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Experimental Analysis of Closed Loop Pulsating Heat Pipe Using ZnO/Water Nanofluid

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ABSTRACT

In this paper experimental analysis on performance of closed loop pulsating heat pipe using ZnO as working fluid is investigated. The CLPHP used in this experiment , consisting of 3 turns, is fully copper made tubes with 2mm inner diameter. Experiment was conducted to study effect of concentration of water based zinc oxide nanofluid with 65 %filling ratio on the thermal performance of the CLPHP. In order to analyse the effect of concentration of water based zinc oxide nanofluid to thermal performance in the ZnO CLPHP, Different tests are taken. The trends of temperature change , thermal resistance(heat Flux)as the input power increases from 5 Watt to 75 Watt at different concentrations like 0.25%, 0.50%, 0.75%, and 1% w/v are highlighted. Results shows that the thermal resistance of CLPHP using ZnO/water nanofluid as working fluid was minimum than thermal resistance when pure water is used.

Keywords:- Closed loop pulsating Heat Pipe (CLPHP), Nanofluid, ZnO/water nanofluid

1. Introduction.

The closed loop pulsating heat pipe(CLPHP) is considering as one of the promising technologies for a high heat transfer device on small space. Heat management is the challenge of the day in electronic product development and management. The amount of heat generated by the electronic devices has increased enormously. All components of electronic from microprocessors of computers to high-end power converters generate heat and minimisation of this heat is very necessary for their optimum and reliable operation. As electronic component design procedure allows higher output in smaller packages, effective heat load dissipation becomes a critical design factor. In present days many of the electronic devices requires cooling beyond the capability of conventional metallic low temperature heat sinks. One solution to remove excess heat is by utilization of wick structured heat pipes which employed to remove the excess heat by attaching them to the high temperature heat source. The CLPHP is another promising heat transfer device for applications like electronic cooling. These devices have interesting thermo-hydrodynamic operational and performing characteristics. A PHP is partially filled with working fluid which distributes itself naturally in the form of liquid slugs and vapor plugs inside the capillary tubes. The evaporator section side end of this tube receives heat, transferring it to the condenser section side end by a pulsating action of the liquid-vapour interface system. A PHP is essentially a passive two-phase non-equilibrium heat transfer device driven by complex combination of various types of two-phase flow instabilities. The performance success of this PHP primarily depends on the maintenance or sustenance of these operating conditions. The liquid slugs and vapour plugs are transported because of the pressure pulsations caused inside PHP. The construction of the PHP inherently ensures that no external mechanical power source is needed for the fluid transport. The driving pressure pulsations are fully thermally driven. Single and multiple loop PHP studies are done. These studies highlight the influence of various design parameters of PHP performance.

Working of Closed Loop Pulsating Heat Pipe-

The tube is first evacuated and then filled with a working fluid as in required amount. As the inner diameter of this tube is small such that the working fluid will distribute itself along the entire tube length .Due to the effect of surface tension under working condition, liquid sluges and vapour bubbles are formed. The tube of a PHP receives heat at one end(evaporative end)and cooled at the other(condensing end).Due to this operation generation and growth of bubbles continually occurs in the evaporator and simultaneously, bubbles collapse and shrink due to condensation in the condenser. This effect of the bubble action, acts as pumping agent which provide the momentum or uneven hydrostatic pressure which needed to move slugs or bubbles to locations where all the evaporation, boiling and condensation can occur. Because of that the transportation of liquid slug and vapour bubble is caused by induced pressure pulsations inside the pipe. The heat transfer in this CLPHP is essentially a combination of sensible and latent heat portion, which is caused by the tran

Important Factors affecting closed loop pulsating heat pipe(CLPHP) -

From previous Literature on closed loop pulsating heat pipe,it can be investigated that few important thermo-mechanical parameters are considered as the primary design parameters affecting the PHP system dynamics. These include

- Input heat flux to the pipe(device)
- Internal diameter of the PHP tube
- Total number of turns used
- Volumetric filling ratio of the working fluid
- Device orientation with respect to gravity
- Working fluid thermo-physical properties

2. Literature survey and review

Akachi H.[1] proposed and presented the principal of PHP, due to PHP´s excellent features ,it is used in many electronic cooling, heat exchangers etc. In order to inhance the thermal performance of heat pipes, fluid containing nanoparticles have been proposed as working fluids.

Tong al[2] in 2001investigated that during the starting of PHP, the working fluid oscillate with higher (larger) amplitude, after that continuous circulation of the working fluid occurs the direction of circulation for fluid can be different for same experimental run. smaller vapour bubbles have larger upward flow velocities and slower downward flow velocity

Khandekar and Groll [3] in 2003conducted various experiments on PHP made of copper material having capillary tube of 2mm inner diameter for three different working fluids viz water, ethanol and R-123.The PHP was tested in vertical as well as in horizontal orientation and observed that, a 100%filled PHP is performing thermally better than a partially filled pulsating mode device under particular operating conditions, higher input heat fluxes result in a transition of slug flow to annular flow at the output of the U-bends of evaporator. Since convective boiling through the thin liquid film rather than nucleate type boiling in slug flow regime is experienced at evaporator U-section

Khandekar and Groll[4] in 2004 investigated that complete stop-over is in the open loop pulsating heat pipe occurs more frequently for filling ratio greater than 50% coupled with low heat input power. This operation is also observed for higher filling ratios.

Kammuang-lue *et al*[5]in 2008examined that, the higher latent heat of the working fluid higher critical heat flux.

In 2008,Yu-Hsing Lin *et al.*[6] perform experiment with silver nanofluid having 20 nm size at different concentration (100 ppm and450 ppm) and various filled ratio (20%, 40%, 60%, 80%, respectively).60% filled ratio gives better result. At 100ppm concentration, heating power of 85 W and 60% FR, the average temperature difference of evaporator and condenser compared with the pure water is less than 7.79^{o}C,and the thermal resistance is also less than 0.092^{o}C/W.

S. Wannapakhe *et al*. [7] in 2009 investigated the effect of aspect ratios (evaporator length to inner diameter of capillary tube), inclination angles, and concentrations of silver nanofluid on the heat transfer rate of a closed-loop oscillating heat pipe with check valves (CLOHP/CV).and he found that, CLPHP using silver nanofluid gives better performance than CLPHP using pure water, because silver nanofluid increases the heat flux by more than 10%.

N. Bhuwakietkumjohn *et al.* [8] in 2010 experimentally analysied that the internal flow patterns and heat transfer characteristics of a closed-loop oscillating heat-pipe with check valves (CLOHP/CV).Both Ethanol and a silver nano-ethanol mixture were used as CLPHP working fluids with a filling ratio equal to 50%. Results from this experiment shows that, as well as the velocity of slug increases, the length of vapor slug rapidly decreases and the heat flux rapidly increases. further, the silver nano-ethanol mixture has higher heat flux than the ordinary ethanol.

Qu *et al.*[9] in 2010,conducted an experiment using Al_2O_3 $_3$nanofluid of 56 nm to investigate The effects of filling ratios, mass fractions of alumina particles as well as power inputs on the total thermal resistance of the open loop heat pipe(OHP). shows result that, the value of maximal thermal resistance was decreased by 0.14 °C/W (or 32.5%) when the power input was 58.8Watt 70% filling ratio and 0.9% mass fraction.

P.Gunnasegaran *et al*. [10] in 2104 work on impact of nanopartical concentration of Al_2O_3 on heat transfer characteristics of Loop heat pipe (LHP). 0% to 3% mass concentration is used. It is found that when nanoparticles mass concentration of Al_2O_3-H_2O nanofluid increases, thermal resistance of LHP decreases.

Md. Riyad Tanshen *et al*. [11] in 2013, studied an influence of multi-walled carbon nano tube (MWCNT) based aqueous nanofluids with different concentrations like 0.05 wt.%, 0.1 wt.%, 0.2 wt.% and 0.3 wt.%. on the heat transport of oscillating heat pipe (OHP).. Result shows that, lowest thermal resistance has been achieved with 0.2 wt.%MWCNT based aqueous nanofluids.

V.K. Karthikeyan *et al*. [12] in 2014, investigate the effect of copper and silver colloidal nanofluids on the closed loop pulsating heat pipe (CLPHP) performance. Experimental findings show that the nanofluid charged CLPHPs increase the heat transfer limit by 33.3% and have lower evaporator wall temperature compared to that of Distilled water.

Rudresha S[13]in 2014,performed an experiment and computational analysis on CLPHP using SiO2/Distilled Water and Al2O3/Distilled Water as the working fluids with concentrations having different mass 10g/lit, 20g/lit, 30g/lit. Experimental analysis shows that at a heating power of 10w, 14w, 18w and 22w the Thermal resistance, Thermal heat transfer Co-efficient, Thermal conductivity as well as Efficiency for CLPHP SiO2/Distilled Water and Al2O3/Distilled Water heat pipe are 69.37%, 75.99% and 11.98% respectively

As various nanofluids at different conditions ie. various input heat flux, internal diameter, filling ratio, concentration of nanofluid, angle of inclination, gives different results. At present many nanofluids were used in many researches having good thermal conductivity but until and now ZnO/Water nanofluid not much used for research. No data is available regarding to ZnO/ Distilled Water nanofluid as working fluid in CLPHP . Thus the purpose of this present study is to experimentally investigate the effect of different concentration of ZnO/Water nanofluid on the thermal resistance in three turn CLPHP

3. EXPERIMENTATION

Experimental Set-up –

Fig.1of experimental setup shows the schematic diagram of the experimental set up. Copper used as the tube material in both evaporator and condenser section with inner dia 2mm.the total length of this CLPHP is 300mm.The evaporator is of 150 mm length and condenser length is 150mm.The whole experiment is done on CLPHP with vertical position. after that working fluid is filled. After filling the tube on their desired filling ratio. Evaporator section consist of coil heater of 5W-75W capacity with 3mm width and 120mm length is used during the experiments for heating the working fluid eight K type thermocouples are used for the temperature measurement. the operating temperature range of these K type thermocouple is o°c to 2500°c having maximum error of 0.1°c.two thermocouple are mounted on the evaporator section and three on the condenser section. similarly one on the oil bath and 2 are used to measure the inlet and outlet temperature of water at condenser section. these thermocouple temp are measured with the help of digital temp indicator on them.

Following procedure is adopted during the present steady state experimentation

- Clean the CLPHP using the di-ionized water injected by a micropump. other components are cleaned with some alcohol, this process is used to remove any surface impurities, if these impurities are not removed from CLPHP, it could disturb the pattern. after that heated to dry out water or alcohol completely.
- Then CLPHP is filled with working fluid using a syringe for the required amount. the experiments are conducted for different concentration of ZnO/Water nanofluid of 0.25 0% to 1%w/v
- The PHP is heated with help of a power source from control panel.
- The cooling water is allowed to flow through yje CLPHP to the condenser section of PHP from the constant water bath at a flow rate 50 ml/min.
- Required wattage is set using the dimmer and heat load is varied from 5W-75W.Experiments are conducted in vertical orientation of CLPHP with different working fluids concentrations

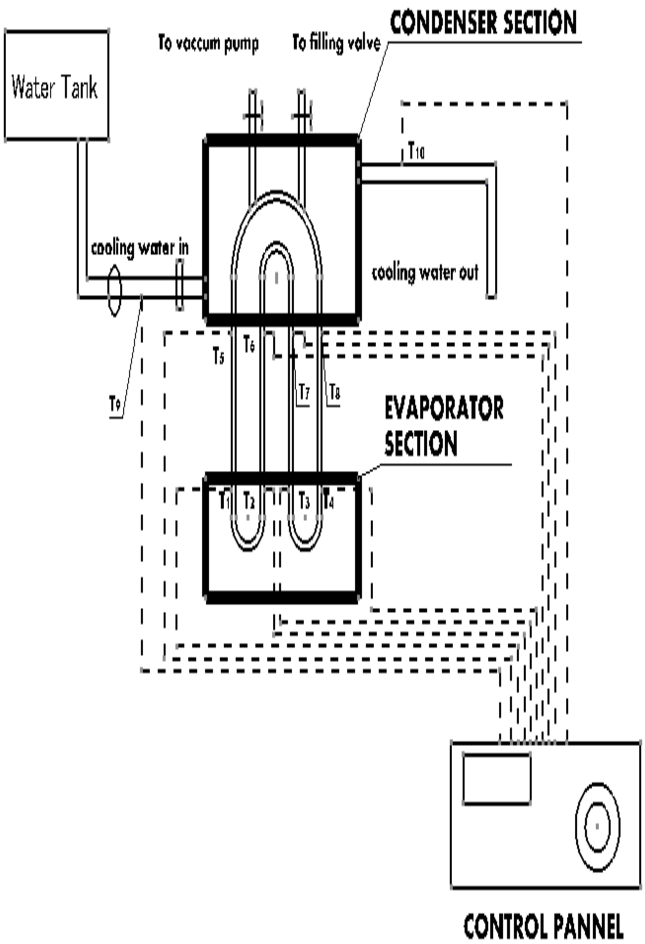

Figure 1: Schematic of Experimental setup

Figure 2: Actual Working Experimental setup

4. EQUATIONS

The heat output from condenser is calculated from the following equation:

$$Q_{out} = mC_p(T_2 - T_1) \quad (1)$$

Where, m – mass flow rate
C_p - specific heat at constant pressure
T_2 - outlet temperature of cooling water
T_1 - inlet temperature of cooling water

The total thermal resistance is obtained from the following equation:

$$R_{thermal} = Te - Tc / Qin \quad (2)$$

Where, $R_{thermal}$ - Thermal resistance
T_e - Average temperature of evaporator
T_c - Average temperature of condenser
Q_{in} – Heat input (W)

5. RESULTS AND DISCUSSION

From the experimental analysis, graphs are plotted against the readings obtained showing effect of different concentration of ZnO/water nanofluid and pure water on average evaporator temperature, average condenser temperature, evaporator-condenser temperature difference and thermal resistance with different heat inputs as shown in figure 3, 4, 5 and 6 respectively. As increasing the heat input to the device, the temperature of evaporator rises resulting in a greater density gradient in the tubes. Simultaneously the liquid viscosity also drops which causes the lowering of wall friction and it is proportional to heat input given therefore thermal resistance is going to decrease with increase in heat input for all concentration of working fluids. Figure 3 shows the change in average evaporator temperature of CPHP for different heat inputs as well as various concentration values of ZnO/water nanofluids and pure distilled water. Average evaporator temperature increases with increasing heat load. Also average evaporator temperature decreases as increase in w/v concentration of nanofluid. It is due to the higher saturation temperature and high specific heat of water. As concentration of nanoparticles in water increases saturation temperature of pure water and specific heat of water decreases tends to decrease in average evaporator temperature. Minimum evaporator temperature is obtained for the concentration of 1%w/v ZnO/water nanofluid

Figure 4 shows the change in average condenser temperature of PHP for various heat inputs as well as different concentration values of ZnO/water nanofluids and pure distilled water. As average condenser temperature increases with increasing heat load. And it increases as increase in w/v concentration of working nanofluid. Because thermal conductivity of fluid is increases due to addition of ZnO nanoparticles, hence more heat is transported towards condenser section of CLPHP.

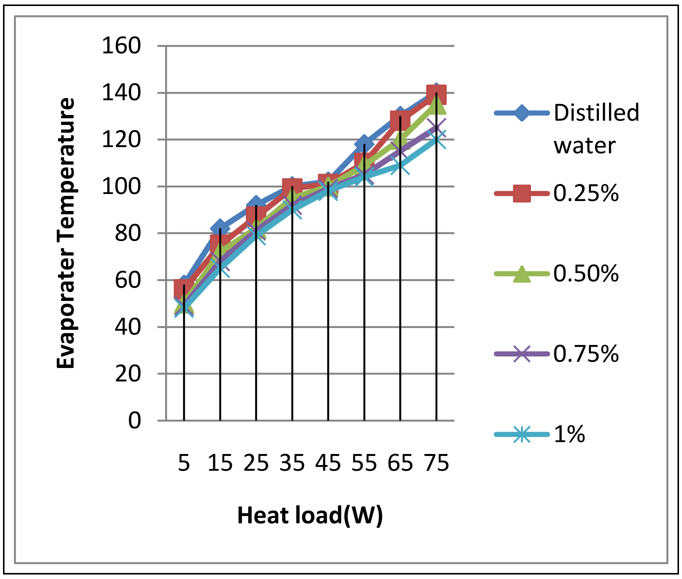

Figure 3. Average Evaporator temp of ZnO/Water Nanofluid

Figure 5 shows the change in evaporator-condenser temperature difference for various heat inputs as well as different w/v concentration values of ZnO/water nanofluids and pure distilled water. From fig. it is concluded that Evaporator-condenser temperature difference increases with increasing heat load. And it increases with increase in w/v concentration of nanofluid. Minimum value is found for pure distilled water and maximum value is found for 1% w/v concentration nanofluid.

Figure 6 shows the change in CLPHP thermal resistance for various heat inputs given as well as different w/v concentration values of ZnO/water nanofluids and pure distilled water. Thermal resistance of CLPHP decreases with increasing heat load given and decreases with increase in w/v concentration of nanofluid. It is because of the presence of different w/v concentration of nanoparticles in base fluid. This increases thermal conductivity of base fluid. Reason for enhancement of thermal conductivity is larger relative surface areas as well as nano-convection between solid and liquid molecules, motion of nano size particles and clustering in nanofluids. From results it clears that the Minimum value of thermal resistance 0.66/W is obtained for 1%w/v concentration at 75W heat input. This is 77% less than pure water.

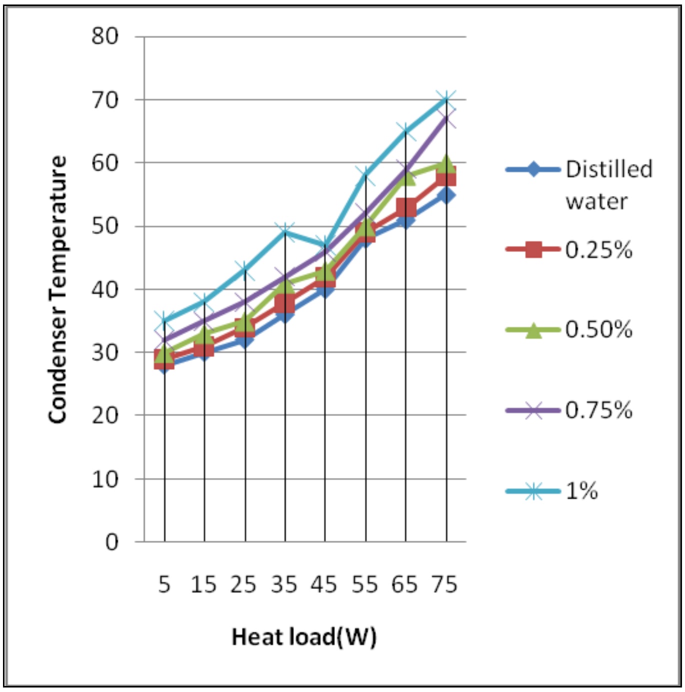

Figure 4: Average condenser temperature of ZnO/water nanofluid

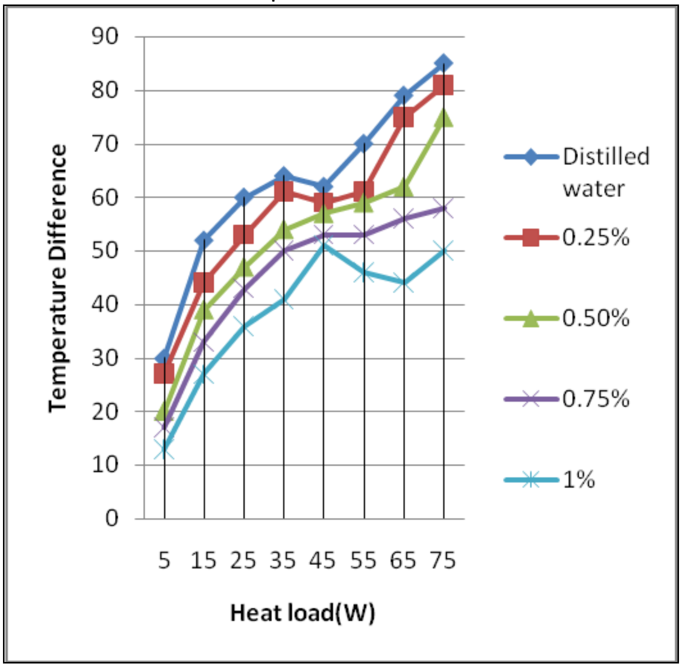

Figure 5: Evaporator-condenser temperature difference Of ZnO/water Nanofluid

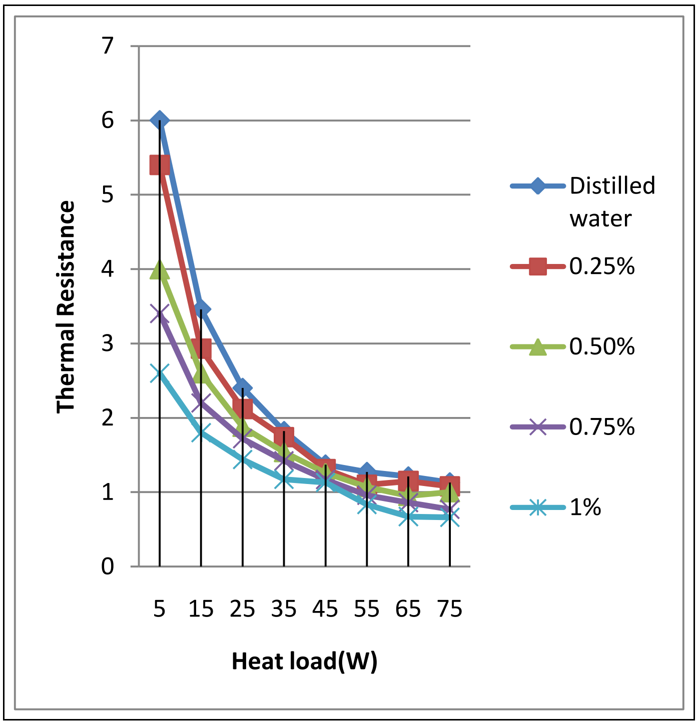

Figure 6: Thermal resistance of ZnO/water nanometer

6. CONCLUSION

From experimental studies and graph ploted using different experimental values for different w/v concentration of ZnO/water, following conclusions are drawn:

- At the heat input lower than 42W,thermal resistance decreases with large difference. and at heat input higher than 42W,it has smaller difference. Thermal resistance of CLPHP decreases with increase heat input for both pure distilled water and ZnO nanofluids.

- For CLPHP thermal resistance decreases with increase in w/v concentration of ZnO/water nanofluid.

- The CLPHP thermal resistance value of 0.90^{o}C/W is obtained which is minimum for 1% of ZnO/water w/v concentration at heat input of 70W. This is 77% less than pure distilled water.

- Thermal performance of CLPHP is strongly depends on thermo physical properties of working fluids like volumetric concentration,filling ratio etc.

- ZnO/water nanofluid CLPHP having 1% of w/v concentration gives the good thermal performance than pure distilled water CLPHP.

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