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A Review on Effects of NANO Fluids on Thermal Performance of Heat Pipes

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Abstract - Research in heat transfer using suspensions of nanometer sized solid particles in base liquids started over the past decade. The addition of the nano particles to the base fluid is one of the significant issues to enhance the heat transfer of heat pipes. This review article provides information for the design of heat pipes with optimum conditions to study the heat transfer characteristics of nanofluids in heat pipes.

Index Terms – *Heat pipes, Nanofluids, Thermal Efficiency, Thermal Resistance.*

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I. INTRODUCTION

Heat pipes are used in several applications, where one has limited space and the necessity of a high heat flux. It is used in space applications as well as it is used in heat transfer systems, cooling of computers, cell phones and cooling of solar collectors. They constitute an efficient, compact tool to dissipate substantial amount of heat from various engineering systems including electronic components. Heat pipes are capable to dissipate substantial amount of heat with a relatively small temperature drop along the heat pipe while providing a self-pumping ability due to an embedded porous material in their structure. A limiting factor for the heat transfer capability of a heat pipe is related to the working fluid transport properties. In order to overcome this limitation, the thermo physical properties of the fluid can be improved..

Fluids with nanoparticles suspended in them are called nanofluids; a term proposed by Choi in 1995 of the Argonne National Laboratory, U.S.A. Nanofluids can be considered to be the next generation heat transfer fluids as they offer exciting new possibilities to enhance heat transfer performance compared to pure liquids. Nanofluids are prepared by suspending nano sized particles (1-100nm) in conventional fluids and have higher thermal conductivity than the base fluids. They are expected to have superior properties compared to conventional heat transfer fluids, as well as fluids containing micro-sized metallic particles. The larger relative surface area of nanoparticles improves heat transfer capability [1].

Based on the applications, nanoparticles are made out of variety of materials. In general there are four types of nanomaterials: Carbon based nanomaterials (eg: Carbon nanotubes), Metal based nanomaterials (metal oxides such as aluminium oxides), Dendrimers (nanosized polymers) and Composites (nanosized clays). Nanofluids clearly exhibit improved thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficient. The property change of nanofluids depends on the volumetric fraction of nanoparticles, shape and size of the nanomaterials.

TABLE 1
Thermal conductivity of some materials, base fluids and nanofluids [2].

	Materials	Thermal Conductivity (W/k)
Metallic material	Copper	401
	Silver	429
	Silicon	148
	Alumina (Al_2O_3)	40
Carbon	Carbon nano tubes (CNT)	2000
Base fluids	Water	0.613
	Ethylene glycol (EG)	0.253
	Engine oil (EO)	0.145
Nano fluids (nanoparticle concentration %)	Water/ Al_2O_3 (1.50)	0.629
	EG/ Al_2O_3 (3.00)	0.278
	EG. water/ Al_2O_3 (3.00)	0.382
	Water/TiO_2(0.75)	0.682
	Water/CuO(1.00)	0.619

A. Preparation of Nanofluids

Preparation of nanofluids is the first key step in experimental studies with nanofluids. Nanofluids are produced by dispersing nanometer-scale solid particles into base liquids such as water, ethylene glycol (EG), oils, etc. To prepare nanofluids by suspending nanoparticles into base fluids, some special requirements are necessary such as even suspension, durable and stable suspension, low agglomeration of particles and no chemical change of fluid. There are three general methods used for preparation of stable nanofliud: (1) Addition of acid or base to change the pH value of suspension (2) Adding surface active agents and/or dispersants to disperse particles into fluid (3) Using ultrasonic vibration. These methods can change the surface properties of the suspended particles and can be used to suppress the formation of particle clusters in order to obtain stable suspensions. The use of these techniques depends on the required application of the nanofluid [1]. A summary of preparation process of nanofluids used by different researchers is shown in table.

Table 2
Preparation methods of different nanofluids [2]

Sr.no.	Nanofluid	Method	Surfactant	Stability
1.	Al_2O_3-water	Two step	No	24hrs
2.	TiO_2	Two step	Oleic Acid and CTAB	
3.	Cu-Water	Two step	Laurate salt	30hrs
4.	MWCNT-Water	Two step	SDS	
5.	Ag-Water	Two step	No	24hrs

The single-step direct evaporation approach was developed by Akoh, called VEROS (Vacuum Evaporation onto a Running Oil Substrate) technique. In this technique, it was difficult to separate the nano particles from the fluid. The two step method is extensively used in the synthesis of nanofluids considering the available commercial nanopowders supplied by several companies. In this method, nanoparticles was first produced and then dispersed in base fluids. Generally, ultrasonic equipment is used to intensively disperse the particles and reduce agglomeration of particles. This method can be used to prepare Al_2O_3 nanofluids. As compared to the single-step method, the two-step technique works well for oxide nanoparticles, while it is less successful with metallic particles.

Except for the use of ultrasonic equipment, some other techniques such as control of pH or addition of surface active agents are also used to attain stability of the suspension of the nanofluids against sedimentation. These methods change the surface properties of the suspended particles and thus suppress the tendency to form particle clusters [1].

B. Heat Pipes

Heat pipes are effective heat transfer devices with a phase transformation of an intermediate heat medium in a closed cycle (evacuated tube). Heat pipes are used due to their ability to achieve high thermal conductance in steady state operations and are known as super thermal conductors. As seen in Figure 1 heat pipes are composed of three sections: evaporator (hot part), condenser (cold part) and an adiabatic section, where vapour and liquid circulates between evaporator and the condenser.

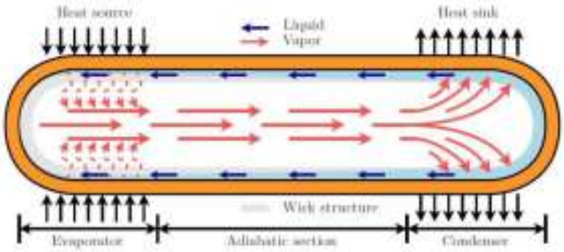

Figure 1: Schematic diagram of heat pipe [3].

The figure illustrates the heat pipe as a closed tube where the inner surface is lined with a wick or a porous material that is filled with liquid near its saturation temperature. The liquid in the wick and the open vapour corridor is separated by a vapour-liquid interface, which is found in the inner surface of the wick. Heat pipe characteristics are dependent upon size, shape, material construction, working fluid and heat transfer rate. The operational characteristic of a heat pipe is defined by heat boundaries, effective thermal conductivity and temperature difference.

Nanofluids are used in heat pipes in order enhance the thermal efficiency of the heat pipe and they are evaluated by their effect on the thermal efficiency. The thermal efficiency represents the ratio of heat rejected at the condenser section and the heat input at evaporator section. Recently, many researchers have presented the heat transfer characteristics of heat pipe using nanofluids.

II. LITERATURE REVIEW

The objective of this paper is to present an overview of literature dealing with recent developments in the study of heat transfer using nanofluids in heat pipes.

R. Reji Kumar et.al, [4] experimentally investigated effects of using Al_2O_3-DI (De-ionized) water nanofluid on the heat transfer performance of heat pipe. A copper tube was used for test section with an internal diameter of 20.8 mm and external diameter of 22 mm. Aluminium oxide of 0.1% mass concentration was used. The properties of the nanofluid are average particle size=50 nm, density=3800 kg/m3, thermal conductivity=40 W/mK, specific heat=773 J/kgK. The heat pipe was tested for various angle of inclination, different fill ratio and for different heat inputs. The results were recorded for the thermal performances of the cylindrical heat pipe under various operating parameters. The temperature gradient along the heat pipe axis increases with increase in heat input and the temperature difference across the condenser and evaporator section is larger.

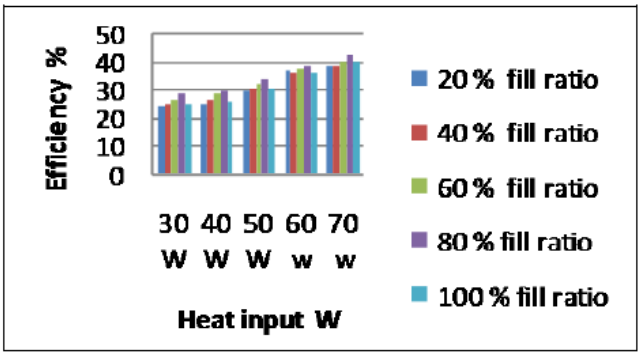

Figure 2: Efficiency for different fill ratio and heat input at 0°inclination.

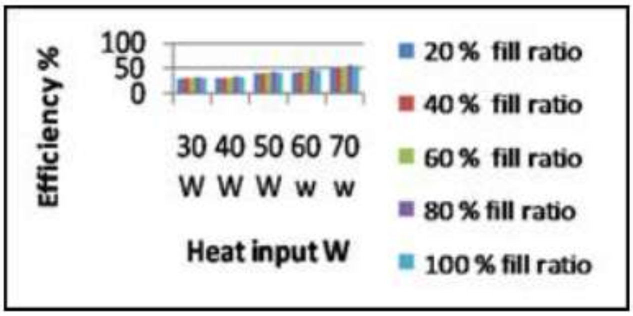

Figure 3: Efficiency for different fill ratio and heat input at 30° inclination.

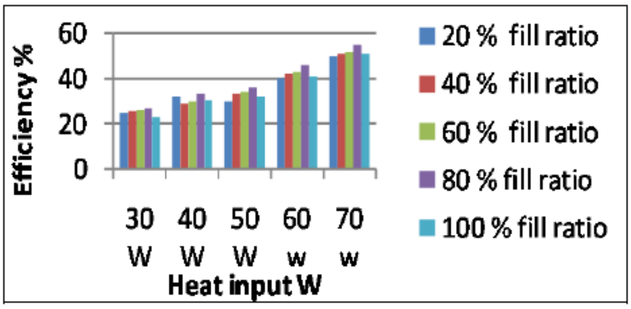

Figure 4: Efficiency for different fill ratio and heat input at 90° inclination.

It can be seen from figure 2, 3 and figure 4 that the thermal efficiency of the heat pipe increases when the fill ratio increases and reaches the maximum value when the fill ratio is 80% and shows a decline in efficiency for further rise in fill ratio.

Senthilkumar R et al [5] experimentally demonstrated the improvement in thermal performance of heat pipe using copper nanofluid with aqueous solution of n-Butanol. Heat pipe of copper container and the stainless steel wrapped screen is used as a wick material. The copper nanofluid with a size of 40 nm and the aqueous solution of copper nanofluid prepared by adding the 2 ml/lit of n- Butanol is used as working fluid. The concentration of copper nanofluid in the DI water is 100 mg/lit. The results concluded that the thermal efficiency of heat pipe increases about 10% with copper nanofluid as a working fluid when compared with the DI water. Besides, the heat pipe which uses copper nanofluid with aqueous solution of n-Butanol increases the thermal efficiency to nearly about 15% as compared that of DI water due to the positive surface tension gradient possessed by n-Butanol. From Figure 5, 6 and 7 it has been observed that the efficiency of heat pipe increases with increasing values of the tilt angle.

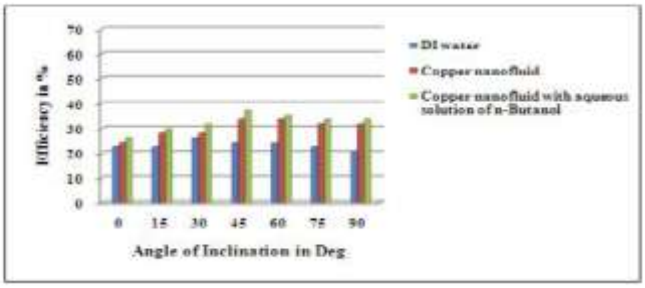

Figure 5: Efficiency of different fluids at 30W heat input for various inclinations.

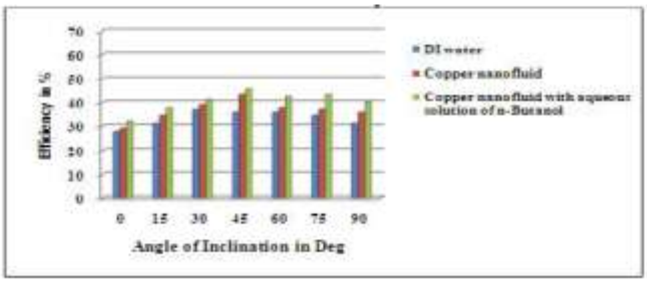

Figure 6: Efficiency of different fluids at 50W heat input for various inclinations.

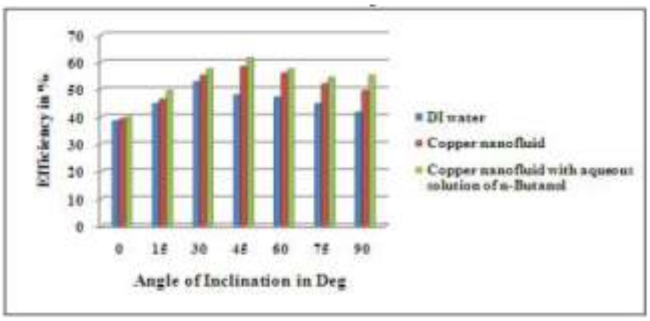

Figure 7: Efficiency of different fluids at 70W heat input for various inclinations.

Wang et al. [6] performed an experiment concerning an inclined miniature mesh heat pipe. The working fluid was 50nm-CuO/ DI-water nanofluid that prepared by oscillating CuO nanoparticles for 10 h in an ultrasonic water base without any surfactant. The length, outer diameter and wall thickness of the heat pipe were 350 mm, 8 mm and 0.6 mm, respectively. The evaporator section, adiabatic section and condenser section of the heat pipe were 100 mm, 100 mm and 150 mm long, respectively. They showed the existence of an optimal concentration of 1.0 wt% for all inclination angles that takes a balance between the capillary force and the flow drag force. They observed that the thermal performance of an inclined miniature mesh heat pipe can be strengthened with increasing nanoparticles loading in the base fluid up to an optimum concentration.

Asirvatham et al. [7] experimentally investigated the effects of using silver water nanofluid on the heat transfer performance of a heat pipe and showed a substantial reduction in thermal resistance of 76.2% and an enhancement in the evaporation heat transfer coefficient of 52.7% for 0.009% silver nanofluid. Their results demonstrated that the use of nanoparticles enhances the operating range of heat pipe by 21% compared with that of DI (De-Ionized) water.

Saleh et al. [8] experimentally showed that the temperature distribution and the thermal resistance decreased with the increasing volume concentration and the size of the ZnO nanoparticles for a conventional screen-mesh wick heat pipe. In their experiment, ZnO nanoparticles were synthesized using a co-precipitation method and were dispersed in ethylene glycol at concentrations from 0.025 to 0.5 vol.% and also the as-synthesized ZnO particles had average crystallite sizes of 18 or 23 nm.

Senthilkumar et al. [9] discussed about the thermal efficiency enhancement of the heat pipe based on the ratio of cooling capacity rate of condenser fluid at the condenser section and the supplied power at the evaporator section. Experimental procedure was repeated for different heat inputs (30, 40, 50, 60 and 70 W) and different inclinations (0°, 15°, 30°, 45°, 60°, 75° and 90°). The evaporator temperature was controlled at a temperature of 30°C. The following conclusions can be drawn from this study: (a) by using nanofluid as working fluid in the evaporator section, the temperature of the working medium increases and hence more amount of heat can be removed in the condenser section. (b) The thermal efficiency of the heat pipe enhances about 10% when copper nanofluid is utilized as the working fluid. (c) The heat pipe thermal efficiency increases with increase in inclination of the heat pipe up to 30° for DI water and 45° for copper nanofluid. It is attributed to the fact that the heat transfer rate increases with an increase in inclination angle by using nanofluid because of the increase in domination of gravitational forces. The authors stated that the higher rate formation of liquid film inside the condenser at larger inclination angles led to the increase of the thermal resistance.

III. CONCLUSION

This paper presents an overview about heat transfer characteristics of different nanofluid in heat pipes. From above experimental studies and references it can be concluded that for different fill ratio with varying heat input, the thermal efficiency of the heat pipe varies. From figure 2 and 3, it is seen that for 70W heat input and zero degree inclination the fill ratio is 80% with efficiency around 40%. Similar condition but with inclination 30 degree the efficiency is around 50%. Hence, here it can be concluded that with increase in inclination with same input conditions the efficiency increases. Whereas from figure 3 and 4, it is seen at 70W heat input, 80% fill ratio the efficiency remains around 50%, no further increase is observed. Here we can conclude that efficiency of heat pipe for the given conditions it maximum at 30degree inclination.

Also graph figure 5, 6 and 7 shows that at 30W, 50W and 70W heat input, for different fluids the efficiency varies. For 0° inclination at any heat input the thermal efficiency of all fluids used is minimum, but gradually increases as the angle of inclination is increased till 45° of inclination. Thereafter, thermal efficiency decreases with increase in angle of inclination. Hence we can conclude that the efficiency of heat pipe not only depends on the filling ratio of the working fluid but also on the volume concentration of the fluids. Further theoretical and experimental investigations are needed to understand the heat transfer properties of nano fluids in heat pipes also optimum concentration of nano particles in nanofluids.

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