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Influence of Al₂O₃ Nanoparticles on Thermal Performance of Closed Loop Pulsating Heat Pipe

With the rapid development of electronic technology, many new promising ideas and technologies were introduced into thermal management, one of which is pulsating heat pipe (PHP), which is different from traditional heat transfer strategy. Hence, an investigation on pulsating heat pipe with multi turns will be conducted in order to examine nanoparticles effect on heat transport ability. The pulsating heat pipe consists of copper tube having inside radius of 1 mm, thickness of 0.5 mm and total length of 1605 mm. The investigation is done with acetone with a filling proportion of 60% for different % mass concentration of 1%, 2%, 3%, 4% and 5% of Al₂O₃ nanoparticles for differed heat contribution from 20 W to 60 W. From the results of different % mass concentration, the most reduced value of thermal resistance is 0.28 K/W at 1% mass concentration. Hence the PHP operates better with 1% mass concentration of Al₂O₃ nanoparticles.

Keywords: Nanoparticles, Pulsating heat pipe, Thermal performance.

1. INTRODUCTION

The pulsating heat pipe (PHP) plays an important role in cooling technologies as there is a demand in increase in developing the technologies in heat dissipation devices in the field of space technology and microelectronics. The PHP was coined by Akachi [1]. The PHP is more efficient heat transfer device, which is made up of long slender tube with multi turns that partially loaded up with working fluid. In PHP, by means of liquid slugs and vapour bubbles i.e. by sensible heat and latent heat, heat transfer takes place through oscillation, hence the name oscillating or pulsating heat pipe. The PHP's performance is enhanced by various criterions such as working fluid, filling ratio, tube diameters, orientation, heat flux etc. In the recent years, Nano fluids as an alternative to working fluids in various applications have been widely used. Since Nano fluids have exorbitant thermal conductivity and better heat transfer co-efficient compared to base fluid. Large number of research investigations has been carried out on the effect of various nano fluids to check the performance of pulsating heat pipe. Many researches have proven an improvement in performance with the usage of various nano fluids [2-4]. The most explored nanomaterial is Al₂O₃ nanoparticles and Al₂O₃-water based nanofluid is

commonly used for enhancement in heat transfer [5-7].

Some of the works have reported the deterioration of the pulsating heat pipe performance due to usage of nano fluid [8,9]. Lin et al [9] researched the silver nano fluid effect for various filling ratios of 20%, 40%, 60% and 80%. Among all four kinds of filling ratios, 60% filling ratio gives better bubble production and pulsations get balanced. Also as Nano particle concentration increases, the performance of PHP decreases. Hassan et al [10] enhanced the performance of heat pipe with Nano particles in pure water due to stability of the Nano particles in the base fluid due to change of phase of water. The particle aggregation impacts the thermal resistance in heat pipe performance. Gunasegaran et al [11] optimized the SiO₂ nanoparticle mass concentration in loop heat pipe. In his study, he varied the SiO₂ particle mass concentration from 0% to 3% and proved that at 0.48% particle mass concentration, the thermal resistance is minimum of about 2.66°C/W. Goshayeshi et al [12] deliberate inclination angle effect on heat transfer of ferrofluids in CLPHP. It is proved that FeO₃ nanoparticles can improve the thermal resistance and heat transport capability under magnetic field with an increase in heat input. Optimum orientation angle is 750 as the heat transfer co-efficient is enhanced due to increased orientation angle. Goshayeshi et al [13] describe the heat transfer coefficient effect in a PHP for gamma Fe₂O₃/kerosene and Fe₃O₄/water with working range of 0–140W heat input power and inner diameter of 2, 2.5 and 3 mm. Two fluids with a charging ratio of 50% by volume were used. Outcome of experimentation shows that 2.5 mm inner diameter when charged with

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Fe₃O₄/water has better thermal performance as compared with gamma Fe₂O₃/kerosene. Tharayil et al [14] selected graphene with water as a nanofluid. From the investigation, entropy diminishes with the utilization of nanofluid of 31.6% and 23.9% for 0.006 Vol.% and Vol.% respectively. Additionally the second law efficiency demonstrates a normal increment of 37.5% and 19.4% for the same concentrations. To the authors, insight, there is no much examination on exhibitions of PHP's using nano fluid up to 5% mass concentration. So the objective of this experimentation is to check the performance of PHP with Al₂O₃ nanoparticles based fluid. The impacts of thermal resistance along with the heat transfer co-efficient on thermal performance of PHP's are altogether examined in this paper.

2. EXPERIMENTATION

The simplistic diagram of a setup is presented in Figure 1. It comprises of a power supply unit, a cooling system and a temperature measuring system. The PHP is comprised of copper with thermal conductivity of 385W/mK. The PHP comprises three zones (adiabatic, evaporator and condenser zone). The evaporator zone is exposed to a heat flux with mica heater of 150 W capacity. The heat input is changed from 20 W to 60 W with an augmentation of 10 W. The condenser zone is exposed to cooling water with a stream rate of 0.85mlt/sec.. In order to view the flow visualization of pulsations of working fluid, a borosilicate glass tube is adopted in adiabatic zone. In the experimental setup the lengths of adiabatic, evaporator and condenser zones are 800 mm, 640 mm and 512 mm respectively. To quantify the temperature, eight K-type thermocouples were utilized in which four were utilized in evaporator zone and rests were utilized in condenser zone. The temperatures are measured by collecting through a data acquisition when the system reaches steady state.

Acetone is used as the base fluid for the preparation of nanofluid in a digital ultrasonic cleaner as shown in Figure 2. Aluminium oxide nanoparticles were purchased from Nano labs, India and then dispersed into the base fluid. The size Al₂O₃ nanoparticles were in the range of 30-50 nm. To produce an ideal % mass concentration of nanofluids, the weights of acetone and nanoparticles were estimated with a sensitive balance having an accuracy of 0.1 mg. In the present research work, the % mass concentration (volume fraction) of 1%, 2%, 3%, 4% and 5% were chosen. The percent mass concentration of the powder is determined by using following equation.

$$\%Mass\ concentration = \frac{W_{np}}{W_{np} - W_{bf}} \times 100 \quad (1)$$

where W_{np} = Amount of Nano particles in grams.

W_{bf} = Amount of base fluid in grams

The nanofluid is set up by dispersing the specified quantity of aluminium oxide nanoparticles (Al₂O₃) in acetone for different % mass concentration by ultrasonication process for 6 hours. This ultrasonic vibrator generates ultrasonic pulses in the power 180W at 40 KHz. The reason behind sonication is to break the agglomerates of Al₂O₃ nanoparticles and disperse them

uniformly throughout the base liquid. By ultrasonication the Al₂O₃ nanoparticles will suspended as an individual particles rather than clusters. The nano fluids prepared was kept under observation for more than one hour to check the particle settlement and it was observed no settlement of particle at the base of the Erlenmeyer flask. The photographic perspective on nano fluid suspension after sonication process appeared good dispersion of Al₂O₃ nanoparticles in acetone which is shown in Figure 3. Further, Figure 4 (a) to (e) shows the scanning electronic microscopy (SEM) images of Al₂O₃ nanoparticles dispersed in acetone with particle mass concentration of 1% to 5% at room temperature. It is observed that good dispersion of Al₂O₃ nanoparticles in acetone was achieved.

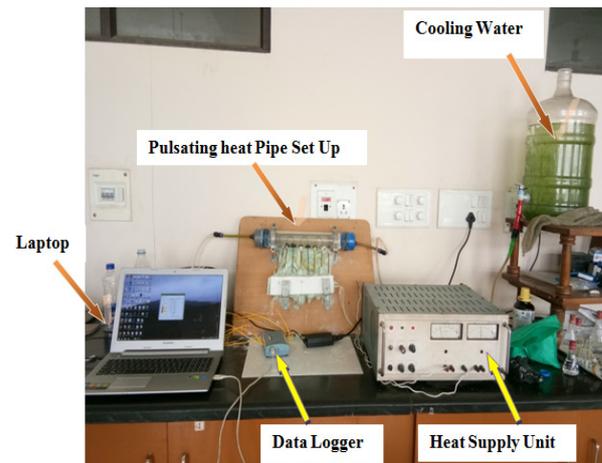
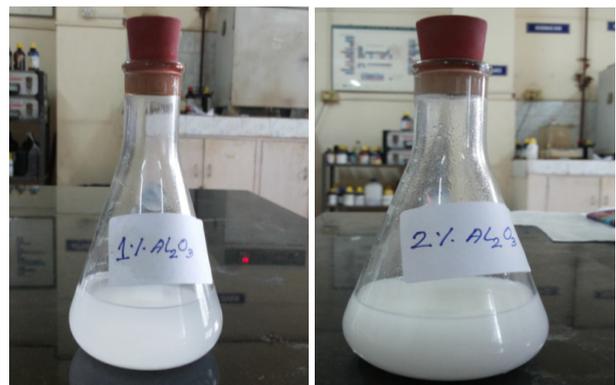


Figure 1. Experimental test set-up.



Figure 2. Preparation of Al₂O₃ nanoparticles based fluid using ultrasonication technique.



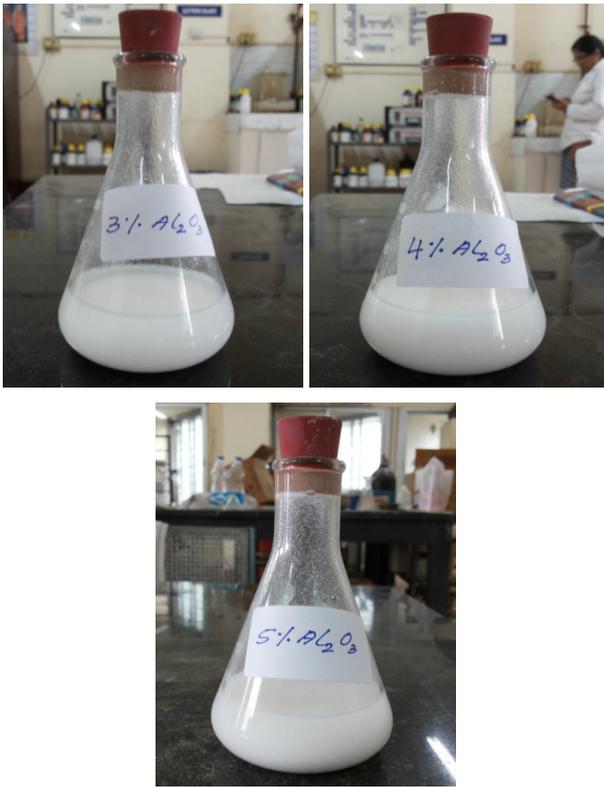


Figure 3. Nano fluid of Al_2O_3 at 1%, 2%, 3%, 4% and 5% mass concentration

3. RESULT AND DISCUSSIONS

Impact of mass concentration of Al_2O_3 nanoparticles on thermal performance of PHP is discussed in detail in this section.

3.1 Effect of evaporator temperature on thermal performance of PHP

Variation of evaporator temperature v/s heat input for different mass concentration of Al_2O_3 nanoparticles is shown in Figure 5. It is observed that the evaporator temperature is very low at lower heat input and increments with increment in heat input for all % mass concentration considered. As the evaporator temperature increases, the vapor bubbles and the liquid plugs in PHP accelerate, which enhances the convective heat transfer and consequently more amount of heat is transferred through the sensible heat. Upon comparing the evaporator temperature for different % mass concentration, it is observed that at 2% mass concentration has higher evaporator temperature of $62.50^\circ C$ as compared with other % mass concentration at higher energy levels.

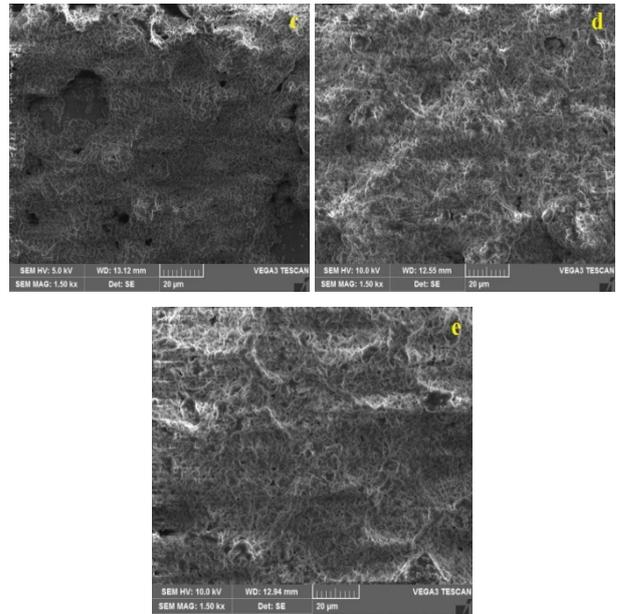
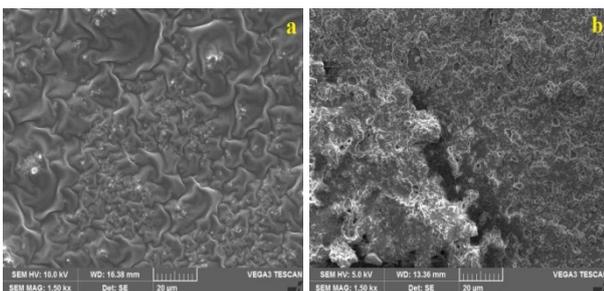


Figure 4. SEM micrographs of nano fluid with (a) 1%, (b) 2%, (c) 3%, (d) 4% and (e) 5% Al_2O_3 nanoparticles

3.2 Effect of condenser temperature on thermal performance of PHP

Figure 6 shows condenser temperature variation with respect to heat input for different % mass concentration of Al_2O_3 nanoparticles. It is seen that the condenser temperature is very low at lower heat input and enhances with the increase in heat input. The condenser temperature is lower because of very slow and irregular movement of the working liquid at lower heat input. The working fluid movement is moderate at lower heat inputs because of lower vitality (energy) levels, the hot working fluid takes greater time to reach the condenser zone from the evaporator section. As more as the heat input, more are the fluid fluctuations inside the PHP and hence more heat transfer rate. At low heat input, the temperature rise of cooling fluid was very less; hence lower variation of condenser temperature. On contrary at higher heat loads, due to inertia of the system, slow fluid movement at initial stage, however the movement of fluid is picked up after 25 min there by results in increase in condenser temperature.

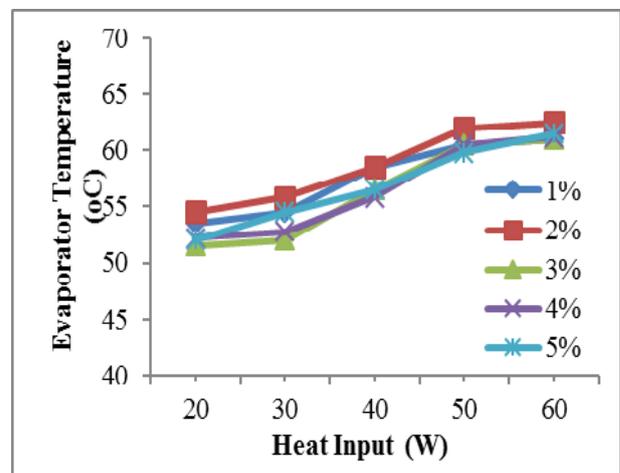


Figure 5. Evaporator temperature v/s Heat input for different mass concentration

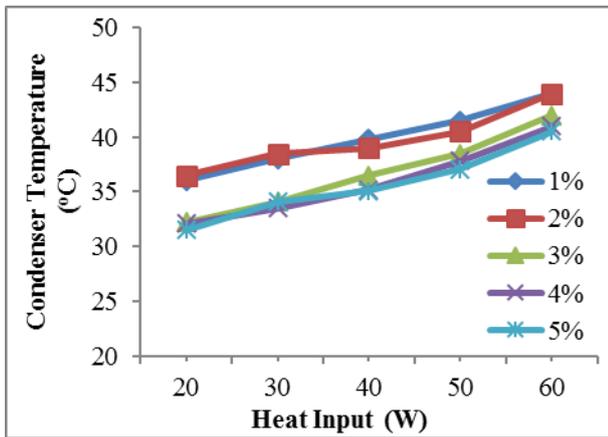


Figure 6. Condenser temperature v/s Heat input for different mass concentration

As the condenser temperature increases, the liquid plugs and vapour bubbles in the pulsating heat pipe accelerate, which enhances the convective heat transfer and consequently more amount of heat is transferred through the sensible heat. Upon comparing the temperature at condenser for different % mass concentration, it is clear that at 1% and 2% mass concentration has higher evaporator temperature of 44°C as compared with other % mass concentration at higher energy levels.

3.3 Effect of thermal resistance on thermal performance of PHP

In general the thermal resistance can be defined as the ratio of temperature difference between the evaporator and the condenser to the heat input in the system. Thermal resistance is calculated by using the following equation,

$$R_{th} = \frac{T_E - T_C}{Q} \text{ K/W} \quad (2)$$

where Q= Heat input (W)

T_E = Evaporator temperature in average (K)

T_C = Condenser temperature in average (K)

Figure 7 shows thermal resistance variation with respect to heat input with different mass concentration of Al_2O_3 nanoparticles. Increase in heat input for the same filling ratio with different mass concentration of Al_2O_3 nanoparticles, decrease in thermal resistance and increase in heat transfer is observed. In Figure 6, it is observed a lowest thermal resistance of 0.28 K/W, 0.31 K/W, 0.32 K/W, 0.34 K/W, 0.35 K/W for 1%, 2%, 3%, 4% and 5% Al_2O_3 mass concentration respectively at 60W heat input. It is seen that, the percentage decrease in thermal resistance at higher heat input of 60 W with acetone as 22.2%, 13.88%, 11.11%, 5.5% and 2.77% for 1%, 2%, 3%, 4% and 5% mass concentration of Al_2O_3 respectively. From the results, as % mass concentration increases, the thermal resistance increases. However it is well known that the nanofluid has higher heat conduction co-efficient that removes excess heat. But as the concentration increases, the viscosity of the fluid increases. This higher viscosity is greatly influenced by the formation of bubbles and hence the force of friction increases between the walls of tube and liquid plugs, which influence the whole efficiency of pulsating heat

pipe. Among all the % mass concentration considered for Al_2O_3 when compared with base fluid i.e. acetone, the percentage decrease in thermal resistance is about 22.2% for 1% mass concentration of Al_2O_3 nanoparticles. Hence the PHP operates best at 1% mass concentration of Al_2O_3 nanoparticles when compared with other % mass concentration.

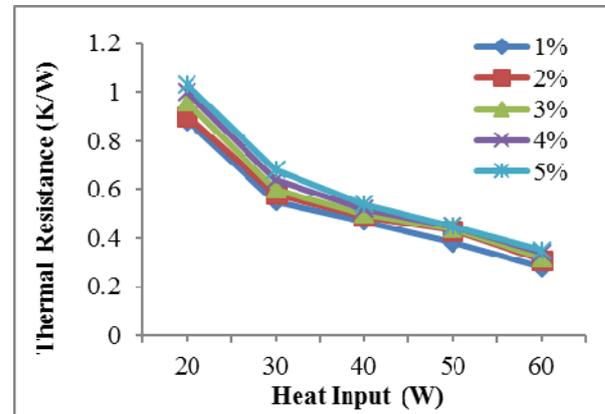


Figure 7. Thermal resistance v/s Heat input for different mass concentration of Al_2O_3

3.4 Effect of heat transfer coefficient on thermal performance of PHP

The heat transfer coefficient in PHP's is found by using the equation,

$$H = \frac{Q}{A_c (T_E - T_C)} \text{ W/m}^2\text{K} \quad (3)$$

where A_c = Area of Condenser ($\pi \cdot d \cdot L_c$)

d = Tube diameter (m)

L_c = Length of the condenser (m)

Q = Heat input (W)

T_E = Evaporator temperature in average (K)

T_C = Condenser temperature in average (K)

Figure 8 shows heat transfer coefficient v/s heat input of PHP. It is seen that increase in heat input increases the heat transfer coefficient with respect to Al_2O_3 mass concentration. In Figure 7, the highest value of heat transfer coefficient of 877.38 W/m^2K , 806.24 W/m^2K , 785.03 W/m^2K , 738.39 W/m^2K , 710.26 W/m^2K for Al_2O_3 nano fluid for 1%, 2%, 3%, 4% and 5% mass concentration at 60 W heat input respectively. It is observed from the results, the percentage increase in heat transfer coefficient at a thermal load of 60 W with the base fluid i.e. acetone with an increase in Al_2O_3 % mass concentration was 20.78%, 12.67%, 10.26%, 4.94%, 1.73% for 1%, 2%, 3%, 4% and 5% mass concentration of Al_2O_3 nanoparticles respectively. Among all the % mass concentration considered, 1% Al_2O_3 mass concentration shows higher value of heat transfer coefficient, hence PHP operates better at 1% mass concentration of Al_2O_3 nanoparticles. Hence at this % mass concentration, the vapor bubbles pushes liquid slug that includes sensible heat which enhances the efficiency of PHP. Also it is observed that as % mass concentration increases beyond 1% Al_2O_3 , the PHP did not show further enhancement in heat transfer.

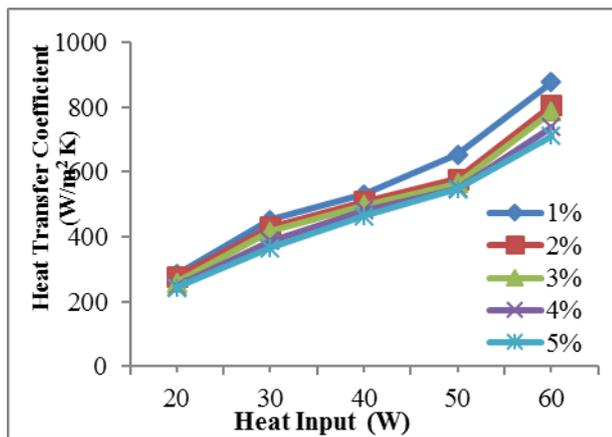


Figure 8. Heat transfer coefficient v/s heat input for different mass concentration of Al_2O_3

4. CONCLUSIONS

The conclusions drawn from this investigation are as follows,

- It is observed that the temperatures at evaporator and condenser increases with increase in heat input for different Al_2O_3 mass concentration considered.
- It is seen that the performance of pulsating heat pipe increases with the addition of nanoparticles compared to the base working fluid.
- With all the % mass concentration considered, there is a decrement of thermal resistance with an increment of heat input. However, 1% mass concentration shows lower value of thermal resistance 0.28 K/W as compared with other % mass concentration and the percentage decrease in thermal resistance is about 22.2% for 1% mass concentration of Al_2O_3 nanoparticles. Hence at 1% mass concentration the PHP operates more efficiently.
- The heat transfer coefficient was increased with increase in heat input for all % mass concentration and the percentage increase in heat transfer coefficient is 20.78% for 1% mass concentration of Al_2O_3 nano particles with the base fluid. For further increasing of the % mass concentration the enhancement intensifies.

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**УТИЦАЈ Al_2O_3 НАНОЧЕСТИЦА НА
ТОПЛОТНЕ ПЕРФОРМАНСЕ ПУЛСИРАЈУЋЕ
ТОПЛОТНЕ ЦЕВИ ЗАТВОРЕНЕ ПЕТЉЕ**

**Бабу Е.Р., Н.Ц. Реди, Х.Н. Редапа, К.В.Ш. Мурти,
Г.В.Г. Реди, П.Г. Копад**

Са брзим развојем електронике многе нове идеје и технологије су уведене у управљање топлотом, у које спада и пулсирајућа топлотна цев (ПТЦ) а која се разликује од класичне стратегије преноса топлоте. Истраживање је вршено на ПТЦ са великим бројем кривина у циљу испитивања утицаја наночестица на капацитет преноса топлоте.

ПТЦ се састоји од бакарне цеви унутрашњег полупречника 1мм, дебљине зида 0,5мм и укупне

дужине 1605мм. За истраживање је коришћен ацетон у концентрацији од 60% за различите % масене концентрације Al_2O_3 наночестица: 1%, 2%, 3%, 4% и 5% и снагу напајања од 20-60W. Резултати су показали да се најмања вредност топлотног отпора добија при 0,28K/W и 1% масене концентрације. Отуда, ПТЦ боље функционише када масена концентрација Al_2O_3 наночестица износи 1%.