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Effect of Filling Ratio on Thermal 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 from copper tube having internal and external diameter of 2 mm and 3 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 10 to 60 Watt and condenser section is cooled by means of cooling water at a constant flow rate. The effect of filling ratio on thermal performance of closed loop pulsating heat pipe was investigated. The result shows that, the thermal resistance decreases rapidly with the increase in the heating input and it is observed that lower value of thermal resistance is obtained at a filling ratio of 60%. Hence Acetone exhibits better performance at a filling ratio of 60%.

Key words: *Pulsating heat pipe, Heat input, Acetone, Filling ratio.*

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1. INTRODUCTION

Pulsating heat pipe (PHP) is a two phase heat transfer device, which is developed by akachi [1] in 1990. The PHP consists of capillary tubes having three zones i.e. evaporator zone, condenser zone and adiabatic zone, which is arranged in a serpentine manner as shown in Fig.1.

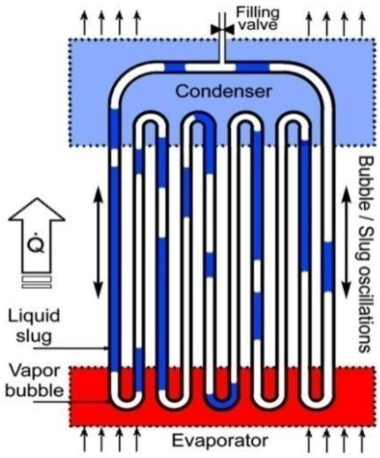


Fig.1. Schematic representation of pulsating heat pipe

The PHP is classified into two types i.e. open loop and closed loop PHP. In the present investigation closed loop PHP is used because it has better circulation of working fluid than open loop PHP also it gives better performance [2]. In PHP, the heat transfer takes place by means of vapor bubbles and liquid slugs i.e. by Latent heat and Sensible heat by means of pulsating movement, hence the name pulsating heat pipe (PHP). Number of research persons have presented their experimental results for optimum filling ratio, tube diameters, orientation , maximum heat load of PHP etc. Sarangi [3] reported the effect of heat load on performance of PHP. Their experimental observation indicates that start up heat load does not vary with fill ratio and optimum filling ratio depends on properties of working fluid and their operating temperatures. Himel baruna [4] investigated the effect of filling ratio on performance of PHP and it was reported that the PHP operates at different filling ratio for different working fluids i.e. for ethanol it is 50% and for water it is 70% and also showed that the variation of evaporator temperature and condenser temperature for various heat inputs. Frank pai [5]conducted finite element analysis on PHP and stated that heat transfer coefficient increases with increase in amplitudes of oscillation when the difference in temperature between evaporator and condenser increases. Aboutalebi [6] experimentally investigated the performance of rotated closed loop PHP and made a conclusion that the rotational speed of closed loop PHP generates a centrifugal force which helps to slow down the dry out and increases thermal efficiency. Also proved that the optimum filling ratio of 50% for all rotational speeds.

2. EXPERIMENTAL SET UP AND PROCEDURE

The experimental set up shown in Fig.2. Consists of closed loop PHP made up of copper which have a higher value of thermal conductivity. The PHP is fabricated with four turns in evaporator and condenser zones, while in adiabatic zone a borosilicate glass tube is used to view the pulsating movement. The lengths of evaporator, condenser and adiabatic zones were chosen as 640, 512 and 800 mm respectively. The inside diameter of PHP is 2 mm, while the outside diameter of PHP is 3 mm. In the experimental set up, eight K-type thermocouples were used to measure the temperature, in which four were used to measure evaporator temperature and rest were used to measure condenser temperature. The evaporator section is exposed to a heat flux by means of heater which having a capacity of 150 Watt. The heat input at this section is varied form 10 Watt to 60 Watt with an increment of 10 Watt. The condenser zone is cooled by means of cold water which flows at a constant rate of 0.85 mlt/sec.

Fig.2. Experimental setup

3. GEOMETRIC MODEL AND MESH GENERATION

Geometries can be created top-down or bottom-up. Top-down refers to an approach where the computational domain is created by performing logical operations on primitive shapes such as cylinders, bricks, and spheres. Bottom-up refers to an approach where one first creates vertices (points), connects those to form edges (lines), connects the edges to create faces, and combines the faces to create volumes. Geometries can be created using the same pre-processor software that is used to create the grid. Geometry files are imported into HM to create computational domain. The extracted fluid domain of pulsating heat pipe is shown in Fig.3.

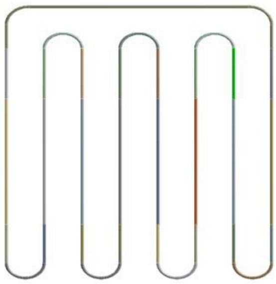


Fig.3. Geometry Model of the Heat Pipe

A Hexahedral mesh is generated using ANSYS meshing pre-processor. First, the surface is meshed with QUAD element. In order to resolve the turbulent boundary layer on the solid surfaces, it is best to have growing prismatic cells from the valve surfaces. Finally the remaining region in the domain is filled with tetrahedral cells. No of elements is used for all the strokes approximately 0.5 millions. For the mesh generation special care has been taken to the zones close to the walls. In the proximity of the crest the mesh is finer than any other part of the domain. The domain has been subdivided into growing boxes to make it easier to generate the grid. The choice for the elements has been both tetrahedral and hexahedral mesh volumes. Representations of the different meshes that take part in the study are depicted in the following detailed figures.

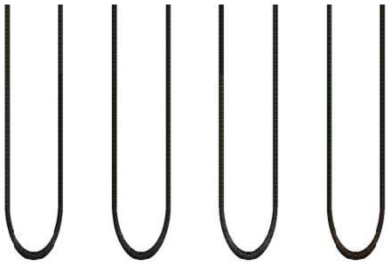


Fig.4.Meshing Methodology

Fig.5.Mesh Boundary

The transient RANS simulations are conducted on the geometry using Fluent. Segregated solver is used for the computations which employs a cell-centered finite volume method. A second-order upwind discretization is used for the momentum equation and a first order upwind discretization is used for turbulent kinetic energy and specific dissipation rate. In the present analysis PHP, the flow is assumed as turbulent, transient and incompressible with segregated solver. At the inlet, pressure boundary condition is applied. The heat pipe walls are defined as stationary no slip walls.

4. RESULTS AND DISCUSSIONS

This section deals with experimental investigations and CFD analysis carried out on PHP.

4.1 Experimental Results

In the following, the effects of filling ratio on the thermal performance of PHP at different heat inputs will be discussed.

4.1.1 Effect of Thermal Resistance on Thermal Performance of PHP

Figure.6. shows the effect of thermal performance in terms of effective thermal resistance which is defined as the ratio of the temperature difference between the evaporator and the condenser to the net heat input in the system. It is clear that the thermal resistance decreases with increase in heat input and it is also observed that among all filling ratios considered, at 60% filling ratio lower value of thermal resistance of about 0.36 °K/W is obtained at 60Watts. Hence PHP operates better at 60% filling ratio compared to other filling ratios.

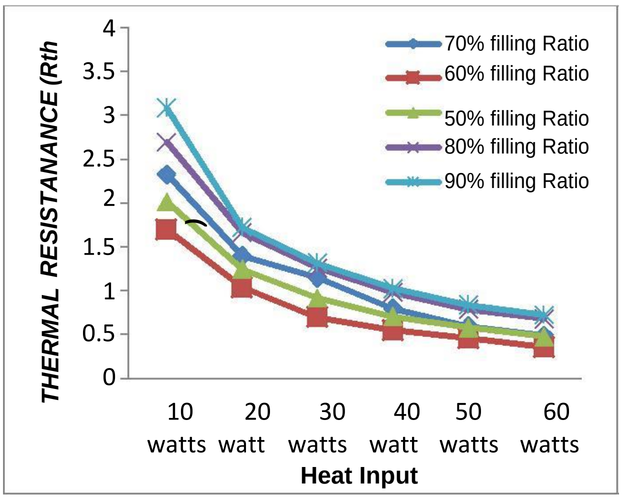


Fig.6. Effect of heat input on thermal resistance.

4.1.2 Effect of Heat Transfer Co-efficient on Thermal Performance of PHP

Fig.7. shows the effect of heat input on heat transfer coefficient of PHP. It is clear that heat transfer coefficient increases with increase in heat input for all the filling ratios considered. The heat input is the 'pump' for-fluidic action the .Thus, thermo increasing pumping power increases the performance. Further, it is seen that at 60% filling ratio exhibits higher values of heat transfer coefficient compared to other filling ratios. This is due to lower value of thermal resistance. The higher value of heat transfer coefficient at 60% indicate that better heat transport capability at this filling ratio compared to other filling ratios.

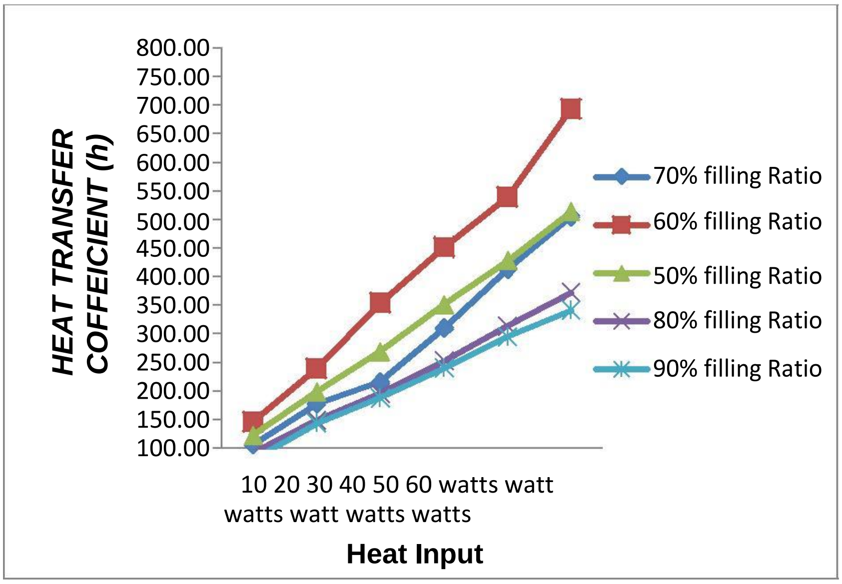
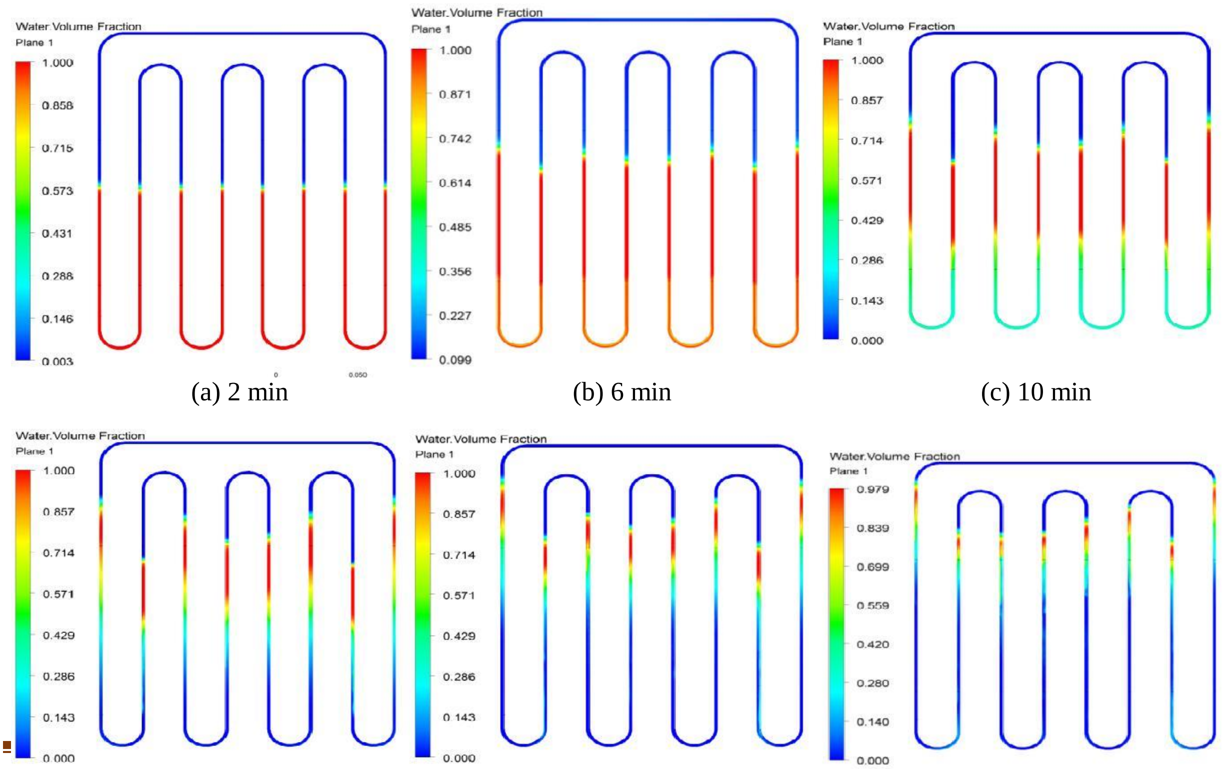


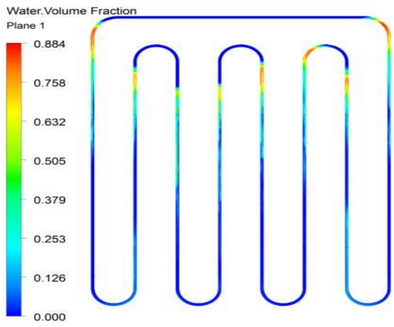
Fig.7. Effect of heat input on Heat transfer coefficient.

4.2 CFD Results

In case of simulation carried out, it is observed that change in volume fraction of PHP operation is shown in Fig.8.(a) to (g) .



(d) 14 min (e) 18 min (f) 22 min



(g)

Fig.8. (a) to (g) Water Volume Fraction contours from 2 to 28 min

From Fig.8. (a) and (b) shows the generation of vapour at the beginning and from Fig.8. (c) to (g) shows the growth of generation of vapour bubble and its movement towards condenser section. As the heat input is increased more and more vapour bubble formation takes place and are moved with high velocity of about 0.678m/s as shown in Fig .8. (c). The vapour phase is condensed in condenser section and the condensed liquid slug comes back to evaporator, and then the heat transfer cycle repeats. From the water volume shown in figures, the working fluid circulates in the adjacent channels as it reaches to stable oscillation. From the simulation results it is also proved that heat transfer in PHP depends upon the fluid oscillation.

4.3 Comparison of experiment results with CFD analysis

The Fig.9.shows the comparison between experimental and CFD simulation results. The simulation result was in close relation with the experimental results i.e. trend of both the results were same having small error about 10%. The reasons for the variation of simulation and experimental result may be due to loss of heat in the evaporator and condenser sections. From the CFD analysis it is found that lower value of thermal resistance is found at 60% filling ratio, hence acetone exhibit better performance at 60% optimum filling ratio.

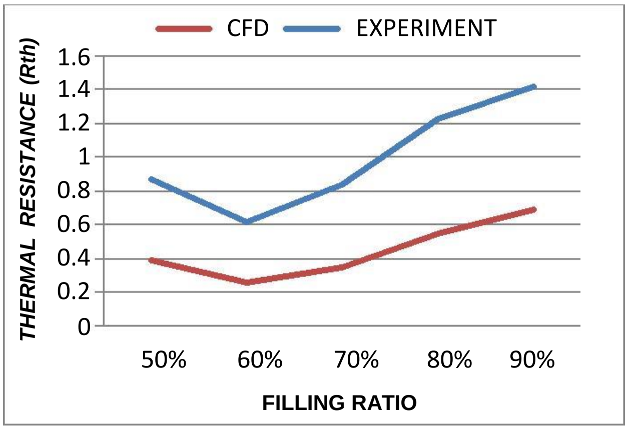


Fig.9.Comparison of experimental and CFD results for filling ratio v/s thermal resistance

4.4 CONCLUSION

An experimental investigation on thermal analysis of a Closed Loop Pulsating Heat Pipe was conducted for different filling ratios with different heat inputs. The conclusions that could be drawn from this investigation are as follows:

1. Generally, Thermal Resistance is reduced as a result of increasing heat input power.

2. It could be also observed that PHP has better operational performance and self- sustained thermally driven pulsating action for charging ratio of 60% for Acetone in vertical position.

3. As compared with the experimental results there is small difference in thermal resistance for acetone by CFD analysis.

4. The PHP operates better at 60% filling ratio c

Acknowledgment

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