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Review on Thermal Performance of Two-Phase Closed Thermosyphons Using Nanofluids

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ABSTRACT

A relatively new way for utilizing the thermal performance of heat pipes is to use nanofluids as working fluids in the heat pipes. Heat pipes are effective heat transfer devices in which the nanofluid operates in the two phases, evaporation and condensation. The heat pipe transfers the heat supplied in e.g. a laptop, from the evaporator to condenser part. Nanofluids are mixtures consisting of nanoparticles (e.g. nano-sized copper oxide particles) and a base fluid (e.g. water). The aim of this paper has been to examine the effect of nanofluids on heat pipes on the subject of temperature parameters and thermal resistance in the heat pies, through findings in literature and an applied model. The study, based on literature and an applied model, found that higher particle conductivity and higher concentration of nanoparticles consequently decrease the thermal resistance in the heat pipes, resulting in an enhanced thermal performance of the heat pipes with nanofluids as working fluids. It is however concluded that difficulties in finding the optimal synthesis of nanofluids, the concentration level of nanoparticles and the filling ratio of nanofluids in heat pipes, set bounds to the commercial use of nanofluids in heat pipes. It is suggested that, in order to enhance the heat transfer performance of nanofluids in heat pipes, to conduct further research concerning e.g. synthesis of nanofluids and concentration level of nanoparticles in nanofluids.

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I. INTRODUCTION

1.1 Heat pipe description

Heat pipes are effective heat transfer devices with a phase transformation of an intermediate heat medium in a closed cycle (evacuated tube). The two phases: evaporation and condensation are used to transfer the heat supplied e.g. from a processor. Heat pipes are used due to their ability to achieve high thermal conductance in steady state operations (Bozorgan and Bozorgan, 2013).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 (Heat pipe, 2010).

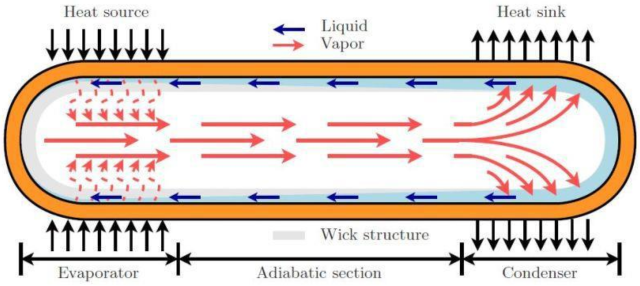

Figure 1: Technical description of a heat pipe (Heat pipe, 2010)

The general heat pipe transfers heat efficiently between two solid interfaces using capillary forces generated by a wick and a fluid as seen in Figure 1. The heat is transported at high rate (with two phase heat transfer) with temperature drop and does not require any external pumping power. Thus, heat pipes have two distinct advantages. First, it does not require an external source to circulate the working fluid. Second, the two phase heat transfer occurs with one-two order of magnitude higher heat transfer coefficient than that of a single phase heat transfer (Reay and Kew, 2007a, b).

Figure 1 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. Heat pipes have been used in controlling the temperature of vehicles and space units (Chi, 1976). Furthermore they are used in innovation intensive hard ware applications as for instance laptops and game consoles (Heat pipe, 2010).

The incremental effect of nanofluids in heat pipes

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 (Senthilkumar et al., 2011). The considered parameters of thermal efficiency are the following (Naphon et al., 2008):

i) Charge amount of working fluid
ii) Tilt angle of heat pipe
iii) Volumetric concentration of nanoparticles
iv) Thermal resistance
v) Temperature gradient

1.2 Morphology of nanoparticles

Morphology is by biologists describes as the study of the size, shape and structure of organisms and the relationship of the parts including them (Britannica, 2014).

Research done by Li et al. has shown that nanofluids with smaller nanoparticles enhance the thermal conductivity. In this particular experiment aluminum nanoparticles of diameter 36 and 47 nm were used in the same base fluid. Experiments were performed between the temperature 27 - 37% witch volume fractions between 0.5 - 6%. The result was an 8% higher thermal conductivity for nanofluids with the 36 nm particles i.e. the smaller particles (Sankar et al., 2012).

The influence of shape was first studied by Xie et al., who reported changes in thermal conductivity of a silicon carbide (SiO_2) nanofluid based on whether spherical or cylindrical nanoparticles were used (Xie et al., 2002). In another research, conducted by Murshed et al., the application of spherical and rod-shaped titanium oxide (TiO_2) nanoparticles showed that rod-shaped particles enhance the thermal conductivity (Behi and Mirmohammadi, 2012).

The structure of nanoparticles can be evaluated by the specific surface area (SSA), which states the relationship between the surface area and volume of the particle (Rice University, SSA). Xie et al., has in research declared that a higher SSA of nanoparticles enhances the thermal conductivity of the nanofluid (Xie et al., 2002). The SSA is related to the pH value of the nanofluid. An increasing difference in pH from the isoelectric point induces hydration forces among the particles. This results in a higher SSA and mobility of the particles which both increase the thermal conductivity (Das et al., 2007a, b, c, d and e).

Table 1: Thermal conductivity of different solids and liquids (Das et al., 2007a, b, c, d, e)

Solid/Liquid	Material	Thermal Conductivity (W/mK)
Metallic solid	Silver	429
	Copper	401
	Aluminum	237
Non-metallic solids	Diamond	3300
	Carbon nanotubes	3000
	Silicon	1458
	Aluminum oxide	40
Metallic liquids	Sodium @ 644K	72,3
Non-metallic liquids	Water	0,613
	Ethylene glycol	0,253
	Engine oil	0,145

II. LITERATURE REVIEW

Moraveji et al. studied the effects of aluminum oxide (Al_2O_3) and water-based nanofluids in heat pipes. The experiment was based on a straight copper tube with an outer length of 8 and 190 mm and a 1mm wick-thickness sintered circular heat pipe. Three working fluids were used: pure water and water-based aluminum oxide with volumetric concentration of 1 and 3%. Furthermore the heat load varied from 5 to 60 W. The essential findings are referred to two effects (Keshavarz Moraveji and Razvarz, 2012): a) the temperature difference between evaporator and condenser in relation to heat load and b) the thermal resistance of the heat pipe in relation to heat load. Concerning effect a) Moraeveji et al. concluded that higher volumetric concentrations of aluminum oxide resulted in smaller temperature differences up to heat loads of 52 W. With higher heat load than 52 W, the temperature difference of 1% aluminum oxide turned out to have the smallest temperature difference, while pure water constantly had the highest temperature difference. All working fluids also present the same sequential behavior with increased heat load: increasing temperature difference, sudden decrease in temperature difference and another cycle of increased temperature difference. This behavior depends on the improved rate speed between condenser and evaporator and the fraction of vapor in the process (Keshavarz Moraveji and Razvarz, 2012).

The incremental decrease of thermal resistance was negligible for heat loads higher than 40 Watt for all three working fluids: pure water, 1% and 3% aluminum oxide based water. In fact, there was also a notable anomaly in regard to the 3% concentration of Aluminum oxide. A decrease in temperature difference between evaporator and condenser with increasing heat input to critical point was observed in the findings of Moraveji et al. The temperature decrease of aluminum oxide was identified as smaller than that of the base fluid. Moraveji et al. also concluded that increased nanoparticle concentration resulted in decreased thermal resistance ensuring an improved thermal performance (Keshavarz Moraveji and Razvarz, 2012).

Research conducted by Senthilkumar et al. on a copper heat pipe is based on three variable parameters: inclination of heat pipe to the horizontal axis, heat inputs and concentration of nanoparticles. The maximum thermal efficiency, approximately 60%, is obtained at 45º angle of inclination, at maximum heat input of 70 W and with the 100 mg/lit concentration of copper nanoparticles. The highest concentration of 125 ml/lit did not outperform due to the fact of resistance to the fluid flow caused by the nanoparticles Notably, the thermal efficiency of 50 mg/lit nanofluid is higher or equal to the thermal efficiency of 125 mg/lit nanofluid at all heat inputs and angle of inclinations. Consequentially, this has positive economic and environmental outcome, with less nanoparticles performing overall better than more. The most effective nanofluid of 100 mg/lt has an incremental increase in thermal efficiency of less than 5% at 70 W input and 45º angle of inclination. This increase does not differ much at other heat inputs and inclinations (Senthilkumar et al., 2013).

Naphon et al. evaluated the thermal efficiency of various volumetric concentrations at the optimum of 45º angle of inclination. Due to the suspension of nanoparticles the overall thermal efficiency increased with the nanoparticle concentration. The volumetric concentration of 0.1% titanium nanoparticles in pure alcohol (base fluid) resulted in the highest thermal efficiency of approximately 80% at heat flux of 7.27kW / m^2. Compared with pure alcohol the incremental thermal efficiency enhancement is 10.5% (Naphon et al., 2008).

Teng et al. conducted comparable research to Moraveji et al. and came to the conclusion that nanofluid of aluminum oxide weight fraction 1% at inclination 60º and charge amount 20% had the highest thermal efficiency with 79.3%. Analogous to experiments by Naphon et al., the higher concentration of aluminum oxide nanoparticles with 3% wt. (weight percent) resulted in fact in a lower thermal efficiency reaching 75.6%, due to reduced convection performance at the evaporator section (Teng et al., 2010).

Research by Asirvatham et al. showed the that thermal conductivity of silver based nanofluid increased with 42.4%, 56.8% and 73.5% respectively for 0.003%, 0.006% and 0.009% volumetric concentration. Additionally a 76 % decrease in thermal resistance is observed for the 0.009% volumetric concentration. The authors declared three reasons for the heat transfer enhancement. First, an increased thermal conductivity due to the silver nanoparticles. Second, the coating layer formed on the wick and heating surface by the nanoparticles that improved the heat transfer effect. Third, the occurrence of Brownian motion due to silver and distilled water particles collision (Asirvatham et al., 2013).

Research conducted by Kang et al. focused on heat pipe temperature distribution and thermal resistance as parameters of thermal efficiency. Experiments on heat loads 30W, 40W, 50W and 60W with 10 nm nanoparticles reveal that the highest temperature gradient decrease from the base fluid (water) occurred when nanofluids with 50 ppm concentration were applied. However the highest incremental decrease of temperature gradient occurred when going from base fluid to the 1ppm nanofluid concentration, shifting from 41.06º to 40.56º at the same position with 30W heat-load (Kang et al., 2006). The application of 35 nm nanoparticles revealed analogous results in temperature gradient variations for the same concentrations and heat loads, implying that there is no significant difference in using 10 nm to 35 nm nanoparticles at given heat loads concerning temperature gradients (Kang et al., 2006).

Tsai et al. applied gold nanoparticles of diameters 2-75 nm by reducing adjusted amounts of the materials: aqueous hydrogen tetrachloroaurate with trisodium citrate and tannic acid. The nanoparticles were then added to distilled water (base fluid) at four different synthesis conditions of the materials mentioned. The thermal resistance of the base fluid and nanofluid during various heat inputs were evaluated on thermal performance. Distilled water obtained an average thermal resistance of 0.27ºC/W compared to nanofluid of condition (0.2ml trisodium citrate, 2.5ml tannic acid and 3ml tetrachloroaurate) with an average thermal resistance of 0.17ºC/W. That corresponds to a 37% decrease in thermal resistance (Tsai et al., 2004).

Shafahi et al., performed experiments on a cylindrical heat pipe using three different nanofluids at various concentrations consisting of water and aluminum oxide (Al_2O_3), copper oxide (CuO) and titanium oxide (TiO_2) nanoparticles The heat pipe was exposed to different heat inputs for exploration of thermal resistance; temperature gradient and maximum heat transfer limits (Shafahi et al., 2010b). The thermal resistance was studied under heat load varying from 200W to 800W for all three nanofluids at four different concentrations. The study reveals that increasing concentrations of nanoparticles result in decreasing thermal resistance, implying a better thermal performance. Copper oxide particles had throughout the biggest effect on thermal resistance reduction, accounting for 75% reduction with a 4% concentration. At the same concentration level aluminum oxide and titanium oxide particles accounted for a 77% and 86% reduction respectively. The temperature gradient changes were studied with up to 4% particle concentration. The results reveal an incremental decrease of end to end temperature gradient (evaporator to condenser) with 5% for nanoparticles aluminum oxide and titanium oxide, while copper oxide account for a 3% decrease (Shafahi et al., 2010b). It is notable that the temperature difference between evaporator and condenser increases with bigger nanoparticle diameter implying that smaller sized nanoparticle are more effective. That corresponds to the findings of Li et al. The experimental results of Shafahi et al. also reveal that there for every nanofluid exist a maximum heat transfer capacity at a given concentration level. A continues increase of concentration after reaching given levels in fact decreases the heat transfer. The optimum concentration level was found to be approximately 5 %, 15 % and 7 % for aluminum oxide, copper oxide and titanium oxide respectively (Shafahi et al., 2010b).

The model applied in this report is based on the mathematical model of Shafahi et al. for investigating the thermal performance of cylindrical heat pipes using nanofluids (Shafahi et al., 2010b). However, the model applied in this report is an overall simplification of realistic heat pipe functions with focus on nanofluids impact for solely temperature parameters (T_e, T_a, T_c, and $T_{difference}$) and thermal resistance.

Table 2: Descriptive summary of experiments on effect of nanofluids on thermal performance of heat pipes

Year	**Researcher**	**Heat pipe description**	**Working fluid**	**Effect on thermal performance**
2012	Moraveji et.al	Straight copper tube with length 8 and 190 mm, 1mm wick-thickness sintered circular tube	Al_2O_3 0%, 1% and 3 % wt	Increase with higher %wt of nanofluid
2013	Senthilkumar et al.	Copper with legth 600mm, outer diameter 20mm and stainless steel wick	Copper nanoparticles of size 40 nm	Increments up to 100 mg/lit concentration
2008	Naphon et al.	Copper tube with length 600mm and diameter 15mm	Titanium nanoparticles of size 21nm	Thermal efficiency enhancement is 10.5 %
2010	Teng et al.	Straight copper tube with length 600mm and diameter 8mm	Al_2O_3 0%, 1% and 3 % wt	Aluminum oxide weight fraction 1% at inclination 60 ℃ and charge amount 20% had the highest thermal efficiency with 79.3%.
2013	Asirvatham et al.	Straight copper tube with length 180mm and diameter 10mm	Silver nanoparticles of average size 58.35nm	Thermal conductivity of silver based nanofluid increased with 42.4%
2006	Kang et al.	211 microm wide and 217 microm deep grooved circular heat pipe. Outer diameter 6mm and length 200mm	Silver nanoparticles of size 10 nm and 35nm	The highest incremental decrease of temperature from 41.06 ℃ to 40. 56 ℃
2003	Tsai et al.	Straight copper tube with length 170 mm and diameter 6 mm	Aqueous hydrogen tetrachloroaurate ($HAuCl_4$) Variying Particle size from 2 to 75nm.	37 % decrease in thermal resistance
2009	Shafahi et al.	Cylindrical heat pipe with total length 890mm and inner radius 9.4 mm.	Al_2O_3, CuO and TiO_2	The optimum concentration level were found to be approximately 5 %, 15 % and 7 % for aluminum oxide, copper oxide and titanium oxide respectively

III.CONCLUSIONS

This paper describes the review 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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