Effect of SiO$_2$ on Thermal Performance of Pulsating Heat Pipe

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Abstract-- **Pulsating Heat Pipe (PHP) is essentially a passive two-phase heat transfer device, capable of transferring heat from a source to sink, against the force of gravity, without the aid of a wick or any moving mechanical parts. Heat transfer is through natural oscillations of the working fluid between the evaporator and condenser sections. An experimental investigation on pulsating heat pipes with multi turns has been conducted in order to determine the impact on heat transport capacity of SiO$_2$ Nano-particles in the working fluid, with different mass concentration. The PHP consists of 4 turns made up of copper tube with an inside diameter of 2 mm and a wall thickness of 0.5 mm. Total length of the pulsating heat pipe is 1785 mm. The experiments are conducted on pulsating heat pipes charged with working fluids such as Acetone, Methanol and Di water with SiO$_2$ Nano-particles for different mass concentrations and filling ratios of 50 % of its volume for different heat inputs. From the experiment results it's contemplated that as mass concentration of SiO$_2$ Nano-particles increases in working fluid, the thermal resistance decreases and heat transfer rate increases. With all the three working fluids, it's observed that Acetone with SiO$_2$ Nano-particles gives better performance compared to other fluids.**

Keywords: Pulsating Heat Pipe, Methanol, Acetone, SiO$_2$ and DI water.

I. INTRODUCTION

HEAT pipes are efficient heat transfer devices and their considerable thermal performance is mainly due to their phase change heat transfer. New generation of heat pipes are pulsating heat pipes (PHPs) invented in 1990 by Akachi [1]. Basically, a PHP is formed by bending a capillary tube into several turns and is partially filled with a working fluid. PHPs are composed of three major parts: evaporator, condenser, and adiabatic section as shown in Figure 1. The presence of adiabatic section is not mandatory and is only used when a distance between condenser and evaporator is needed [2]. Heat input to the evaporator is the driving force in PHPs. It results in the evaporation of the liquid film which surrounds the vapour bubbles [3]. Researchers have shown that geometry and design material of PHP's are key issues influencing its thermal behavior. Counting the geometry effects; number of turns, total length of the tube, tube diameter, and the height of whole system should be considered. Jamshidi *et al.* [4] tested a water-silver nanofluid charged PHP's and a water-titanium oxide nanofluid one at different charging ratios.

They found that the PHP's benefits both sensible and latent heat transfer in charging ratio between 30% and 80%. However, the value of optimum charging ratio for each nanofluid was different. These optimum values were reported to be 40% for water-titanium oxide nanofluid and 50% for water-silver nanofluid.

The rate of heat transfer falls with the increase in nanoparticle concentration and eventually becomes inferior even to pure water. Chopkar *et al.* [5] conducted tests with nucleate pool boiling of ZrO$_2$ based nanofluid on a Copper block. At low volume concentration, heat transfer performance was enhanced, but at higher a decrease in heat transfer was seen. They reported that addition of surfactant to the nanofluid shows a drastic deterioration in nucleate boiling heat transfer. Also, they reported Nanoparticle deposition on the heated surface.

Narayan *et al.* [6] tested Al$_2$O$_3$ nanofluids on a vertical tube with a variety of surface finishes. They defined a "surface interaction parameter" as called the surface roughness. They reported that when the interaction parameter is close to or less than unity, boiling heat transfer performance is deteriorated. If the parameter is higher than unity, and heat transfer performance is improved. They concluded that nucleation cavities can be basically blocked if particles are roughly the same size as the nucleation sites causing deterioration. Most interestingly, they suggested that enhancement or deterioration can be controlled by surface conditions.

Shafahi *et al.* [7, 8] investigated flat and cylindrical heat pipes with nanofluid analytically based on thermal property correlations such as thermal conductivity, viscosity and density etc. Their analytical studies on heat pipes with nanofluids (Al$_2$O$_3$, CuO, and TiO$_2$) show the thermal enhancement and their analytical studies did not show comparable results with experimental results. Murshed *et al.* [9] conducted measurement of thermal conductivity of water-based nanofluids with two shapes of titanium oxide Nanoparticles that were rod-shaped and spherical. Results showed that the rod-shaped Nanoparticles cause a higher increase in thermal conductivity than that of the spherical ones.
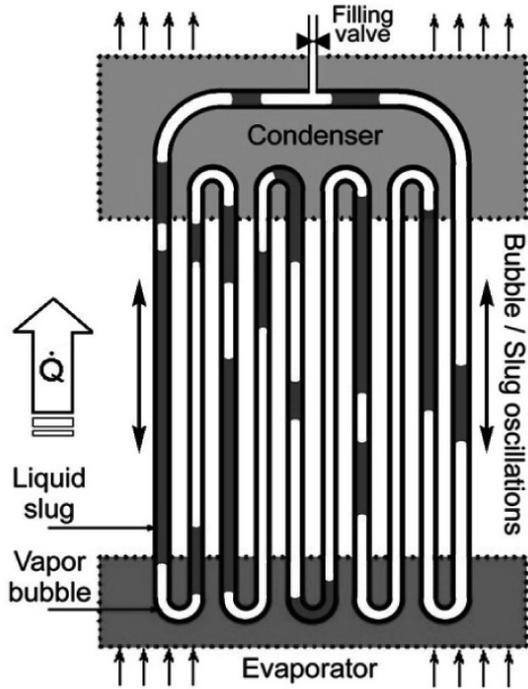
Figure 2 illustrates the experimental set-up used in the present study. The PHP's is fabricated using copper with a bending radius of the U bend in the evaporator section and the inverted U bend in the condensation section of 20 mm, forming four snake-shaped PHP's structure. The heat load is applied by mica heater which is placed on the outer wall surface of the evaporator, and it is dissipated from the condenser by cooling water with a constant inlet temperature of 220C. Both the evaporator and adiabatic section are well thermally insulated by glass wool fibers.

The PHP's is to be filled by different mass concentration of 10g/lt, 20g/lt and 30g/lt with three working fluids as mentioned above with constant filling ratio of 50%. The filling procedure is done by a syringe injector. After filling the tube on their desired filling ratios, the evaporator section has to be heated. By changing the voltage, different voltage and current are supplied to the evaporator. For heating the evaporator a mica heater is used and Water is used for cooling the condenser. K type thermocouples are used to monitor the temperature at different positions of the pulsating heat pipe. The temperature is recorded on a regular time interval. Generally, the temperature is recorded when the steady state condition is reached.

Figure1. Configuration of pulsating heat pipe.

II. EXPERIMENTAL SET-UP

In general, the Pulsating Heat Pipe (PHP) operates on the basis of the movement of liquid slugs and vapor plugs, which is governed by surface tension and buoyancy. Therefore, the inner diameter must be small enough so that the working fluid will distribute itself inside the tube length and form the liquid slugs and vapor plugs due to the effect of surface tension. In order to study the influence of thermo physical properties on the start-up performance of PHP, three working fluids such as Acetone, Methanol and Di water are used here.
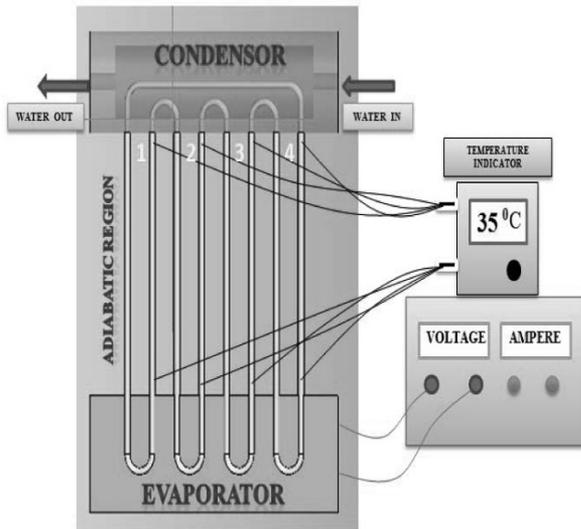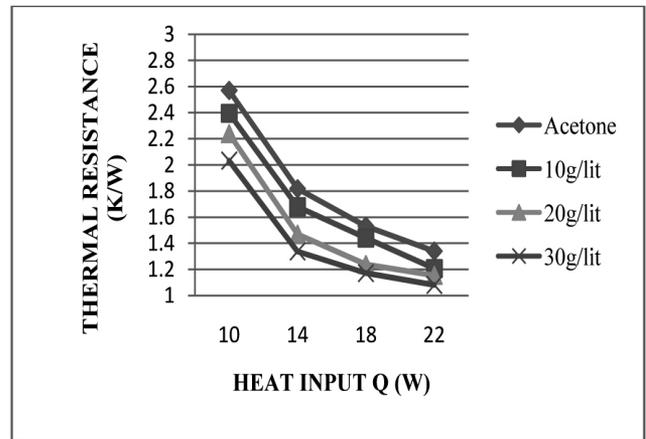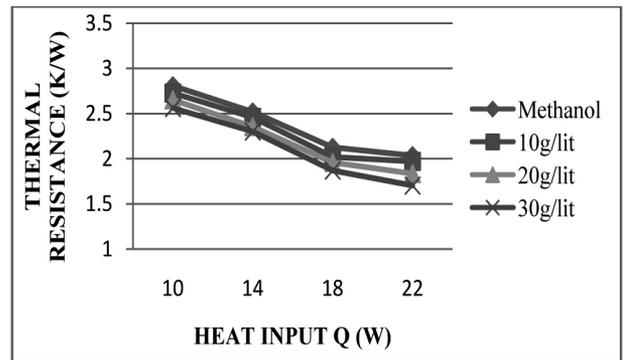

Figure 2. Experimental set-up.

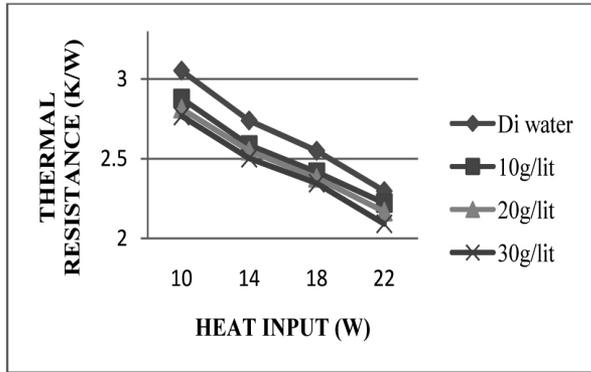## III. RESULTS AND DISCUSSION
Effect of thermal resistance with different heat input:
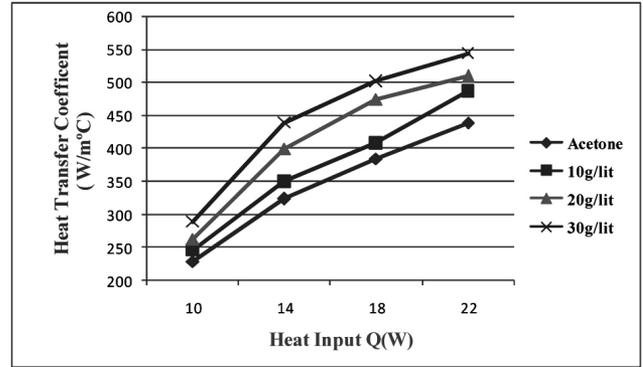

(a) Acetone

(b) Methanol

(c) Di Water

Figure 3(a) to (c). Thermal resistance v/s heat input for different working fluids.

Figure 3 shows 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. With the increment of heat input, thermal resistance decreases. For Acetone without addition of nano particles and at lower heat input, thermal resistance is high. Figure 3 shows variation of thermal resistance with heat input for Acetone, Methanol, and Di-water with and without addition of SiO_2 particles. For addition of 10g/lt and at lower heat input, the thermal resistance is nearly 2.3955K/W which is higher in case of Ethanol and Di-water for the same heat input. With the increment of heat input for the same filling ratio with SiO_2 concentration, thermal resistance decreases quickly. But with the increase of sio2 mass concentration, the rate of decrement of thermal resistance goes down which indicates the slow increment of heat transfer rate. it is also observed that, the highest thermal resistance of 2.5702K/W, 2.808 K/W, 3.0533K/W for lower heat input is obtained for pure acetone, methanol, Di water respectively and the lowest thermal resistance of 2.0329 K/W, 1.7032 K/W, 2.0914 K/W is obtained for 30g/lt at 22W heat input respectively. Percentage decrease in thermal resistance at 22W with increase in SiO_2 mass concentration for acetone is observed as 10.97%, 16.032%, and 23.87% for 10g/lt, 20g/lt and 30g/lt respectively. Similarly, for methanol is observed as 3.23%, 10.79%, 19.43% for 10g/lt, 20g/lt and 30g/lt and for Di water 3.36%, 5.63%, 9.825% for 10g/lt, 20g/lt and 30g/lt respectively.

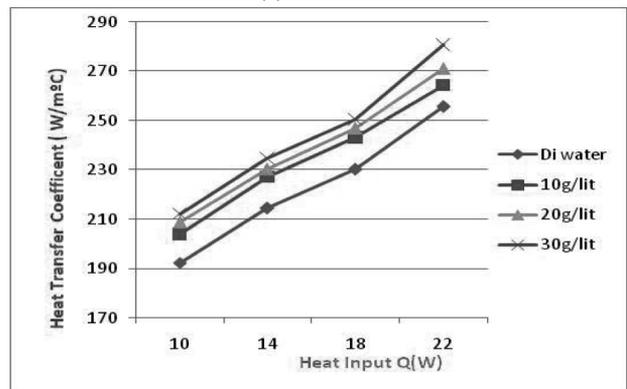*Effect of heat transfer co-efficient with different heat input:*
Figure 4 (a) to (c) show the effect of heat input on the thermal heat transfer coefficient of PHP. It is clear that the thermal heat transfer coefficient increases with increase in heat input as well as SiO_2 mass concentration for all the working fluids considered. The heat input is the 'pump' for the thermo-fluidic action. Thus, increasing 'pumping power' increases the performance.

(a) Acetone
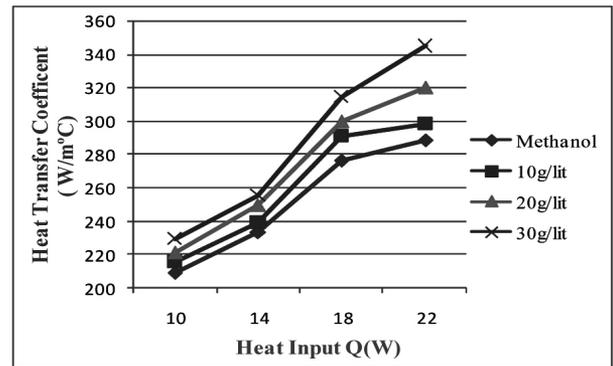
(b) Methanol

(c) Di water

Figure 4(a) to (c). Heat transfer co-efficient v/s Heat input for different working fluids.

Further, it is seen that Acetone exhibits higher values of thermal heat transfer coefficient compared to other working fluids. This is due to lower value of thermal resistance. The higher values of thermal heat transfer coefficient of Acetone indicate that Acetone has better heat transport capability compared to other working fluids. From Figures the lowest heat transfer coefficient of 229W/m^{0}C, 209 W/m^{0}C, and 192 W/m^{0}C for lower heat input is obtained for pure acetone, methanol, Di water respectively and the highest heat transfer coefficient of 513 W/m^{0}C, 354 W/m^{0}C and 265 W/m^{0}C is obtained for 30g/lit at 22W heat input respectively. Percentage increase in heat transfer coefficient at 22W with increase in SiO_2 mass concentration for acetone is

observed as 10.06%, 12.92%, and 14.61% for 10g/lit, 20g/lit and 30g/lit respectively. Similarly, for methanol and Di water is observed as 3.02%, 9.08%, 16.03% and 3.03%, 4.11%, 4.47% for 10g/lit, 20g/lit and 30g/lit respectively 3.3.

IV. CONCLUSION

An experimental investigation on thermal analysis of a Pulsating Heat Pipe was conducted for three different working fluids by adding SiO_2 Nanoparicles to base fluids at varying mass concentrations at different orientations and varying 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. Using SiO2 Nano fluid, heat transfer capability increases at all concentrations of Nanoparticles to base fluids.
3. The optimum fluid and concentration found to be Acetone and 30g/lit of Nanoparticles respectively.
4. Nano fluidic PHP's were able to remove high amount of heat flux effectively.
5. Compare to three fluids Acetone, Methanol and Di Water without adding Nano particles to base fluids Acetone will give better performance.
6. Temperature difference between the evaporator and the condenser decreased, due to Nanofluid utilization.

V. ACKNOWLEDGMENT

VI. REFERENCES

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