Performance Evaluation of Heat Pipe using Nanoparticals: A Review

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Abstract : This paper present a review of the performance evaluation of a heat pipe charged with solid nanoparticals mixed to water as a working fluid. The Aim of this review paper is to Analysis of the important published paper on the enhancement of the thermal performance of heat pipe using nanofluid. The most common nanoparticals, namely Al_2O_3 ,CuO, and TiO_2 are considered as a working fluid, by many authors. The nanoparticals within the liquid enhance the thermal performance of the heat pipe by reducing the thermal resistance while enhancing the maximum heat load it can carry. The thermal performance of heat pipe is investigated at different heat inputs by varying nanofluid concentration as well as tilt.

Keyword: Performance evaluation, nanoparticals, thermal resistance, heat load.

I. INTRODUCTION

For the past many years, two-phase passive heat transfer devices like heat pipes and thermosyphons have played an important role in a variety of engineering heat transfer systems, ranging from electronics thermal management to heat exchangers and reboilers. In this context, the present scenario of high thermal loading coupled with high flux levels demands exploration of new heat transfer augmentation mechanisms besides the conventional techniques. 'Nanofluids' are fast emerging as alternatives to conventional heat transfer fluids. Although recent studies have shown some conflicting trends with regards to their thermo-hydrodynamic behaviour, there are enough indications that exploratory research is indeed required to bench mark the scope and applicability of these fluids in engineering systems [4]. The heat pipe was first invented in 1942 by Rechard S. Gauler a General Motor Engineer. Heat pipes are efficient heat transfer devices with small temperature drops along the length of the heat pipe. The heat transport capacity of the heat pipe is controlled by the thermo-physical properties of working fluids [14]. The common types of heat pipes primarily include as: Two-Phase Closed Thermosyphon (TPCT) heat pipes, Pulsating Heat Pipes (PHPs) and Oscillating Heat Pipes (OHPs) [17]. A heat pipe is an excellent heat conductor, one end of a heat pipe is the evaporation section and the other end is the condensation section. When the evaporation section is heated, the liquid in the heat pipe evaporates rapidly. This vapor releases its heat at the condensation section, which has a small vapor pressure difference, and condenses back into liquid. The condensed liquid in the condensation section then flows back to the evaporation section along the inner wall of the heat pipe and undergoes endothermic evaporation in the evaporation section. The heat transfer of a heat pipe uses a working fluid that changes phases in a continuous endothermic and exothermic cycle, giving the heat pipe excellent heat transfer performance [17]. Heat pipes are used extensively in various applications, for achieving high rates of heat transfer utilizing evaporation and condensation processes. Heat pipes have been used in spacecrafts, computers, solar systems, heat and ventilating air conditioning systems and many other applications [15]. Heat pipes have been used in various applications, including Air-Conditioning Systems, the cooling of Electronic components, Thermal storage, and Solar Heating systems [17].

In recent times, there has been an urgent need in many industrial fields for a new cooling medium with significantly improved heat transfer performance compared to those currently available and it is also well known that fluids typically have lower thermal conductivity compared to crystalline solids. Therefore, fluids containing suspended solid particles can be reasonably expected to have higher thermal conductivities than pure fluids. The idea of using nanofluids, defined as liquids with nanometer-sized particle suspensions, was first introduced by Choi in 1995. It has been shown that when solid nanometer-sized particles are suspended in fluid, the enhancement of thermal conductivity can be significant. This enhancement can improve the efficiency of fluids used in heat transfer applications [18]. Nanofluid is a stable solid-liquid suspension created by mixing of nanoparticles with the traditional working fluid. The nanoparticles in the heat pipe nanofluid include metal particles Diamond and Oxide particles [17]. Different nanoparticles such as Gold, Silver, Diamond, Alumina, Titanium, Copper oxide, Nickle oxide and Iron oxide have been utilized with in thermosyphons and Heat pipe as a working fluid [12].

II. LITERATURE REVIEW

The following literature review describes important research results regarding the nanofluids used in heat pipes:

Cao et al. [1997] reported the results of fabricating and testing two flat miniature heat pipes using electro discharge machining (EDM) to create grooved wicking channels. The longitudinal grooves with widths of 120 μm and 100 μm and height of 250 μm were formed into the surface of the top and bottom copper plates. The method of assembly was not stated, but it was most likely welded. The completed heat pipes were cleaned with an unspecified solution, evacuated to 8x10-4 tore, and then charged with water using the syringe method. K type thermocouples were distributed along the length to determine the temperature distribution. Heat was input at different levels ranging from about 5 to 30 Watts. The condenser was cooled with water at temperatures ranging from 60ºC to 95ºC. The results are presented as the ratio of effective thermal conductivity of the heat pipe to the theoretical performance of copper with equivalent dimensions (assuming k_{Cu}=380 W/m·K). Based on the total cross sectional area, the ratio K_{eff}/K_{Cu} was in the range of 50. Using the vapour space only, the ratio of K_{eff}/K_{Cu} was in the range of 150. The devices were also tested vertically with gravity assistance where the evaporator was located on the bottom and the performance was improved as expected [3].

Wang et al. (1999) measured the effective thermal conductivity of nanofluids by a steady-state parallel-plate technique. The base fluids (water, ethylene glycol (EG), vacuum pump oil and engine oil) contained suspended Al_2O_3 and CuO nanoparticles of 28 and 23 nm of average diameters, respectively. Experimental results demonstrated that the thermal conductivities of all nanofluids were higher than those of their base fluids. Also, comparison with various data indicated that the thermal conductivity of nanofluids increases with decreasing particles size [4].

Lee et al. (1999) suspended CuO and Al_2O_3 (18.6 and 23, 6 nm, 24.4 and 38.4 nm for them, respectively) with two different base fluids: water and ethylene glycol (EG) and obtained four combinations of nanofluids: CuO in water, CuO in EG, Al_2O_3 in water and Al_2O_3 in EG. Their experimental results showed that nanofluids have substantially higher thermal conductivities than the same liquids without nanoparticles. The CuO/EG mixture showed enhancement of more than 20% at 4 vol% of nanoparticles. In the low volume fraction range (<0.05 in test), the thermal conductivity ratios increase almost linearly with volume fraction. Although the size of Al_2O_3 particle is smaller than that of CuO, CuO-nanofluids exhibited better thermal conductivity values than Al_2O_3-nanofluids; no explanation is available for this observation at this time [5].

Xuan and Li et al. (2000) enhanced the thermal conductivity of water using Cu particles of comparatively large size (100 nm) to the same extent as has been found using CuO particles of much smaller dimension (36 nm). An appropriate selection dispersants may improve the stability of the suspension. They used oleic acid for transformer oil–Cu nanofluids and laurate salt for water–Cu suspension in their study and found that Cu particles in transformer oil had superior characteristics to the suspension of Cu particles in water [6].

Wang and Vafai et al. [2000] built and tested a relatively large 19 x 14 x 3.5 cm copper flat plate heat pipe shown in Figure 1.16. Sintered copper powder served as wicking structure lining the case and connecting the top and bottom surfaces. The pore radius was 31μm at 50% porosity and a permeability of 7x10-12 m2. A 14 x 6 cm flexible heater was placed on the top centre and condenser regions existed on the sides adjacent to the heater and on the bottom surface. Thirty thermocouples lined the top and bottom surface and were bonded inside a groove with high thermal conductivity cement. The main objective of this work was to determine the condensation heat transfer coefficient experimentally and to introduce a time constant to describe the transient start-up response of a heat pipe. Over a range of heat fluxes from 0.02 W/cm^2 to 0.2 W/cm^2, the condensation coefficient was constant at about 12.4 $W/m^2 \cdot K$. It was also found that the external temperature of both the evaporator and condenser increased linearly with increasing power input. Finally, it was found that the largest thermal resistance could be found in the wick and that it increased significantly at higher heat loads [7].

Das et al. (2003) in their investigation on pool boiling of Alumina-Water nanofluids in horizontal narrow tubes (4 and 6.5mm in Diameter), observed that in narrow tubes the deterioration in boiling performance was less as compared to larger diameter tubes which made the narrow tubes less susceptible to local overheating in convective applications. The main reason attributed to the behaviour of nanofluids was the difference in bubble sliding mechanism in the case of narrow tubes [9].

Xuan and Li (2003) experimentally investigated flow and convective heat transfer characteristics for Cu–water based nanofluids through a straight tube with a constant heat flux at wall. Results showed that the nanofluids give substantial enhancement of heat transfer rate compared to pure water. They also claimed that the friction factor for the nanofluids at low volume fraction did not produce extra penalty in the pumping power [10].

Xuan et al. (2004) measured the performance of a flat plate heat pipe under different heat fluxes, orientations and amount of the working fluid. Effects of charge amount of the working fluid, thickness of the sintered layer, and orientation of the heat pipe on the performance were discussed [11].

Vassallo et al. (2004) confirmed that the CHF increases for nanofluids (silica–water). They conducted experiments for both nano- and micro-solutions at the same solid volume fraction on a 0.4 mm diameter horizontal NiCr wire at the atmospheric pressure. The heat transfer enhancement was not found in the nucleate boiling regime, but the CHF was increased significantly for both nano- and micro-particles. Addition of nanoparticles resulted in a maximum heat flux of about three times that of pure water and almost twice that of micro-particle/water mixture [12].

Zhou (2004) investigated experimentally the heat transfer characteristics of copper/acetone based nanofluids with and without acoustic cavitations. Results showed that the copper nanoparticles and acoustic cavitation had significant influence on heat transfer in the fluid. However, the addition of nanoparticles did not affect the dependence of the heat transfer on acoustic cavitation and fluid sub-cooling [13].

Wen and Ding (2005) also addressed the problem of natural convective heat transfer of TiO_2 (30–40 nm)/water nanofluids in a vessel which was composed of two horizontal aluminum discs of diameter 240 mm and thickness 10 mm separated by a 10 mm gap. They investigated both the transient and steady heat transfer coefficients for various concentrations of nanofluids[14].

Murshed et al. (2005) studied the thermal conductivities of both rod-shaped and spherical-shaped TiO_2 nanoparticles dispersed in de-ionized water using a transient hot wire technique. Their results demonstrated that the thermal conductivity was influenced by the volume fraction as well as the shape and size of the particles. From the above literature, it is evident that fluids containing nanoparticles have substantially higher thermal conductivities than their base fluids [15].

Bang and Chang (2005) studied the boiling heat transfer using Al_2O_3–water nanofluids on a horizontal smooth surface. They showed that nanofluids have poor heat transfer coefficient as compared to pure water in natural convection as well as in nucleate boiling. They also reported enhancement in CHF in both, horizontal and vertical pool of liquid [16].

Kang et al. (2006) investigated the thermal performance of a micro-grooved circular heat pipe charged with the silver nanofluid, and significant reductions in the thermal resistance and the evaporator temperature of the Heat pipe were detected when using the silver nanofluid instead of distilled water. In addition, the thermal efficiency of heat pipe could also be improved after using nanofluids [17].

Heris et al. (2006) presented the experimental results of the convective heat transfer of CuO/water and Al_2O_3/water nanofluid inside a circular tube with constant wall temperature. It was emphasized that, the increase in the convective heat transfer coefficient due to the presence of nanoparticles was much higher than the prediction of single-phase heat transfer correlation using nanofluid effective properties. However, the Al_2O_3/water nanofluid showed higher enhancement when compared to CuO/water [18].

Heris et al. (2006) investigated laminar flow of CuO/water and Al_2O_3/water nanofluids through a 1 m annular copper tube with 6 mm inner diameter and with 0.5 mm thickness and 32 mm diameter outer stainless steel tube, where saturated steam was circulated to create constant wall temperature boundary condition rather than constant heat flux condition by other researchers. Comparison of experimental results showed that the heat transfer coefficient enhanced with increasing volume fraction of nanoparticles as well as Peclet number while Al_2O_3/water showed more enhancement [19].

Liu et al. (2006) investigated the thermal conductivity of copper–water nanoflu- ids produced by chemical reduction method. Results showed 23.8% improvement at 0.1% volume fraction of copper particles. Higher thermal conductivity and larger surface area of copper nanoparticles are attributed to this improvement. It is also noted that thermal conductivity increases with particles volume fraction but decreases with elapsed time [20].

Nguyen et al. (2007) experimentally investigated on the behaviour and heat transfer enhancement of a particular nanofluid flowing inside a closed system for a cooling of the electronic components. For a particular nanofluid with 6.8% particle volume concentration, heat transfer coefficient increased as much as 40% compared that of the base fluid [21].

Mujumdar et al. (2007) have summarized recent research on fluid flow and heat transfer characteristics of nanofluids in forced and free convection flows and identified opportunities for future research. Convective heat transfer can be enhanced passively by changing flow geometry, boundary conditions, or by enhancing thermal conductivity of the fluid. Various techniques have been proposed to enhance the heat transfer performance of fluids. Alumina ($A_{l2}O_3$) and copper oxide are the most common and inexpensive nanoparticles used by many researchers in their experimental investigations. All the experimental results had demonstrated the enhancement of the thermal conductivity by addition of nanoparticles [22].

Yang et al. (2008) carried out an experiment to study the heat transfer performance of a horizontal micro-grooved heat pipe using CuO nanofluids as working fluids. Mass concentration of CuO nanoparticles having the average diameter of 50 nm and the operating pressure vary from 0.5 wt% to 2.0 wt% and from 7.45 kPa to 19.97 kPa, respectively. The experimental results showed that CuO nanofluids can improve the thermal performance of the heat pipe. Under an operating pressure of 7.45 kPa, the heat transfer coefficients of the evaporator can be averagely enhanced by 46% and the CHF can be maximally enhanced by 30% compared with those of the heat pipe using DI water [23].

Qu et al. (2008) reported a modeling study on the effect of a functional surface with the axial ladder contact angle distribution on the thermal performance of a triangular micro heat pipe. Their modeling shows that a micro heat pipe with a functional surface can remove a greater amount of heat under the same condition in comparison with a heat pipe with a uniform contact angle distribution on its surface [25].

Khandekar et al. (2008) has studied the overall thermal resistance of closed two-phase thermosyphon using pure water and various water based nanofluids (of Al2O3, CuO and laponite clay) as working fluids. It was observed that all these nanofluids show inferior thermal performance than pure water. Furthermore, it was found that the wettability of all nanofluids on copper substrate, having the same average roughness as that of the thermosyphon container pipe, is better than that of pure water. A scaling analysis was presented which shows that the increase in wettability and entrapment of nanoparticles in the grooves of the surface roughness cause decrease in evaporator side Peclet number that finally leads to poor thermal performance [26].

Lee et al. (2008) revealed thermal conductivity of nanofluid is affected by pH level and addition of surfactant during nanofluids preparation stage. Better dispersion of nanoparticles is achieved with addition of surfactant such as sodium do decylbenzenesul-fonate. Optimum combination of pH and surfactantleads to 10.7% thermal conductivity enhancement of 0.1% Cu/H_2O nanofluids. Thermal conductivity of ethylene glycol based ZnO nanofluids measured by transient short hot wire technique is found to be increased non-linearly with nanoparticles volume fraction [27].

Kang et al. (2009) made a heat pipe by charging a 1mm wick-thickness sintered circular pipe with Ag/Water nanofluid to study its heat transfer performance. The particle sizes of the added Ag nanoparticles were 10 nm and 35 nm, respectively, and the nanoparticle concentrations were 1 mg/L, 10 mg/L, and 100 mg/L respectively. The heating power of the heat pipe was 30-70 W. The heating power of the nanofluid in the heat pipe was approximately 20 W higher that of de-ionized water. The nanoparticle size has an insignificant effect on heat transfer performance [28].

S.H. Noie et al. (2009) employed a Two – Phase Closed Thermosyphon (TPCT) with Al_2O_3/Water nanofluid as a working fluid and nanoparticle volume concentrations ranging from 1% to 3%. The heat pipe, in this study a made of copper tube with internal diameter of 20 mm, 1 mm thickness and 1000 mm in length. Their experimental results indicate that for different input powers, the thermal efficiency of the TPCT increases up to 14.7% when using Al_2O_3/Water nanofluid instead of pure water [29].

Das et al (2009) had numerically analyzed turbulent flow and heat transfer of three different nanofluids (CuO, Al2O3 and SiO2) in an ethylene glycol and water mixture flowing through a circular tube under constant heat flux condition. They have developed new viscosity correlations for nanofluids as a function of volume concentration and temperature. Computed results are validated with existing well established correlations. It was found that nanofluids containing smaller diameter nanoparticles have higher viscosity and Nusselt number. Heat transfer coefficient of nanofluids increases with increase in the volume concentration of nanofluids and Reynolds number. Pressure loss was observed to increase with increase in the volume concentration of the nanofluids[30].

P. Naphon et al. (2009) used TiO_2/R-11 mixture as a working fluid in a copper tube heat pipe. In this study, the heat pipe is fabricated from the straight copper tube with the outer diameter and length of 15 mm and 600 mm respectively. The found that the heat pipe charged with the TiO_2/R-11 nanofluid of 0.1% nanoparticle concentration operated with the thermal efficiency 1.4 times higher than the heat pipe charged with pure refrigerant(R-11) [31].

Baojin et al. (2009) to compare the heat transfer characteristics of titanium/water two-phase closed thermosyphon with the same geometry of a copper/water thermosyphon. Their results showed that there are no remarkable differences in heat transfer coefficients in the evaporator section between these thermosyphon. However, the observed heat transfer coefficient in condenser of Ti/H_2O thermosyphon was about 2–3 times more than that of Cu/H_2O one [32].

Ho et al. (2010) investigated the forced convective cooling performance of a copper MCHS with an Al_2O_3–water nanofluid; they found that the nanofluid-cooled heat sink had a significantly higher heat transfer coefficient,markedly lower thermal resistance at high pumping powers, and a slightly higher friction factor. Several researchers have performed numerical studies on heat transfer with nanofluids in MCHS (microchannel heat sink) [33].

Wang et al. (2010) investigated the operation characteristics of a cylindrical miniature grooved heat pipe using aqueous cuo nanofluid as the working fluid. They adopted a steady operation process and unsteady start up process. Their result show that the total heat resistance and the maximum heat removal capacity of a heat pipe containing cuo nanofluids decreased by 50 % and increased by 40% respectively, compared with a heat pipe containing water. The CuO nanofluid also significantly reduced the start up time of a heat pipe [34].

Liu et al. (2010) investigated the thermal performance of an inclined miniature grooved heat pipe using cuO/Water nanofluid as the working fluid. They focused on the effects of the inclination angle and the operating pressure on the heat transfer of heat pipe using nanofluid with a 1.0% mass concentration of nanoparticles. An inclination angle (tilt angle) of 45^0 corresponds to the best thermal performance for heat pipes using both water and nanofluid [35].

M. Shafai et al. (2010) studied the thermal performance of a cylindrical heat pipe containing different nanofluids as Al_2O_3, CuO and TiO_2. The nanoparticles in the liquid enhanced the thermal performance of heat pipe by reducing the thermal resistance and enhancing the maximum heat load. Smaller nanoparticles have a more pronounced effect on the temperature gradient along the heat pipe [36].

Do and Jang (2010) developed a mathematical model for quantitatively evaluating the thermal performance of a water-based Al_2O_3 nanofluid heat pipe with a rectangular grooved wick. They considered the effects of the thermophysical properties of nanofluids as well as the surface characteristics formed by nanoparticles such as a thin porous coating on the thermal performance of the nanofluid heat pipe. The model prediction results showed the feasibility of enhancing the thermal performance up to 100% although water-based Al_2O_3 nanofluids with the concentration less than 1.0 Vol. % was used as the working fluid. Also, they concluded that the thin porous coating layer formed by nanoparticles suspended in nanofluids was a key effect of the heat transfer enhancement for the heat pipe using nanofluids [37].

Ji et al. (2011) studied the effects of Al_2O_3 particle size on the heat transfer performance of an oscillating heat pipe (OHP). They studied four particles sizes, with average diameters of 50 nm, 80 nm, 2.2 nm, and 20 nm. Experimental results show that Al_2O_3 particles significantly affect the heat transfer performance of the OHP, and help startup the oscillating motion. When charged with water and 80 nm Al_2O_3 particles, a 6-turn OHP achieves the best heat transfer performance [38].

Humanic and Huminic et al. (2011) adopted Fe_3O_4/Water nanofluids in a TPCT to study the heat transfer characteristics. The TPCT is fabricated from the copper tube with the outer diameter and length of 15 mm, 2000 mm respectively. In this study, two fluid concentrations of Fe_3O_4/Water nanofluids were 2.0% and 5.3% by volume and the Fe_3O_4 nanoparticle had a mean diameter of 4-5 nm. The minimum thermal resistance occurred for a tilt angle of 90^0 at a nanoparticle concentration of 5.3% by volume. The decline rate of thermal performance reached approximately 38% compared with DI water [39].

Qu and Wu et al. (2011) studied the thermal performance of two identical Oscillating Heat Pipes (OHPs) charged with SiO_2/Water and Al_2O_3/Water nanofluid. The mass concentrations of SiO_2 and Al_2O_3 nanoparticles were 0-0.6% and 0-01.2% by weight respectively. In this study, experiments conducted at a volume filling ratio of 50% were performed and compared. Using Al_2O_3/Water nanofluid decreases the thermal resistance by 25.7% and Using SiO_2/Water nanofluid increases the thermal resistance by 23.7% compared with pure water as the OHPs working fluid. The change of surface conditions at the evaporator and condenser caused by different nanoparticle deposition behaviours is the main reason for the thermal performance improvement or deterioration of OHPs charged with different nanofluids [40].

AB Soloman et al. (2012) studied the thermal performance of a heat pipe operated with nanoparticle coated wick. The heat pipe is fabricated from straight copper tube of outer diameter 19.5 mm and length 400 mm respectively. Copper particles with average particle size of 80-90 nm are coated over the surface of the screen mesh. In this study, the thermal performance of the heat pipe is investigated at three different heat inputs as 100W, 150W and 200W respectively. Their experimental results indicate that the total resistance of heat pipe operated with coated wick is lower than that of conventional one and it decreases with increasing heat input. It is found that the decrement in total resistance is 19%, 15% and 14% at heat inputs as 100W, 150W and 200W respectively [41].

Alizad et al. (2012) used flat-shaped heat pipes with CuO, Al_2O_3, and TiO_2 nanofluids to investigate their transient behaviour and operational start-up characteristics. Their results show that a higher concentration of nanoparticles increased the thermal performance of both flat-plate and disk- shaped heat pipes [42].

Hajian et al. (2012) experimentally investigated the thermal resistance and response time of a heat pipe, showing them to be the characteristics of steady states and transient states, respectively. The prepared Ag/DI water nanofluids with various nanoparticle concentrations of 50 ppm, 200 ppm, and 600 ppm at heating rates ranging from 300W to 500W. The thermal and response time of the heat pipe with Ag/DI water nanofluids decreased up to 30% and 20% respectively, compared to a heat pipe with DI water [43].

Yi-Hsuan Hung et al. (2013) studied the enhancement of the thermal performance of a heat pipe charged with Al_2O_3/Water nanofluid. The Al_2O_3/Water nanofluid served as the working with three concentrations as 0.5%, 1.0%, and 3.0% by weight in heat pipes. The heat pipe in this study is a straight copper tube with an outer diameter of 9.52 mm and different lengths of 300 mm, 450 mm, and 600 mm respectively. Their experimental results indicate that at heating power of 40W, the optimal thermal performance for Al_2O_3/Water nanofluid heat pipes measuring 300 mm , 450 mm and 600 mm was 22.7%, 56.3% and 35.1% respectively, better than that of pipes using distilled water as working fluid[44].

Fun LiangChangYew MunHung,(2017) : The dielectric pump performs the best when it covers the entire length of micro heat pipe. Compared to the case without dielectric liquid pumping flow, significant enhancement in the heat transport capacity can be obtained where the maximum enhancement exceeds 220%. Even with a significant performance enhancement, the use of dielectric pump renders a sufficiently small solid wall temperature drop of a micro heat pipe, justifying the typical characteristic of a phase-change heat transfer device.

LiuYangabKaiDua (2017): This review concentrates on heat transfer characteristics of TiO2 nanofluid since it has been considered as one of the closest kinds to the practical application owing to its comprehensive properties such as sensational dispersivity, chemical stability and non-toxicity. At last, this review identifies the challenges and opportunities for the future study. It is expected that this review can provide a comprehensive exhibition of research progress in the heat transfer applications of TiO2 nanofluids.

Vladimir S.AjaevaOleg A.Kabovbc (2017): All of these are discussed, with the main focus on how they influence the interface shapes and heat transfer rates near contact lines. In particular, conditions are identified for attaining very large local heat fluxes. Selected topics related to contact line instabilities and viscous flows with solid particles under conditions of significant evaporation are discussed, followed by an overview of some open questions and possible new research directions.

III. CONCLUSION

1. The heat transfer rate increases in case of the TPCT heat pipes with Iron Oxide nanoparticals as the inclination angle increases [12].

2. The thermal resistance of the TPCT with nanoparticals solution is lower than that with pure water. It is shown that the thermal resistance decreases as the volume concentration increases [12].

3.The thermal efficiency of the heat pipe increases with increasing nanoparticals concentration in the base fluid [14].

4. Nanofluid of all concentrations studied showed better thermal performance than pure water. They improved thermal efficiency of the TPCT [6].

5. The thermal performance of a heat pipe is improved and temperature gradient along the heat pipe and thermal resistance across the heat pipe are reduced when nanofluid are utilized as the working fluid. It is shown that the thermal resistance decreases as the concentration increases or as the nanoparticals diameter decreases [10].

6. The thermal performance of heat pipe is improved and temperature gradient along the heat pipe and thermal resistance across the heat pipe are reduced when nanofluid are utilized as the working fluid [10].

7. The thermal performance of nanofluid is influenced by alteration in the fluid-solid interface dueto presence of nanoparicles [11].

8. The thermal resistance of the TPCT heat pipes decreases with the increase of the inclination angle [11].

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