# Effect of $SiO_2$ on Thermal Performance of Pulsating Heat Pipe

**E.R. Babu** [1] and **G. V. Gnanendra Reddy** [2]

Department of Mechanical Engineering,

[1]Bangalore Institute of Technology, Bangalore 560 004 Karnataka India

[2]SJC Institute of Technology, Chickballapur 562 101 Karnataka India

rajjbabu@gmail.com

*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 $Al_2O_3$ 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 ($Al_2O_3$, 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.

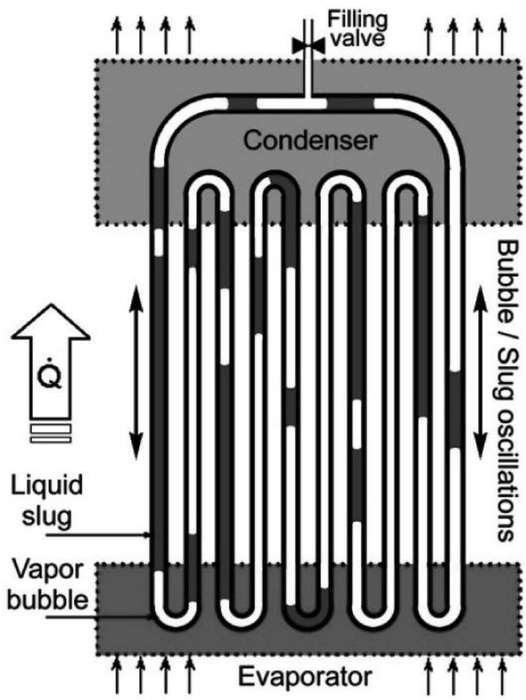



Figure1. Configuration of pulsating heat pipe.

## 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.

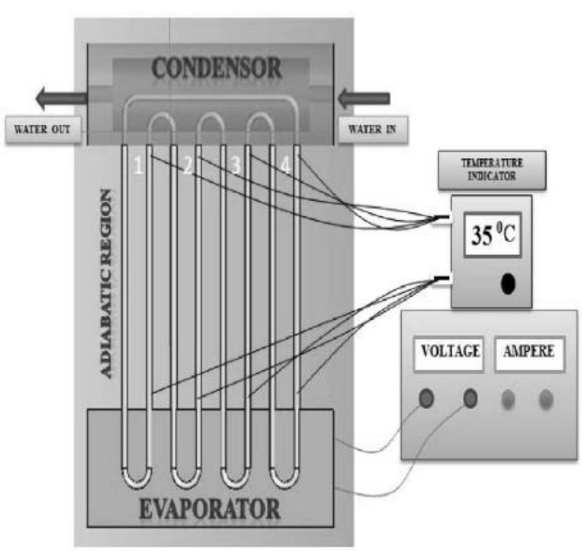


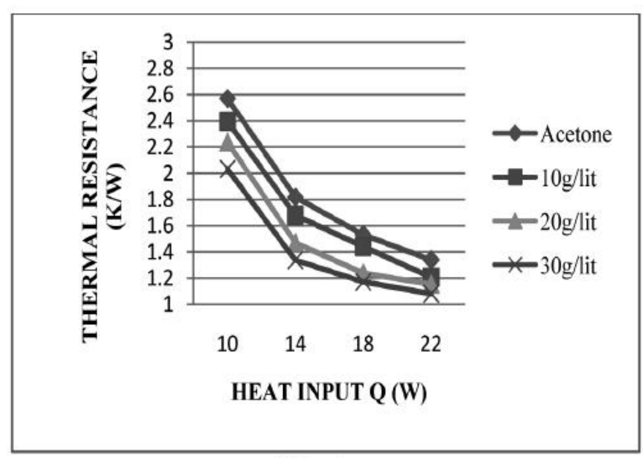

Figure 2. Experimental set-up.

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.

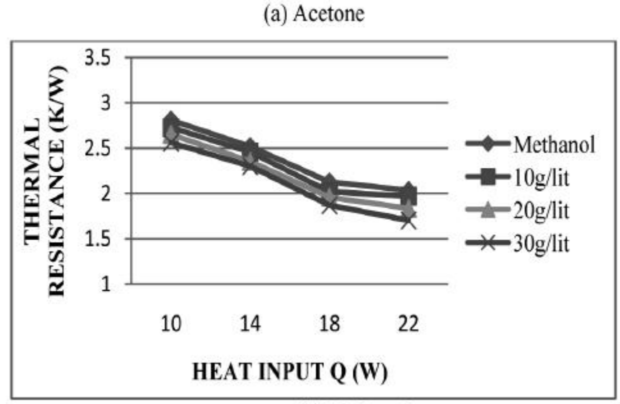
The PHP's is to be filled by different mass concentration of 10g/lt, 20g/lt and 30g/lt with three working fluids as mentioned above with constant filling ratio of 50%. The filling procedure is done by a syringe injector. After filling the tube on their desired filling ratios, the evaporator section has 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.

## III. RESULTS AND DISCUSSION

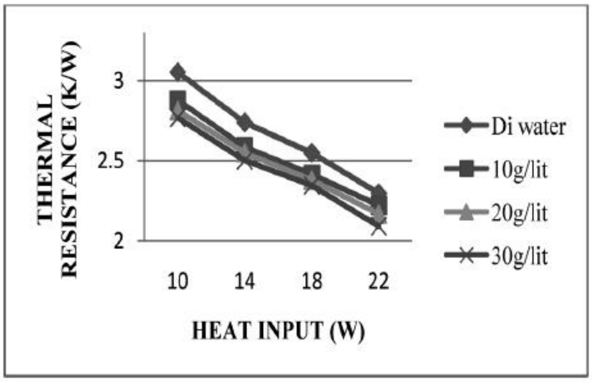
Effect of thermal resistance with different heat input:




(a) Acetone




(b) Methanol

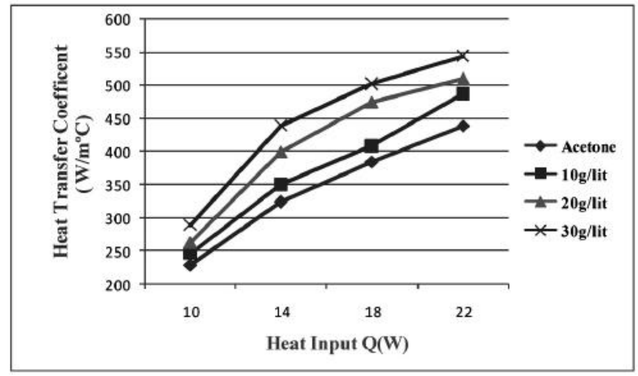



(c) Di Water

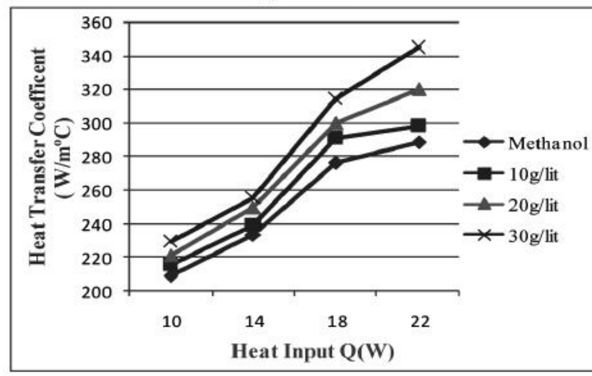
Figure 3(a) to (c). Thermal resistance v/s heat input for different working fluids.

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.

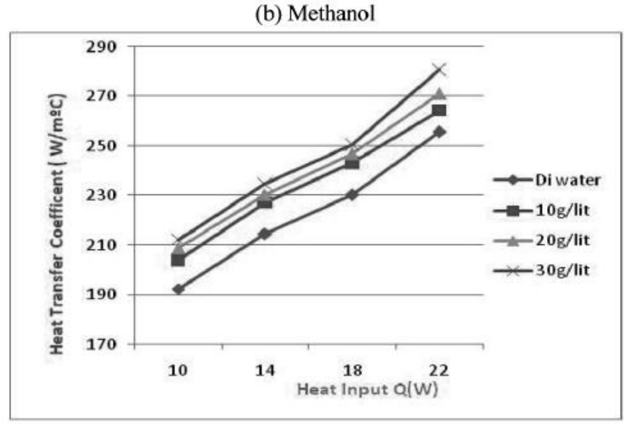
*Effect of heat transfer co-efficient with different heat input:*
Figure 4 (a) to (c) show the effect of heat input on the thermal heat transfer coefficient of PHP. It is clear that the thermal heat transfer coefficient increases with increase in heat input as well as $SiO_2$ mass concentration for all 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

The authors are grateful to the Management and Department of Mechanical Engineering, Bangalore Institute of Technology, Bangalore, Karnataka, India, for extending the facilities to carry out this Investigation.

## VI. REFERENCES

[1]. H. Akachi, "Structure of a heat pipe," US Patent 1990, Patent Number 4921041.

[2]. H. Jamshidi, S. Arabnejad, M.B. Shafii, Y. Saboohi, "Thermal characteristics of closed loop pulsating heat pipe with nanofluids," *Journal of Enhanced Heat Transfer,* 2011.

[3]. M. Mameli, M. Marengo, S. Zinna, "Numerical model of a multi-turn closed loop pulsating heat pipe: effects of the local pressure losses due to meanderings," *International Journal of Heat and Mass Transfer,* 1036 e1047, 2012.

[4]. Jamshidi, H, Arabnejad, S, Shafii, M.B, and Saboohi, Y, "Thermal Characteristics of Closed Loop Pulsating Heat Pipe with Nanofluid," *Journal of Enhanced Heat Transfer,* pp.221-237, 2011.

[5]. Chopkar, M, "Pool Boiling Heat Transfer Characteristics of ZrO2–Water Nanofluids From a Flat Surface in a Pool," Heat Mass Transfer, pp. 999-1004, 2007.

[6]. Narayan. G. P, Anoop. K. B, Das, S. K, "Mechanism of Enhancement/Deterioration of Boiling Heat Transfer Using Stable Nanoparticles Suspensions over Vertical Tubes," *Journal of Applies Physics,* pp. 074317-074324, 2007.

[7]. Shafahi. M, "An Investigation of the Thermal Performance of Cylindrical Heat Pipes Using Nanofluids," *International Journal of Heat and Mass Transfer,* pp.376-383, 2010.

[8]. Shafahi, M, "Thermal Performance of Flat-Shaped Heat Pipes Using Nanofluids," *International Journal of Heat and Mass Transfer,* pp.1438-1445, 2010.

[9]. Murshed, and Yang. C, "Enhanced Thermal Conductivity of TiO2-Water Based Nanofluids," *International Journal of Thermal Science,* pp. 267–373, 2005.

**E.R. Babu** completed his Bachelor of Engineering in Mechanical Engineering from SJC Institute of Technology, Chickballapur, Karnataka, India, in 2006. He completed his Master of Technology from MS Ramaiah Institute of Technology, Bangalore, Karnataka, India, in 2008. He presently works as Assistant Professor in the Department of Mechanical Engineering in Bangalore Institute of Technology, Bangalore, Karnataka, India. He published many papers in national and international conferences and journals. His research interests lie in Design and Thermal Engineering covering mainly the fields of Finite Element Analysis, Composite Materials, Pulsating heat pipe, etc.