}: Number of channels being 2 at each turn.
$A_{T_{canal}}$: Cross sectional area of each channel.

3. RESULTS

The thermal resistance of the pulsating heat pipe $R_{thermal}$ (K/W) is presented in Figure 3 and the effective thermal conductivity K_{eff} (kW/m.K) is presented in Figure 4.
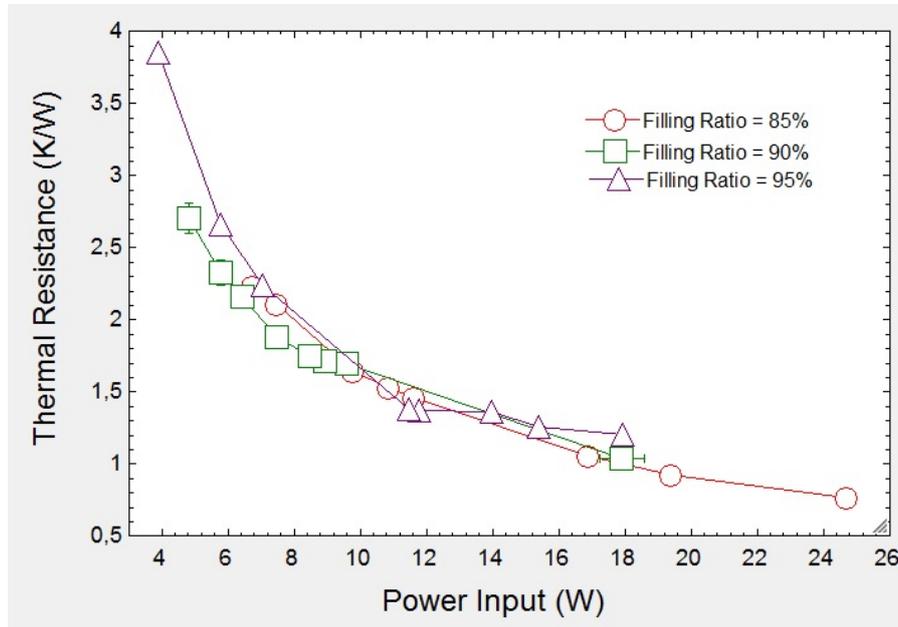

Figure 3. Thermal resistance (K/W)

Analyzing the Figure 3 the highest thermal resistance was obtained for with filling ratio of 95% for power input P=3.9 W a thermal resistance $R_{thermal}$= 3.8 K/W. The smallest thermal resistance was obtained for with filling ratio of 85% for power input P=24.6 W the thermal resistance $R_{thermal}$= 0.76 K/W.
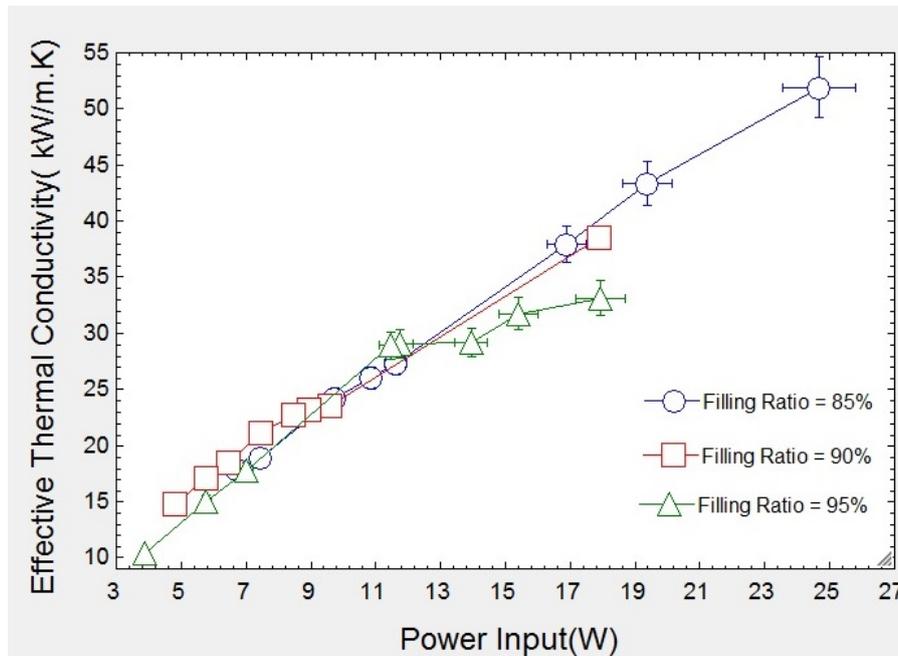

Figure 4. Effective thermal conductivity (kW/m.K)

Analyzing the Figure 4 the biggest effective thermal conductivity was obtained for with filling ratio of 85%, for power input P = 24.6 W the effective thermal conductivity K_{eff}= 51.943 kW/m.K. The smallest effective thermal conductivity was obtained for with filling ratio of 95%, for power input P = 3.8 W the effective thermal conductivity K_{eff}= 10.336 kW/m.K.

4. CONCLUSIONS

From the literature it is known that the optimum operating range of the pulsating heat pipe is between 20% and 80%. The results of this work showed that at high filling ratios the pulsating heat pipes can continue to work properly, having equivalent thermal conductivity up to 52 kW/m.K.

5. ACKNOWLEDGEMENTS

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