The Experimental Study of the Thermal Performance of Heat Pipe using nanofluid: A Review

Mangal Singh Lodhi[#1], Prof. R. C. Gupta[#2]

[#1] Research scholar, Fourth Semester , M. E.(Heat Power Engg.)

Department of Mechanical Engineering, JEC Jabalpur(MP),

Gokalpur , Jabalpur(MP)-482011,India

[#2]Associate Professor, Deptt. of Mech. Engg., JEC Jabalpur (MP)

Department of Mechanical Engineering, JEC Jabalpur(MP),

Gokalpur , Jabalpur(MP)-482011,India

ABSTRACT:

This paper presents a review of the thermal performance of a heat pipe charged with solid nanoparticles added to water as a working fluid. The purpose of this review paper is to summarize the important published papers on the enhancement of the thermal performance of heat pipes using nanofluids. The most common nanoparticles, namely Al_2O_3, CuO, and TiO_2 are considered as the working fluid, by many authors. The nanoparticles with in 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 angle.

KEYWORD:

Heat Pipe, Nanofluids, Thermal Performance, Tilt Angle, Fluid Concentrations

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].

LITERATURE REVIEW:

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

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 [1].

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 [2].

Nguyen et al. (2007) experimentally investigated on the behavior 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 [3].

Khandekar et al. (2008) showed that a closed two-phase thermosyphon having the water-based nanofluids as working fluids had inferior thermal performance than the same thermosyphon having pure water as working fluid [4].

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 [5].

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 [6].

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) [7].

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 startup 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 startup time of a heat pipe [8].

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 [9].

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 [10].

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 [11].

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 [13].

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 [14].

Alizad et al. (2012) used flat-shaped heat pipes with CuO, Al_2O_3, and TiO_2 nanofluids to investigate their transient behavior 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 [15].

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 [16].

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 pipes 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 [17].

All the Literature Review are summarized in table-1 given below as:

S. No	AUTHERS	Nano Fluid	Nanoparticle Size	Fluid Concentration	Description of Experimental Setup
1.	Kang et al.(2009)	Ag/Water	10-35 nm	1mg/L,10mg/L,100mg/L	-
2.	S.H. Noie et al.(2009)	Al_2O_3/Water	20 nm	1-3%	ID=20 mm, Length=1000 mm
3.	P. Naphon et al.(2009)	TiO_2/R-11	21 nm	0.1%	OD=15 mm, Length=600 mm

4.	Liu et al. (2010)	CuO/Water		1%	-
5.	Humanic and Humanic et al.(2011)	Fe_3O_4/Water	4-5 nm	0.0%, 2.0%, 5.3%	OD=15 mm, Length=2000 mm
6	Qu and Wu et al. (2011)	SiO_2/Water, Al_2O_3/Water	30nm, 56nm	0-0.6 %, 0-0.12%	OD=3mm, Length=3000mm
7.	A.B. Soloman et al.(2012)	CuO/Water	80-90 nm	-	OD=19.5 mm, Length=400 mm
8.	Hajian et al. (2012)	Ag/DI Water	-	50ppm,200ppm,600ppm	-
9.	Yi-Hsuan Hung et al. (2013)	Al_2O_3/Water	10-30 nm	0.5%,1.0%,3.0%	OD=9.52mm, Length=1350 mm

CONCLUSIONS:

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

2. 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 nanoparticle diameter decreases [10].

3. 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 nanofluids are utilized as the working fluid [10].

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

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

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

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

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

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