Heat Transfer Enhancement in Heat Pipe Using Nanofluid – A Review

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Abstract— For enhancement of heat transfer in heat pipe, Nano fluid found vital role and a new frontier in various engineering applications. This paper reviews and summarizes the work on heat pipes using nano fluids as a working medium. Various types of nano particle with different base fluids as proved its potential to improve thermal properties of working medium in heat pipe. The effect of filling ratio, volume fraction of nano practices on thermal performance in various kinds of heat pipe with different base fluids under various operating conditions has been discussed. Mechanism of enhancement of heat transfer after utilization of nano fluids in heat pipe has been explained. Also, influence of dimensionless on thermal resistance in terms of correlation has been studied. This paper discusses relativity of total heat resistance between the heat pipe with nano fluid and with existing fluids. Focusing towards the application this paper suggests the suitability of heat pipes in various heat generation problems.

Index Terms—Heat Transfer Enhancement, Heat Pipe, thermal Resistance, Nanofluid

I. INTRODUCTION

Application of nanomaterial technology to heat transfer field began since the 1990s and has achieved many meaningful results on heat transfer enhancement. In 1995,

Choi [14] firstly proposed the concept of ‘‘nanofluid’’, which is a fluid with some kinds of nanometer-sized particles suspended into a base liquid. Some examples of applied nanoparticles are pure metals (Au, Ag, Cu, and Fe), metal oxides (CuO, SiO_2, Al_2O_3, TiO_2, ZnO, and Fe_3O_4), Carbides (SiC, TiC), Nitrides (AlN, SiN) and different types of carbon (diamond, graphite, single/multi wall carbon nanotubes). Traditional liquids, such as water, ethylene glycol and engine oil are some examples of base fluids. Under appropriate operating conditions, nanofluids will exhibit high thermal conductivity and stability and are increasingly being used in many heat transfer applications in industrial fields. In recent years, the studies on nanofluids mainly focused on its thermal conductivity, and on forced convection and boiling heat transfer mechanisms. Various mechanisms of the heat transfer enhancement have been proposed including the interface effect (liquid layering around the nanoparticle makes the atomic structure of the liquid layer more ordered than that of bulk liquid, due to higher thermal conductivity of the nanoparticle than liquid, the liquid layer at the interface would reasonably have a higher thermal conductivity than the bulk liquid), Brownian motion, ballistic transport of energy carriers (ballistic phonon transport through the nanoparticles, heat is carried by phonons, i.e., by propagating lattice vibrations), and thermophoresis (nanoparticles can diffuse under the effect of a temperature gradient).

II. LITERATURE REVIEW

The thermal efficiency enhancement of a heat pipe on the different operating state was examined using aluminum oxide nanofluid as additives. A sintered circular straight heat pipe with an outer length of 8 and 190 mm and a 1 mm wick-thickness was experimentally performed. Evaporator section and condenser section were connected through adiabatic section with 90° curve. M. Keshavarz Moraveji, et.al [1] studied experimentally the enhancement of thermal characteristics of a heat tube with employing Al_2O_3 nanoparticle. Two cases were examined for Al_2O_3 nanoparticles in water with volume concentrations 1% and 3%. They observed that charging of the nanofluid to the heat pipe significantly increases the thermal performance by reducing the thermal resistance and wall temperature difference. Also, they found the lowest temperature in the heat at the curved zone and this temperature decreases from the evaporator to the curve and then increases. The effect of angle of inclination, amount of charging and weight fraction of heat pipe charged with Al_2O_3/ DI water nanofluid over thermal performance enhancement with 0.5, 1.0 and 3.0 % concentration experimentally studied by Teng, et al [2]. The heat pipe used was straight copper tube with inner diameter and length of 8 and 600mm, respectively. They found that 1.0% wt is the optimum condition of heat pipe performance. Also, thermal efficiency found was 16.8%. Medium size cylindrical meshed heat pipe under steady as well as transient states were tested with nanoparticle suspensions of silver in DI water as base fluid to record

the response time, surface temperature variation, and also to determine thermal resistance by Ramin Hajian, et al [3]. Suspensions of silver nanoparticles in DI water were utilized in various concentrations of 50, 200 and 600 ppm. Also, nanofluid behavior with various concentration was discussed. Experiments were performed under heat rates in the range of 300-500 W. They commented that in comparison with DI water, nanoparticle addition was more stable showing decrement of thermal resistance and response time of the heat pipe 30% and 20%, respectively. An open loop pulsating heat pipe (OLPHP) experimentally performed under water as working fluid with copper nanoparticle addition by 5% in mass by Roger R. Riehl et al [4]. A working fluid of 6 g of deionized water was used with 99.8% pure copper nanoparticles with diameter of 29 nm. Effect of angle of inclination, types of working fluid and heat input on thermal efficiency and resistance of heat pipe was investigated in copper nanofluid of average size of 40 nm and concentration of Cu nanoparticles was 100 mg/lit by Senthilkumar R, et al [5]. In this analysis, heat pipe of copper container and two strands of SS wrapped screen are used as a wick material. To enhance heat transfer characteristics of heat pipe in solar collector attempt was made by Sung Seek Park, et al [6]. To determine best nanoparticle mixture ratio, measurement of thermal conductivity and viscosity in DI water as function of temperature were carried out via transient hot wire method and rotary type digital viscometry. Influence of nanofluid on heat transfer in loop heat pipe (LHP) was tested by P. Gunnasegaran, et al [7]. silica (SiO_2–H_2O) as a nanofluid with particle volume fraction of 3% which was used as a coolant for heat input range from 20 W to 100 W. Transparent plastic tube to visualize the fluid flow patterns was used. The thermal analysis performed under forced convection mode and the results were verified by FEM. They found that thermal resistance decreases in the range of 28%-44% at heat input ranging from 20 W to 100 W. Also, total thermal resistance as a function of heat input and transient temperature distribution in the LHP were reported. Impact of alumina (Al_2O_3) nanoparticle concentration on heat transfer characteristics in a LHP where mass concentration ranging from 0% to 3% and water as base fluid was selected and performed by

Critical Literature Review

Parameter	I	II	III	IV	V	VII	VIII	IX	X	XI	XII
Container Material	Copper	SS	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper
Wick Material	-	SS	-	-	SS	-	-	-	Copper	Copper	-
Total length of pipe	190	1000	600	4000	600	-	-	1000	350	350	-
Evaporator length	70	200	-	100	150	50	50	400	100	100	55
Adiabatic length	55	550	-	100	300	830	830	200	100	100	350
Condenser length	65	250	-	100	150	321	321	400	150	150	76
Outer dia of the pipe	6	33.5	-	-	20	-	-	-	19.5	8	10
Inner dia of the pipe	-	-	8	1.5	17.6	-	-	13			8
Thickness of pipe	-	4.07	-	-	-	-	-	2	1	0.8	
Mesh size	-	30x30	-	-	60	-	-	-	-	-	-
No. of strands/m	-	-	-	-	2365	-	-	-	-	-	-
No. of layers	-	-	-	-	2	-	-	-	4		
Condenser outer dia.	-	-	-	-	36	-	15	-	-	-	-
Condenser inner dia.	-	-	-	-	30	-	13.5	-	-	-	-
Cooling water flow rate	-	-	-	-	0.08 kg/s	-	-	5, 7.5 and 10 g/s	-	-	-

Gunnasegaran, et al [8]. The experimental results were verified by FEM using 3D model based on the heat transfer by conduction. The thermal performance of a two-phase closed thermo-syphon heat pipe using MgO/water nanofluid carried by Tayfun Menlik, et al [9]. Triton X-100 nonionic surfactant was used in the study. The nanofluid was filled up to 33.3% (44.5 ml) the volume of heat pipe operating under 200 W, 300 W and 400W heat input. The experiments were performed with three different flow rates of cooling water (5, 7.5 and 10 g/s). Also, thermal performance comparison was made of between nanofluids with nanoparticles of MgO and Al2O3. They suggested that nanofluid with 26% concentration at 200 W heating power and 7.5 g/s flow rate has effective performance. A Brusly Solomon, et al [10] did numerical analysis of a screen mesh wick heat pipe with Cu/water nanofluid by solving the mass, momentum and energy equations. The liquid and vapor velocities of the heat pipe charged with 0.1 wt% of Cu-water nanofluid is found to be 20% higher when compared with that of the heat pipe with DI water at the same operating conditions. It is also observed that the decreased pore size of the wick due to the addition of nanoparticles increases the effective thermal conductivity of the wick structure. Ping-Yang Wang, et al [11] investigated the thermal performance of an inclined miniature mesh heat pipe using water-based CuO nanofluid as the working fluid. Effects of the inclination angle and the operating temperature on the heat transfer performance of the heat pipe using the nanofluid with the mass concentration of CuO nanoparticles of 1.0 wt% were found. The Experimental results shows that the inclination angle of 45◦ corresponds to the best thermal performance for heat pipes using both water and the nanofluid. Thermal performance of a miniature loop heat pipe (mLHP) using water-copper nanofluid which has an average particle size of 50 nm (dia) was studied by Zhenping Wan [12]. Reductions of 12.8% and 21.7% are achieved in the evaporator wall temperature and total thermal resistance, respectively. Also, the heat transfer coefficient (HTC) of the evaporator increases 19.5% when substituting the nanofluid with 1.0 wt% of deionized water at a heat load of 100 W.

III. EXPERIMENTAL SETUP

The heat pipe is mounted on a platform with changeable tilt angle [2, 5]. Thermal couples are installed to measure the temperatures at different points. Evaporator section is made up of said material in Table 1 which has electric heater, provided with fixed heating power. There is a cooling water passage at condenser section, allowing the external thermostatic device to provide cooling water at fixed temperature. The heat pipes have their vacuum pumped out, and are charged with nanofluids of different charge amounts as discussed in literature and weight fractions. Many researchers has calculated the ratio of removed energy of cooling water by condenser section to the heating power by evaporator section with different charge amounts, weight fraction of nanoparticle, and tilt angle of heat pipe, the effects of thermal efficiency under different experimental parameters has been evaluated.

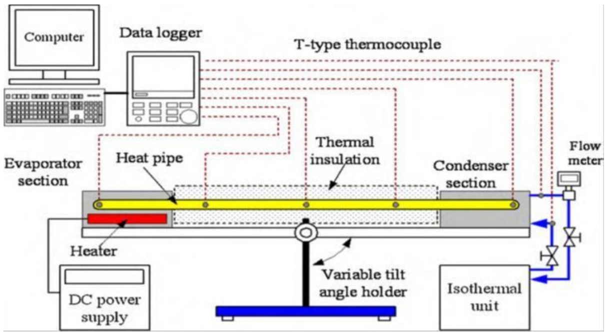


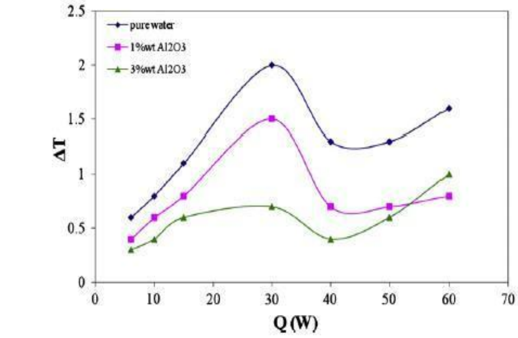
Figure: Experimental Setup

IV. NANOFLUID PREPARATION

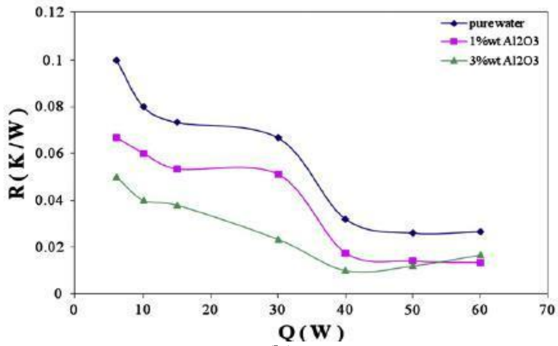
Spherical aluminum oxide nanoparticles (with 35–45 nm nominal diameter, density 3.88 g/cc) were utilized. Al_2O_3 nanoparticles were produced by using a catalytic chemical vapor deposition method. The mixture was created by using an ultrasonic homogenizer [1]. Silver in DI-water nanofluid was produced by a chemical method which consists of reduction of Ag ions. Various concentrations of 50, 200 and 600 ppm have been produced and utilized in the heat pipe in this investigation. No surfactant was used [2]. The nanofluid was dispersed for several times by ultrasonic vibrator and electromagnetic agitator. The Al_2O_3 nanofluid formed was added with cationic dispersant (0.3 wt% of chitosan) in order to obtain good suspension [3]. CNTs fabricated to 95% purity by chemical steam deposition. MWCNTs were dissolved in 50 mL of distilled water with variable volumetric ratios of 0.001e0.1%. After processing the solution, 2 h was required to disperse the nanoparticles in the water using an ultrasonic dispersion unit [6]. To stabilize the suspension against sedimentation of nanoparticles, use of ultrasonic processor, addition of surfactant and change the PH value of the nanofluid were used. Magnesium oxide was produced by means of calcinations of magnesium carbonate. MgCO3 is very cheap mineral due to the extensively present in the world. The purity of 99.9% MgO was supplied from Merck. The size of the MgO particles were reduced and the particles were refined to a uniform particle size prior to any further processing via Spex-8000 ball milling [9]. Nanofluid samples were prepared by dispersing Cu nanoparticles with mean diameter of 50 nm in deionized water. The dispersion was carried out using magnetic stirring for 30 minutes followed by ultrasonic vibration for 4 hours to ensure proper mixing of nanoparticles into the base fluid. For a better dispersion, some amount of sodium dodecyl benzene sulfonate (SDBS) was added to the nanofluid samples [10].

V. RESULT ANALYSIS AND DISCUSSION

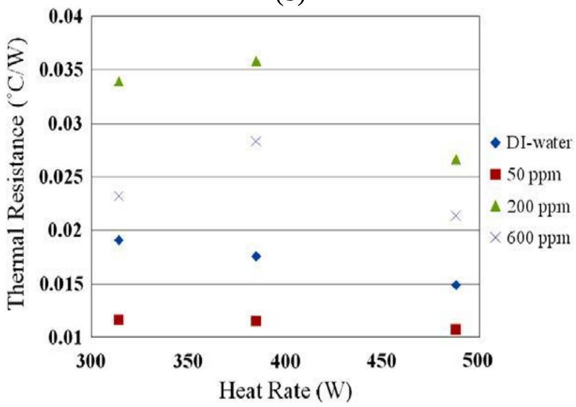
A. Effect of nanoparticle concentration



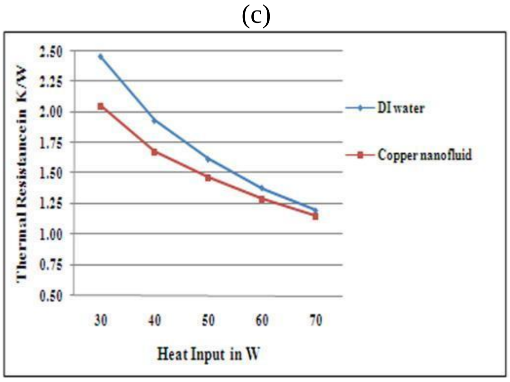
(a)



(b)



(c)

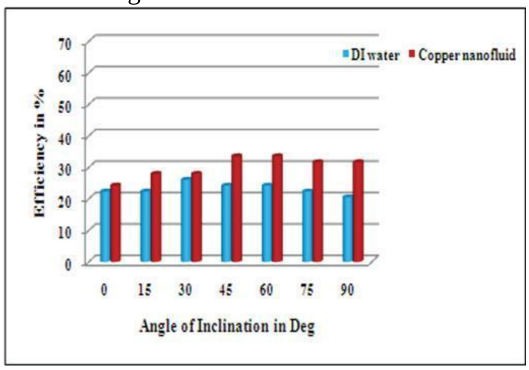


(d)

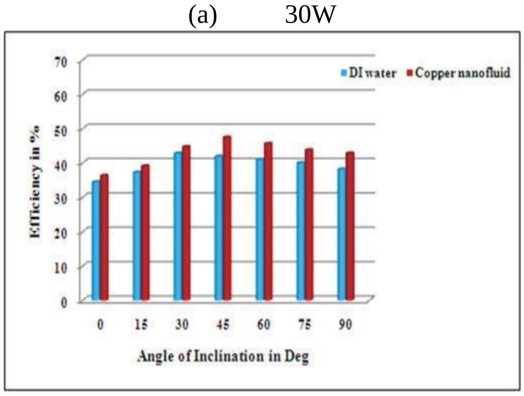
Fig. 1 Effect of nanoparticle concentration

Fig 1 (a) shows the influences of the nanoparticle concentration level on the temperature difference of the heat pipe under various input powers. It can be seen that by increasing the nanofluid concentration, the temperature difference decreased. Improvement in the value of vapor and rate of transnational speed between condenser and evaporator results in an increase and then sudden decrease in temperature difference with increase in heat load. Fig 1 (b) shows the effect of the nanofluid concentration on the thermal resistance of heat pipe versus heat pipe heat load. Since, the nucleation size of the vapor bubble is much smaller for the fluid with suspended nanoparticles than the fluid without nanoparticle, increasing the nanoparticle concentration decreases the heat pipe thermal resistance [1]. Fig 1 (c) shows that aluminium oxide with 50 ppm nanofluid has the best steady state thermal performance so that it made about 30% decrease in the heat pipe thermal resistance at 488 W, compared to DI-water. But 200 ppm and 600 ppm nanofluids did not enhance the heat pipe performance [2]. Effect of copper nanoparticles over thermal resistance with the concentration of 100 mg/lit were used in horizontally (0°) oriented heat pipe [5] are shown in Fig. 1
(c).

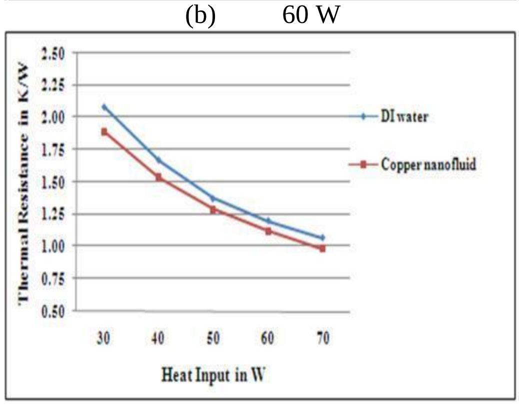
A. Effect of angle of inclination



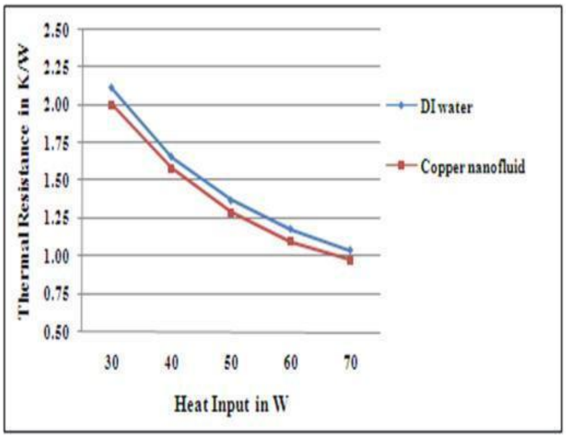
(a) 30W



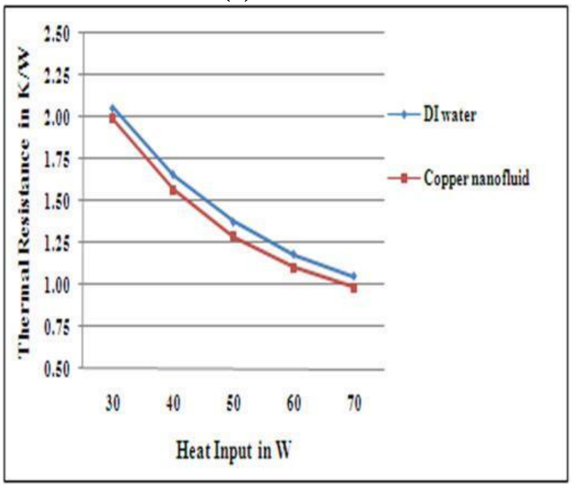
(b) 60 W



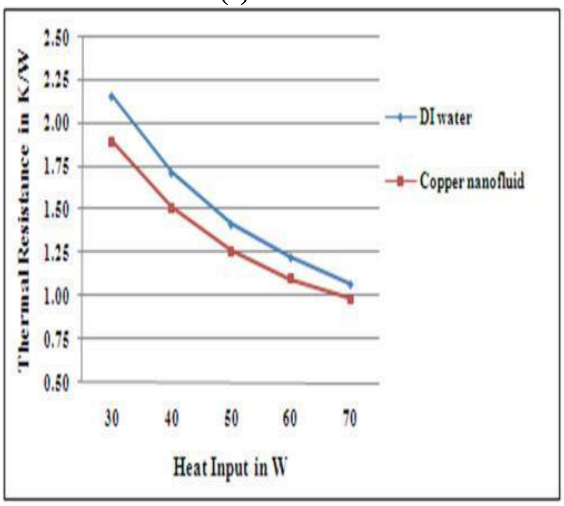
(c) 0°



(d) 60°



(e) 70°



(f) 90°

Fig. 2 Effect of angle of inclination of heat pipe

It is clear, as shown in Fig. 2 (a, b) for heat input 30W, 60W respectively, the thermal efficiency of heat pipe increases with increasing values of the angle of inclination up to 30° for DI water and 45° for copper nanofluid with respect to the horizontal position of the heat pipe. Further, when the angle of inclination of heat pipe exceeds 30° for DI water and 45° for copper nanofluid, the heat pipe thermal efficiency starts to decrease from its value. It is found that the thermal efficiency of the heat pipe enhances about 10% when copper nanofluid is used as a working fluid than the DI water. It is clear, as shown in Fig. 2 (c, d, e, f) with inclination 0°, 60°, 75°, 90°, respectively, the thermal resistance of heat pipe decreases for both the working fluids with increasing values of angle of inclination and the heat input. At low heat input, the thermal resistance of both the heat pipes is high because of the relatively solid liquid film that resides in the evaporator section.

B. Response time of Heat pipe

Response time of the heat pipe is an appropriate characteristic to study its transient behavior and performance. The midpoint of the adiabatic section, is the best point, since, due to its distance from evaporator and condenser, it is less affected by any possible impulse from evaporator or condenser than the other points and hence its temperature variation shows the state of the heat pipe operation, i.e. transient or steady. Based on the temperature variation of middle point and by using the Eq. (1), the response time is plotted against the heat rate for various working fluids, in Fig.3

$$T_{RT} = 0.9\,(T_F - T_i) + T_i \quad \text{............ (1)}$$

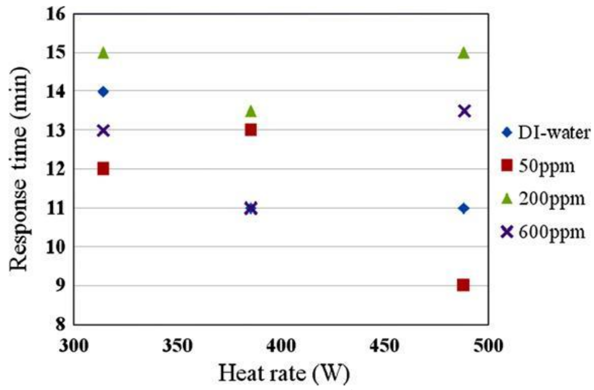


Fig.3 Response time of the heat pipe

It is clear that the heat pipe with 50 ppm nanofluid had better performance than the other fluids so that its response time, at higher heat rates, was about 20% less than what the heat pipe with DI-water demonstrated. No surfactant was used [3] to investigate only effects of pure nanofluids. Thus, van der Waals forces among nanoparticles made them to conglomerate or cluster, stick to the wick and deposit, partially. The consequence of such phenomena is the variation of nanofluid concentration during the time which may result in some irregularities [3].

VI. CONCLUSION

This paper describes the research results of heat transfer characteristics of various types of heat pipes using nanofluids as working fluids. Results of the limited number of available references have shown that nanofluids have great application prospects in various heat pipes. Adding nanoparticles to the working liquid

can significantly enhance the heat transfer, reduce the total heat resistance and increase the maximum heat removal capacity. At the same time, there are still some problems and challenges on the mechanisms of the heat transfer enhancement and the actual applications. The present research of nanofluids in heat pipes is still at its initial stage and needs further development.

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