Heat Transfer Enhancement of Heat Pipe Using Nanofluid

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Abstract— Heat pipe is a special type of heat exchanger that transfers large amount of heat due to the effect of capillary action and phase change heat transfer principle.Traditional fluids have poor heat transfer properties compared to most solids. The objective of this paper is to present an overview of literature dealing with the study of heat transfer using nanofluids in heat pipes.Influence of various factors such as heat input, fill ratio, % concentration, heat flux, dry run condition, wet run condition, inclination angle, nano particles size and its effect on thermal performance.

***Key words*: heat pipe, performance characteristics, nanofluid**

I. INTRODUCTION

The effective thermal management becomes one of the majority serious challenges in many technologies because of constant demands for faster speeds and continuous reduction of device dimensions. As reliable and efficient devices, heat pipes have been of keen interest for many years.

A heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat from its one point to the other point. A heat pipe typically consists of a sealed container charged with a working fluid and wick structure. It utilizes the latent heat of the vaporized working fluids instead of the sensible heat.

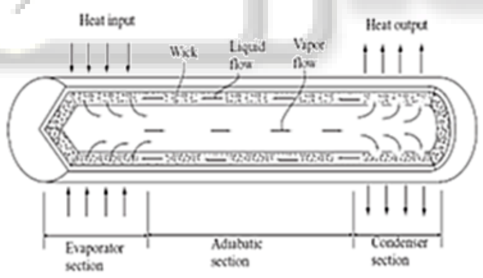

Fig. 1: Heat pipe

The length of the heat pipe can be divided into three parts viz. evaporator section, adiabatic section and condenser section as shown in Fig.1.At the evaporator section the cold liquid is evaporated, vapor flow from the evaporator to the condenser is caused by the vapor pressure difference and the liquid flow from the condenser to the evaporator is produced by the capillary force, gravitational force etc.

Traditional fluids have poor heat transfer properties compared to most solids. Research and development activities are being carried out to improve the heat transport properties of fluids. Solid metallic materials, such as silver, copper and iron, and non-metallic materials, such as alumina, CuO, SiC and carbon nanotubes, have much higher thermal conductivities than Traditional fluids [24]. Argonne National Laboratory has developed a new class of heat transfer fluids called ‘‘Nanofluid’’.

Many researchers have reported experimental studies on the thermal performance of heat pipe.Nanofluids containing a small amount of nanoparticles have substantially higher thermal conductivity than those of base fluids so Nanofluids enhances the heat transfer characteristics.

Shung-Wen Kang et al. [1] conducted experiment on deep grooved circular heat pipe with silver Nanoparticles of diameter 35 nm and 10 nm. The experiment was performed to measure effect of the temperature distribution, heat input, nanofluid concentration, nanoparticles size on thermal resistance of heat pipe. Shung-Wen Kang et al. [1] concluded that greater silver nanoparticles dispersed in working fluid, increase in heat pipe wall temperature was smaller than that for a pure water filled heat pipe under various heat loads. The maximum reduction in resistance was 50% and 80% by using 10 nm and 35 nm particles size respectively as shown in Fig. 2.

Thermal resistance calculated by Equation (1.1),

$$R = \frac{T_e - T_c}{Q} \quad \frac{°C}{W} \qquad (1.1)$$

Nomenclature

A	area (m^2)	E	evaporator
c_p	specific heat (J/kg K)	Hp	heat pipe
I	current (A)	In	inlet
K	thermal conductivity (W/m K)	Out	outlet
Q	heat input to the heat pipe (W)	Th	thermal
R	thermal resistance of heat pipe (°C/W)	W	water
ΔT	temperature difference (°C)	Greek symbol	
T_e	Average temperature of evaporator(°C)	η	efficiency (%)
V	voltage (V)	Δ	increment
$\dot{m}$	mass flow rate (kg/s)	MWHP	Mesh Wick Heat Pipe
$\dot{Q}$	Heat transfer rate (W)	SWHP	Sintered Wick Heat Pipe
Subscript			
c	Condenser		

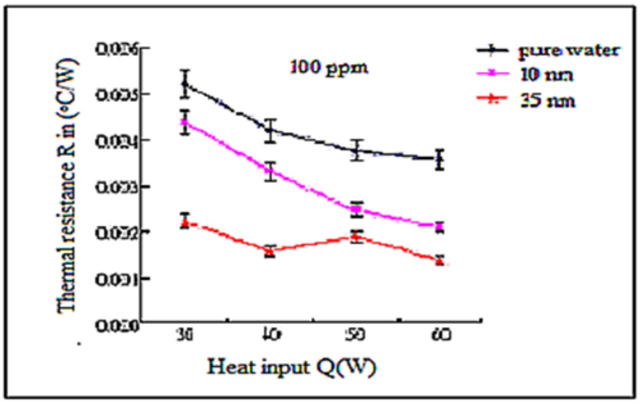

Fig. 2: Thermal resistance of heat pipe with 10 nm and 35 nm nanoparticles

Paisarn naphon et al.[2] analyzed experimentally the performance of heat pipe by using the titanium nanoparticles with diameter of 21nm. Performance evaluated with the de-ionic water, alcohol, and nanofluid (alcohol and nanoparticles).Effects of % charge amount of working fluid, heat pipe tilt angle, % nanoparticles volume concentrations and heat flux on the thermal efficiency of heat pipe was considered. Concluded that heat pipe with 0.10% nanoparticles volume concentration, the thermal efficiency is 10.60% higher than that with the based working fluid. Thermal efficiency decreases as heat pipe tilt angle increased above 60° for de-ionic water and increased 45° for alcohols.As the % charged amount of working fluid (de- ionic water) increases more than 66% by heat pipe volume, the heat pipe thermal efficiency tends to decrease.

A.K. Mozumder1 et al.[3]attempted to design, fabricate and test a miniature heat pipe.Conducted an experiment for different thermal loads and fill ratio to assess the performance of heat pipe in wet run and dry run condition. The working fluids chosen for the study were water, methanol and acetone. Results were shown by the temperature distribution with wet run, dry run, different fill ratio such as 35%, 85% and 100, heat inputs. Thermal resistance and heat transfer coefficients was calculated. Concluded that fill ratios of working fluid greater than 85% of volume of evaporator show better result.For a 2W heat input capacity, the thermal resistance observed in the dry run was 10.5 °C/W and that in wet run was 7.25 °C/W. and also concluded that Aceton gives best results compare to other fluid.

Yu-tang chen[4]studied the effect of various concentrations of silver nano fluid with practical size 35nm on flat heat pipe. Nanofluid prepared using a two-step method. An experimental system was set up to measure the temperature distribution of heat pipes and calculate the thermal resistance. Concluded that more the nanoparticles were dispersed in working fluid the smaller rise in temperature difference of Flat heat pipe than pure was filled in heat pipe under various input power. Thermal resistance of Flat heat pipe filled pure water was higher than nanofluid and also rate of resistance decrease.

R. Senthilkumar et al. [5] employed four cylindrical heat pipe, which were filled with de-ionized water, copper nanofluid, an aqueous solution of n-hexanol and copper nanoparticle in an aqueous solution of n-hexanol separately and tested for its performance. Thermal efficiency of heat pipe calculated by:

$$\eta_{th} = \frac{Q_c}{Q_{in}} = \frac{\dot{m}c_{pw}\,(T_{c,out}-T_{c,in})}{VI} \quad (1.2)$$

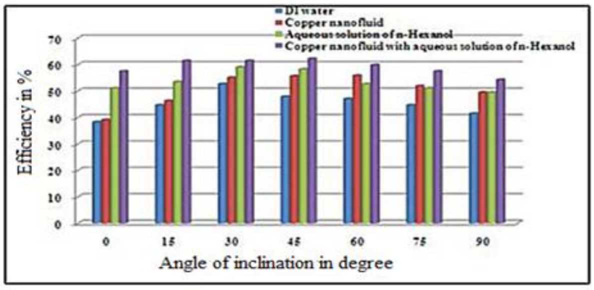

Fig. 3: Variations of heat pipe efficiency for 70 W heat input.

Calculated thermal efficiency and resistance by for different heat input and tilt angels. The experimental results showed that the aqueous solution n-hexanol based copper nanofluids enhances the thermal efficiency of the heat pipe and the effect nanoparticles in the aqueous solution of n-hexanol had a great effect on the reduction of the thermal resistance than that of di water and copper nanofluid loaded heat pipes.

Gabriela Huminicet et al.[6] investigated thermal performance of thermosyphon heat pipe using iron oxide nanoparticles for concentration level of nanoparticles is 0%, 2%,5.3%. Inclination angles 45° and 90° were taken. Concluded that the thermal resistance decreases as the concentration increase, heat transfer rate increases as the inclination angle increases. Thermal resistance was low at 90° and 5.3%. An increase of heat transfer rate of 39% is obtained for a 2% iron oxide nanoparticles and an increase with 42% for 5.3% iron oxide nanoparticles concentration level at 90°.The heat transfer rate can be calculated by equation as follows:

$$\dot{Q} = \dot{m}c_{pw}\left(T_{c,out}\text{-}T_{c,in}\right) \quad (1.3)$$

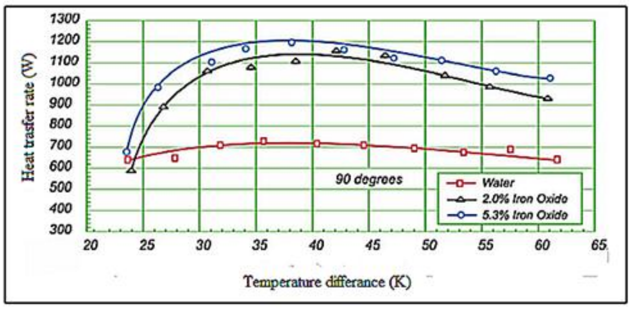

Fig. 4: Heat transfer rate distributions for different concentration levels and an inclination angle of 90°.

Senthilkumar R et al. [7] conducted experiment by taking DI water, copper nano fluid and copper Nano fluid with aqueous solution of n-Butanol in cylindrical copper heat pipe with screen mesh. Effect of heat pipe inclination, type of working fluid and heat input on the thermal efficiency, thermal resistance, Variation of temperature difference between evaporator and condenser. Concluded that Thermal efficiency of copper nanofluid with aqueous solution of n- Butanol was higher than the base fluid DI water and copper nanofluid at any angle and the thermal resistance also reduces.

Nandy Putra et al.[8]conducted thermal performance of screen mesh wick heat pipes with different nanofluids such as TiO_2-ethylene glycol, Al_2O_3-water, Al_2O_3-ethylene Glycol,TiO_2-water, and ZnO ethylene glycol charged with different concentration nano particals varied from 1% to 5%.Concluded that at the same amount of heat load,nanofluids absorb more heat than base fluid.nano particles play important role in reducing the thermal resistance. Al_2O_3 water nanofluid with 5% volume concentration gives higher heat trasfer coeffient both evaporater and condenser.

Lazarus Godson Asirvatham et al. [9]carried out experiment onheat pipe using silver nanoparticles of 58.35 nm diameter dispersed in DI water. The effect of heat inputs, volume fraction, and vapour temperature on the thermal resistance, evaporation and condensation heat transfer coefficient was experimentally investigated. Reduction in thermal resistance of 76.2% is observed for 0.009 vol. % concentration of silver nanoparticles. An enhancement in the evaporation heat transfer coefficient of 52.7% is observed for the same concentration. The dry out condition is observed near 106, 113 and 121W respectively for 0.003, 0.006 and 0.009 vol. % concentrations and beyond 100W for heat pipes with DI water as working fluid. The use of nanoparticles enhances the operating range of heat pipe by 21% compared with that of DI water.

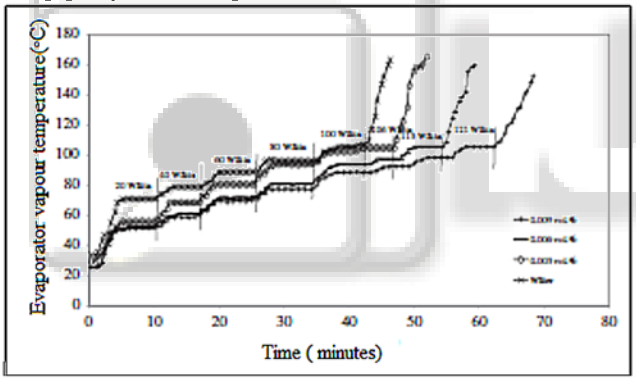

Fig. 5: Vapour temperature in the evaporator with respect to time in minutes.

Yi-Hsuan Hung et al.[10] investigated the thermal performance of a straight copper tube heat pipe using Al_2O_3/water nanofluid with three concentrations 0.5%, 1.0% and 3.0% by weight in heat pipes. effects of the charged volume ratio of the working fluid (20%, 40%, 60%, and 80%), tilt angle (10°, 40°, 70°, and 90°), heating power (20W, 30W, and 40W), and weight fraction of nanoparticles on the overall thermal conductivity of the heat pipe to evaluate the thermal performance. observed that tilt angle at 40° achieved more thermal conductivity at all fill ratio and concentration.

G. Kumaresan et al. [11] conducted experiment for copper sintered wick heat pipe with surfactant free CuO nanoparticles dispersed in DI water. The effect of heat input, tilt angle and weight fractions of nanoparticles on the heat pipe thermal resistance, heat transfer coefficient in evaporator and condenser sections, thermal conductivity and thermal efficiency investigated. Overall thermal conductivity of heat pipe calculated using the following equation:

$$K_{hp} = \frac{Q}{A\Delta T} \tag{1.4}$$

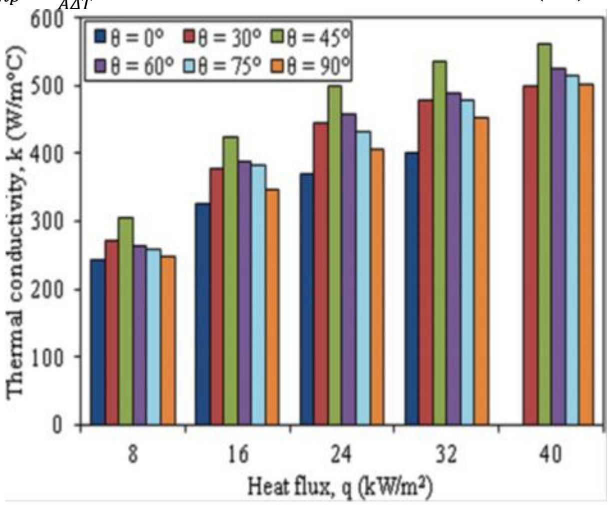

Fig. 6: Overall thermal conductivity of heat pipe with respect to heat flux for 1 wt. %.

Observed that Vapour temperature difference between the evaporator and condenser section reduced when the CuO nanofluid. The reduction in resistance 52% for 1 wt. % of CuO nanofluid for 45˚ tilt angle. Thermal resistance of heat pipe also reduced when the DI water is replaced by CuO nanofluid .Thermal efficiency of heat pipe is improved by 24.9% for 1.0 wt. %CuO nanofluid compared with the DI water at the optimum tilt angle of 45˚.

R. RejiKumar et al. [12] experimented for two layer of stainless steel screen mesh wick het pipe. This study presents the improvement of thermal performance of heat pipe using Al_2O_3-DI water nanofluid. Variation of filling ratio, heat input and angle of inclination have a significant effect on performance. The thermal resistance decreased as the angle of inclination increased and reached a minimum value when the heat pipe was in vertical position and the fill ratio was 80%. Also an optimum efficiency value was obtained when the heat pipe was operated with 80% fill ratio for an angle of inclination 30°.

G. kumaresan et al. [13] compared the enhancement in thermal performance of sintered and mesh wick heat pipe for similar geometrical specification with CuO/DI water nanofluid. Heat transfer capacity of SWHP is 14.3% more than MWHP under the same operating conditions. Study focused on temperature distribution, thermal resistance and effective thermal conductivity. A higher reduction in surface temperature of 27.08% was observed for the sintered wick heat pipe with 1.0 % CuO/DI water .Optimum tilt angles of 45° and 60° for SWHP (sintered wick heat pipe) and MWHP (mesh wick heat pipe) respectively. Reduction in thermal resistance is 49.64% and 35.44% for SWHP and MWHP respectively. Enhance in thermal conductivity is 36.50% and 29.84% SWHP and MWHP respectively. From this paper concluded that SWHP is better than MWHP.

Shailesh Prjapati et al.[14] conducted experimental and analytical by taking heat pipe, copper pipe and stainless steel pipe of identical properties such as length and diameter. Four temperature reading was taken at every 20 min for all pipes with fixed input 57.5 W. Steel pipe having maximum temperature at every stage of heating of pipe compare to copper and steel heat pipe. Temperatures at length of 340 mm of pipe in which steel heat pipe gives maximum temperature 55.5°C, copper pipe gives 48°C and steel pipe gives 40.8 °C. Comparison of analytical and experimental results clearly indicate small difference in the both the results. Concluded that heat pipe can transfer more amount of heat as compared to copper and steel pipe.

II. CONCLUSION

This review describes the research results of heat transfer characteristics of heat pipes using nanofluids as working fluids.

- Improvement in thermal efficiency, heat transfer capacity and reduction in thermal resistance higher using nanofluid than the base fluid.
- Thermal resistance was observed more for dry run compare to wet run.
- Replacing the conventional fluid by nanofluid enhanced the operating range and reduced the dry out problems.
- Size of nanoparticles and its concentration has a strong influence on the temperature distribution.
- Optimum Tilt angles of 45º and 60º for SWHP and MWHP respectively.
- Thermal performance of sintered wick heat pipe was better than that of the mesh wick heat pipe.
- Heat pipe can transfer more amount of heat compared to cu and stainless steel.
- Higher concentration of nanofluids than the optimal value (50 ppm) decreases the thermal performance of the heat pipes due to the water adsorption by the excessive nanoparticles leading to the formation of a coated layer of nanoparticles caused by the sedimentation of it on the evaporator section.
- Porous coating layer formed by nanoparticles on wick surface in evaporator region provides an additional evaporating surface where higher heat transfer rates occurs.

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