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INVESTIGATION ON THERMAL PERFORMANCE OF HEAT PIPE USING NANOFLUID: A REVIEW

Mr.J. S. Atole[1], Prof. V. H. Patil[2], Prof. T. A. Koli[3]

PG Student, Department of Mechanical Engineering, GF's Godavari College of Engineering, Jalgaon, MS, India425002
Asso. Professor, Department of Mechanical Engineering,GF's Godavari College of Engineering, Jalgaon, MS, India425002
Asstt. Professor, Department of Mechanical Engineering, GF's Godavari College of Engineering, Jalgaon, MS, India425002

Abstract: -*Nanofluids have been the subject of intensive study worldwide since pioneering researchers recently discovered the anomalous thermal behaviour of these fluids. Comprehensive research work on heat transfer in heat pipe using nanofluids have been experimentally and theoretically investigated in recent years by various researchers. The suspended nanoparticles effectively enhance the heat transfer characteristics and the transport properties of base fluids in heat pipes. The objective of this paper is to present an overview of literature dealing with influence of various factors such as heat pipe tilt angle, charged amount of working fluid, nanoparticle type, size and concentration, mass/ volume fraction & its effect on the thermal efficiency, heat transfer capacity & reduction in thermal resistance.*

Keywords*: Heat pipe, nanofluid, heat transfer enhancement, thermal performance, thermal resistance.*

1. INTRODUCTION

Heat transfer has been one of the most difficult and inefficient tasks in thermal management. It often results in costly heat transfer losses and reduced overall efficiencies. Heat transfer by heat pipes is one of the fastest and most efficient methods for thermal management. With the advancement in electronics filed, electronics equipment become smarter and smarter with infinite work function ability combined with compactness. With increase in functionality, the rate of heat generation also increases which needs to remove for efficient performance of the electronic equipment. Heat pipes are widely used in the field of electronics cooling due to extremely high effective thermal conductivity as it involves two phase heat transfer. Due to its simplicity in operation and reliability, it has been widely used in other applications such as space, medical and health undertakings, and domestic appliances.

R. S. Gauler of General Motors had patented and recommended the application of capillary-driven heat pipes in 1942, but he did not develop it further. George Grover working at Los Alamos National Laboratory had separately developed and patented the most common configuration of present heat pipe in the year 1963. He was the first to use the term "Heat Pipe". Since then investigators have focused on development of various types of heat pipes and increasing the performance e of heat pipes.

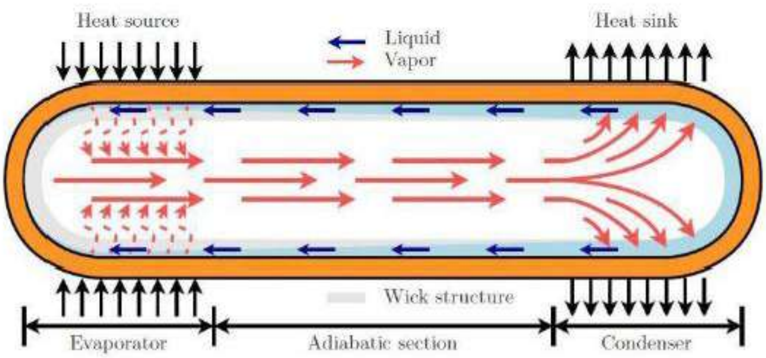


Figure 01. Heat pipe. [16]

The heat pipe consists of three sections viz. (1) evaporator section, (2) adiabatic section and (3) condenser section as shown in figure 01. Heat absorption and rejection takes place in the evaporator and condenser sections respectively. Adiabatic section is completely insulated. Generally, heat pipes are evacuated filled up with the working fluid. At the evaporator section, the working fluid absorbs the heat and evaporated. Evaporated working fluid moves towards the condenser section through adiabatic section. At the condenser section, working fluid releases the heat and gets condensed. Condensed working fluid then returns back to the evaporator section under the action of gravity in case of vertically oriented heat pipe known as thermosyphon. In case other orientation of heat pipe, condensed working fluid returns back to the evaporator section due to the capillary action of different structures at inner wall of heat pipe such as different types of grooves, different types of wire mesh, sintered powder metal and fibre/spring. Normally traditional fluids like water, acetone, methanol, ammonia, or sodium are used in heat pipes to remove the heat. But, now-a –days, non-traditional fluids like nanofluid etc. are also used in the heat pipes to increase the performance of the heat pipe. The performance of heat pipe mainly depends on the various parameters such as (1) type of heat pipe, (2) material of heat pipe, (3) orientation of heat pipe, (4) structure at inner wall of heat pipe, (5) different parameters of structures at inner wall of heat pipe etc.

1.1 Types of heat pipes

There are different type of Heat Pipe depends on the principle of coming back water from condenser to evaporator.

Two-phase closed thermosyphon: A two phase closed thermosyphon is wickless. In this type condenser section is places above the evaporator section and whatever is the base fluid from condenser section that come back into evaporator section by the action of gravity.

Capillary-Driven Heat Pipe: It contains wick type structure. And wick is place on the inner radius of the pipe wall and base fluid return to evaporator through wick structure by the capillary action.

Annular Heat Pipe: It is similar to Capillary-Driven Heat pipe only difference is that cross section of the vapor space in annular heat pipe is annular instead of circular. So, because of increasing surface area the capillary limit is higher in this case.

Many researchers have presented the heat transfer characteristics of heat pipe using nanofluids. The concept of "nanofluid" has firstly proposed by Choi & Eastman. Some steady heat transfer experiments under several steady operation pressures conducted to investigate the heat transfer performance of a cylindrical micro-grooved copper heat pipe. All experiments show that adding nanoparticles into the base liquid can enhance both the heat transfer performance & the maximum input power of heat pipes. Some of the widely utilized nanoparticles such as Al_2O_3, CuO & TiO_2 with a range of nanoparticle diameters were considered. Results show that the presence of nanoparticles in the working fluid reduces the thermal resistance of heat pipe.

1.2 Factors while considering design of heat pipe

1. Working fluid selection.
2. Wick type selection.
3. Container material selection.
4. Determining diameter.
5. Determining thickness.
6. Wick design.
7. Heat sink and source interface design.

2. RATIONALE BEHIND NANOFLUIDS

It is obvious from a survey of thermal properties that all liquid coolants used today as heat transfer fluids exhibit extremely poor thermal conductivity. Thus, it is logical that efforts will be made to increase the thermal conduction behaviour of cooling fluids. Nanofluids shows the great opportunities for improving the thermal conductivity, thermal performance and heat transfer characteristics. Nanofluids are expected to give the following benefits:

1. High heat conduction: - The large surface area of nanoparticles allows for more heat transfer, particles finer more than 20 nm carry nearly 20% of their atoms on their surface, making them instantaneously available for thermal interaction. It is already found that the thermal conductivity of nanofluids increases significantly with a rise in temperature.
2. Stability: - Compared to micrometre sized particles, nanoparticles possess high surface area to volume ratio due to the occupancy of large number of atoms on the boundaries, which make them highly stable in suspensions.
3. Reduced chances of erosion: - Nanoparticles are very small & the momentum they can impart to a solid wall is much smaller. This reduced momentum reduces the chances of erosion of components, such as heat exchangers, pipelines and pumps.

4. Microchannel cooling without clogging: - Nanofluids will not only be a better medium for heat transfer in general but they will also be ideal for microchannel applications where high heat loads are encountered. The combination of microchannel & nanofluids will provide both highly conducting fluids & large heat transfer area.
5. Reduction in pumping power: - To increase the heat transfer of conventional fluid by a factor of two, pumping power must usually be increased by a factor of ten. A very large savings in pumping power can be achieved if a large thermal conductivity increases can be brought about with a small volume fraction of particles.

The above potentials provided the thrust necessary to begin research in nanofluids, with the expectation that these fluids will play an important role in developing the next generation of cooling technology.

3. PREPARATION OF NANOFLUIDS

Choi et al. defined the nanofluids as "an innovative new class of heat transfer fluids that can be engineered by suspending nanoparticles in conventional heat transfer fluids" (Iborra Rubio, 2012)where Nano-sized particles of 1-100 nm were added to base fluids in order to improve performance of heat transfer by significantly enhancing the thermal conductivity of the fluid. The benefits of nanofluids in comparison to microfluids (of micro-sized particles) have been researched and it is found that nanofluids possess longer suspension time, higher thermal conductivity and are more energy efficient. Improving thermal transport properties of nanofluids has been claimed to be vital for obtaining a higher heat exchanging efficiency, cost reduction and reducing the system size (Iborra Rubio, 2012).

The preparation of nanofluid is that the first key step in experimental studies with nanofluids. There are two methods for the preparation of nanofluid i.e. single step and two step methods.

a) Single Step Method

In the single step method, the nanoparticles preparation and nanofluid preparation are carried out simultaneously. The nanoparticles are directly prepared by a physical vapor deposition technique or a liquid chemical method. In this method, agglomeration of nanoparticles is minimized and the stability of the nanofluid is increased as storage, transportation, drying and dispersion of nanoparticles are avoided. However, this method only applicable for small scale production and, at current stage, it is almost impossible to scale up to industrial scale. Furthermore, this method is only applicable for low vapor pressure base fluid which limits its application.

b) Two Step Method

In the two-step method, the nanoparticles manufacturing and nanofluid preparation is separated. Firstly, dry nanoparticles are produced; after which, they are dispersed in a suitable base fluid. This is simpler then single step method as it can easily buy readily available nanoparticles in market and then disperse them in the base fluid. However, it is well known that nanoparticles have a high surface energy which, in turn, leads to aggregation and clustering of nanoparticles and after some time, the particles will clog and sediment at the bottom of container. Partial dispersion may occur in the suspension which cause lower heat transfer enhancement compare to single step method, and hence, high amount of nanoparticles volume fraction is required. This method works well for oxide particle and carbon nanotube; however, it is less successful for metal nanoparticles.

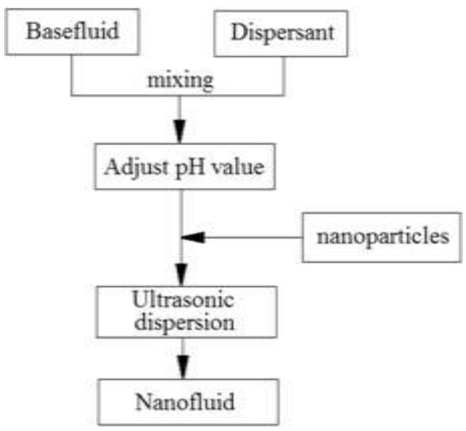


Figure 02: Two step preparation process of nanofluid.

The two-step method is done by producing the nanoparticle powder initially, then disperses them into a host liquid. However, in single step method, the nanoparticles are simultaneously made and directly dispersed into the base fluid. The summary of results reported by various researchers in the area of nanofluid preparation is given in the table below.

System	Synthesis Process	Particle size (nm)	Heat Transfer Enhancement (%)	Ref.
NCTs/Engine oil	Two Step	20-50	30	[2]
NCTs/Poly oil	Two Step	25	16	[3]
NCTs/EG	Two Step	15	19.6	[4]
NCTs/H_2O	Two Step	15	7.0	[4]
NCTs/Decene	Two Step	15	12.7	[4]
H_2O/FC-72	Two Step	9.8	52	[5]
CuO/H_2O	Two Step	33	11.5	[6]
Al_2O_3/H_2O	Two Step	20	20	[7]
TiO_2/H_2O	Two Step	15	30-33	[8]
SiC/H_2O	Two Step	25	15.9	[9]
Ag/toluene	Two Step	60-80	16.5	[10]
Cu/H_2O	Two Step	100	78	[11]
Fe_3O_4/H_2O	Single Step	10	38	[12]
Fe/EG	Single Step	10	18	[13]
Cu/EG	Single Step	10	40	[14]
Cu/H_2O	Single Step	75-100	23.8	[15]

Table 01. Summary of nanofluid preparation methods.

3.1 Parameters affecting thermal conductivity of nanofluids

Figure. 03. illustrated that the parameters affecting the thermal conductivity of the nanofluid are: morphology, temperature, concentration and motion of nanoparticles (Behi and Mirmohammadi, 2012).

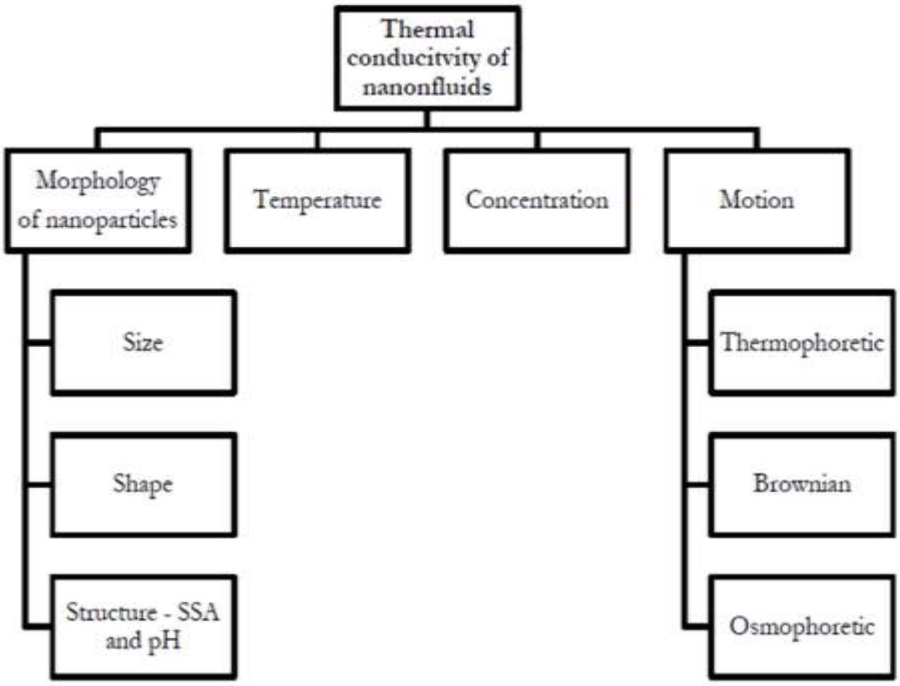


Figure 03: Parameters affecting the thermal conductivity of nanofluids[16]

In Table 02, a synopsis table of the findings, regarding parameters affecting the thermal conductivity of nanofluids, is presented. As can be seen, an increase of a certain parameter has either a positive (+) or negative effect (-) on the thermal conductivity. A negative effect means that the thermal conductivity decreases, while a positive effect means that the thermal conductivity increases.

Parameter	Increase of	Thermal Conductivity
Morphology	Size of particles	-
	Specified Surface Area (SSA)of particles	+
Temperature	Temperature	+
Concentration	Concentration	+
Motion	Thermophoretic	+
	Brownian	+
	Osmophoretic	+

Table 02: Synopsis table of thermal conductivity parameters of nanofluids. [16]

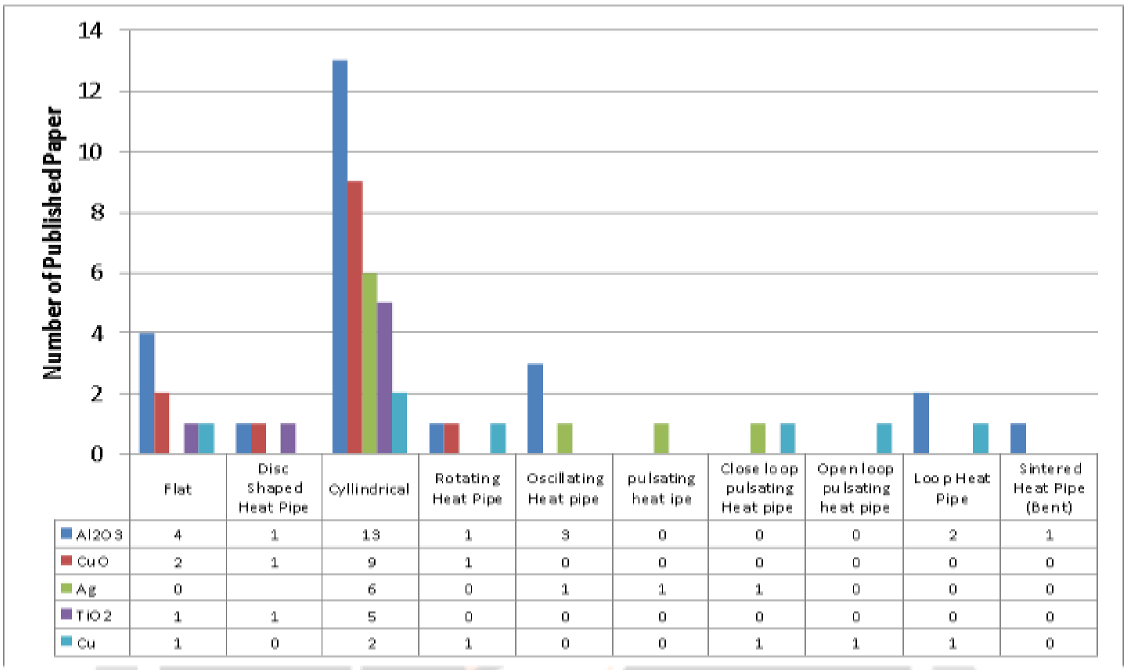
3.2 Nanofluid selection parameters

Selection of working fluid is directly linked to the properties of the fluid. The properties are going to both affect the ability to transfer heat and the comparability with the case and wick material. Below are some things to consider when choosing the working fluid.

- Compatibility with wick and wall materials.
- Good thermal stability.
- Wettability of wick and wall materials.
- Vapor pressures not too high or low over the operating temperature range.
- High latent heat.
- High thermal conductivity.
- Low liquid and vapor viscosities.
- High surface tension.

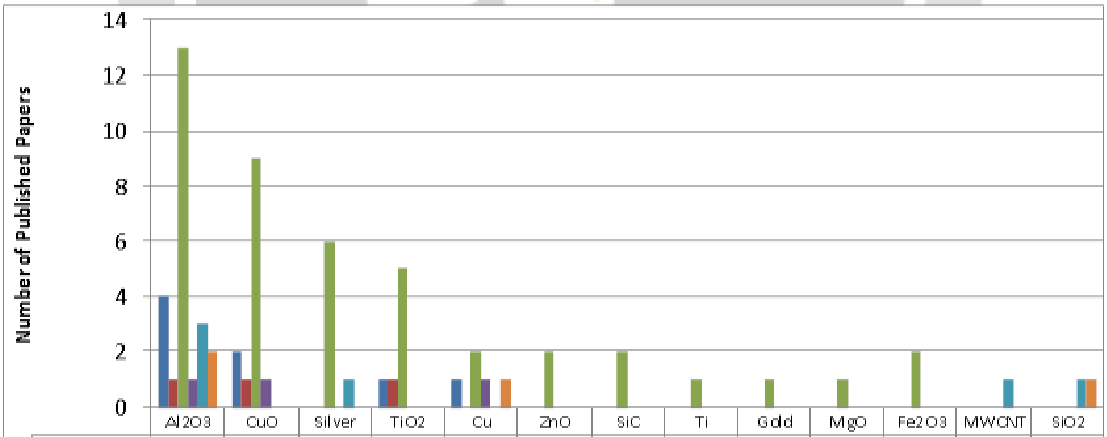
4. FUNDAMENTAL STUDIES OF NANOFLUIDS IN HEAT PIPES

Following figure 04. gives the idea about the number of published paper related to particular nanofluid as working medium and figure 05. gives the idea about the number of published papers related to particular heat pipe.



	Flat	Disc Shaped Heat Pipe	Cylindrical	Rotating Heat Pipe	Oscillating Heat pipe	pulsating heat ipe	Close loop pulsating Heat pipe	Open loop pulsating heat pipe	Loop Heat Pipe	Sintered Heat Pipe (Bent)
Al2O3	4	1	13	1	3	0	0	0	2	1
CuO	2	1	9	1	0	0	0	0	0	0
Ag	0		6	0	1	1	1	0	0	0
TiO2	1	1	5	0	0	0	0	0	0	0
Cu	1	0	2	1	0	0	1	1	1	0

Figure 04. Number of published papers related to particular nanofluid at working medium.



	Al2O3	CuO	Silver	TiO2	Cu	ZnO	SiC	Ti	Gold	MgO	Fe2O3	MWCNT	SiO2
Flat	4	2	0	1	1	0	0	0	0	0	0	0	0
Disc Shaped	1	1		1	0	0	0	0	0	0	0	0	0
Cyllindrical	13	9	6	5	2	2	2	1	1	1	2	0	0
Rotating	1	1	0	0	1	0	0	0	0	0	0	0	0
Oscillating	3	0	1	0	0	0	0	0	0	0	0	1	1
Loop	2	0	0	0	1	0	0	0	0	0	0	0	1

Figure 05. Number of published papers related to particular heat pipe.

4.1. Micro- grooved heat pipe

A cylindrical micro-grooved heat pipe with 6 mm inner diameter & 200 mm length used by Wei et al. [17] The silver nanoparticles with 10 nm average particles size with pure water was considered as working fluid. This research measured the total heat resistance of the heat pipe filled with pure water and nanofluids at the same filling volume of 0.51 mL. Nanoparticle volume fraction of 1 ppm to 100 ppm were used in the tests. The total heat resistance of the heat pipe using nanofluids could decrease by 28% - 44% compared with that of heat pipe using water.

Kang et al.[18]also carried out experiments using nanofluids consisting of silver nanoparticles and pure water. The silver nanoparticle sizes were 10 nm and 35 nm, respectively. The experimental results showed that the total heat resistance of the heat pipe using nanofluids decreased by 10–80% comparing with that using water in the heating power range of 30–60 W. The total heat resistance decreased with the increase in both the nanoparticle concentration and the nanoparticle size.

Zhen-Hua Liu et al. [19] carried out an experimental investigation to study the heat transfer performance of cylindrically micro-grooved heat pipe using aqueous nanofluids as working fluid. Five kinds of nanoparticles were added into base liquid viz. Cu with two mean diameters of 40 nm & 20 nm, CuO with two diameters of 50 nm & 20 nm & SiO with a mean diameter of 30 nm to compose different kinds of nanoparticles size, nanoparticles mass concentration & operating pressures on the evaporation and condensation heat transfer coefficient, the maximum heat flux & the total heat resistance of the heat pipe were investigated. Experimental results show that, adding Cu & CuO nanoparticles into the base fluid can apparently improves the thermal performance of the heat pipe.

Kyu Hyung Do et al. (2010)[20] studied the effects of the water-based Al_2O_3 nanofluids on the thermal performance of heat pipes are experimentally investigated by testing circular screen mesh wick heat pipe using the water-based Al_2O_3 nanofluids with the volume fraction of 1.0 and 3.0 Vol.%. In order to quantitatively evaluate the thermal performance of the heat pipe using the water-based Al_2O_3 nanofluids, the wall temperature distributions and the thermal resistances between the evaporator and the adiabatic sections are measured and compared with those for the heat pipe using DI water. Based on the experimental results it is shown that the utilization of the water based Al_2O_3 nanofluids as the working fluid enhances the thermal performance of the heat pipe.

4.2. Mesh- wick heat pipe

Nandy Putra et al. (2012) [21] done the research on thermal performance of screen mesh wick heat pipes with nanofluids. An experimental investigation was conducted to determine the effect of concentration and type of the nanofluid on the enhancement of thermal performance within a straight copper heat pipe. Under the experimented conditions, the screen mesh wick heat pipe with the best performance was the one with the Al_2O_3–

water nanofluid with 5% volume concentration. Using nanofluids in the heat pipe formed coatings on the screen mesh surface that resulted from the nanoparticles in the fluid. This finding makes nanofluids attractive as working fluids in screen mesh wick heat pipes.

Raghavan Nair Ramachandran et al. (2016) [22] conducted experiment to study the role of hybrid nanofluids in improving the thermal characteristics of screen mesh cylindrical heat pipes. Experiments have been conducted to investigate the performance of heat pipes using various working fluids such as, DI water, Al_2O_3/DI water nanofluid, and (Al_2O_3 50%-CuO 50%)/DI water hybrid nanofluid and (Al_2O_3 25%-CuO 75%)/DI water hybrid nanofluid. It can be seen from the study that the operating temperature of the heat pipe is inversely proportional to the total weight of hybrid nanoparticle in the base fluid and therefore hybrid nanofluid can increase the operating range of heat pipe above 250 W. Experimental results also showed that the thermal resistance of the heat pipe decreases with the use of hybrid nanofluid which in turn increases its effective thermal conductivity by 38.34% for Al_2O_3/DI water, 41.47% for (Al_2O_3 50%-CuO 50%)/DI water, and 79.35% for (Al_2O_3 25%-CuO 75%)/DI water compared base fluid (DI water) for the maximum heat load considered in this study.

Madhusree Kole, T. K. Day (2012) [23] studied thermal performance of screen mesh wick heat pipes using water based copper nanofluids. Thermal conductivity shows an enhancement ofw15% with 0.5 wt% loading of copper nanoparticles at room temperature. Thermal performance of a commercially available screen mesh wick heat pipes with Cu-distilled water nanofluids as the working fluid are investigated for three inclinations (viz. 45°, 60°, and 90°) of the heat pipe. The average evaporator wall temperature of the heat pipe using the nanofluids is reduced compared to those studied with distilled water. Vertical heat pipes are found to perform better than at other inclinations. The average wall temperature of the evaporator (T_e) reduces by w14° C when water is replaced by 0.5 wt.% Cu.

Lazarous Godson Asirvatham et al. (2013) [24] studied heat transfer performance of screen mesh wick heat pipes using silver- water nanofluid. The heat transfer performance of heat pipe using silver–water nanofluid with volume concentrations of 0.003%, 0.006% and 0.009% is experimentally investigated. It is clearly seen that by using silver–water nanofluid, the operating range of heat pipe increases beyond 100Wwhich is the maximum heat transport range for DI water based heat pipe. The dry out condition is observed near 106, 113 and 121W respectively for 0.003, 0.006 and 0.009 vol.% concentrations. It was also observed that the thermal resistance of heat pipe decreases with the use of silver–water nanofluid, which in turn increases the effective thermal conductivity by 42.4%, 56.8% and 73.5% respectively for 0.003, 0.006, 0.009 vol.% concentrations. It was also observed that the evaporation and condensation heat transfer coefficients increase with the increases in the concentration of silver nanoparticles.

4.3. Sintered metal-wick heat pipe

M. Ghanbarpour et al. (2015) [24] studied the effect of silver nanofluid on thermal performance of inclined screen mesh heat pipe in cooling applications. Four cylindrical copper heat pipes containing two layers of screen mesh were fabricated and tested with distilled water and water based silver nanofluids with mass concentrations of 0.25%, 0.5% and 0.75% as working fluids. The experiments were performed at four inclination angles of 0°, 30°, 6° and 90°. The main focus of this study is to investigate inclined heat pipe performance with nanofluid. Experimental results indicate that the thermal performance of heat pipes was improved with nanofluids compared to water and thermal resistance of the heat pipes decreased with the increase of nanoparticle concentration. Moreover, the thermal performance of the heat pipes at inclination angle of 60° is found to be higher than other tested inclination angles, which shows the effect of gravity on heat pipe performance.

Shung-Wen Kang et al. (2009) [25] investigated nanofluids on sintered heat pipe thermal performance experimentally. In this investigation, the thermal performance enhancement of heat pipe indicates nanofluid potential as substitute for conventional pure water in grooved heat pipes and sintered heat pipes. This finding makes nanofluids more attractive as a cooling fluid for devices with high energy density.

4.4. Oscillating heat pipe

Shang et al. [26] experimentally investigated the heat transfer characteristics of a closed loop OHP with a Cu-water nanofluids as the working fluid under different filling ratios & compared found results with DI water as working fluid. Experimental results show that, the use of Cu-water nanofluid in the heat pipe could enhance the maximum heat removal capacity by 83%.

Lin et al. [27]investigated experimentally the thermal performance of a closed loop oscillating heat pipe using nanofluids. They applied water-based silver nanofluids at different volume fractions (100 ppm and 450 ppm) and various filling ratios (20%, 40%, 60%, and 80%). The silver nanoparticle had a diameter of 20 nm. Results showed that the thermal performance of the oscillating heat pipe using nanofluids was better than that using water. The best filling ratio was reported to be 60%.

An experimental investigation was performed by Jian Qu et al. [28] on the thermal performance of an oscillating heat pipe (OHP) charged with base water and spherical Al_2O_3 particles of 56 nm in diameter. The effects of filling ratios, mass fractions of alumina particles, and power inputs on the total thermal resistance of the OHP were investigated. Experimental results showed that the alumina nanofluids significantly improved the thermal performance of the OHP, with an optimal mass fraction of 0.9 wt.% for maximal heat transfer enhancement. Compared with pure water, the maximal thermal resistance was decreased by 0.14 °C/W (or 32.5%) when the power input was 58.8 W at 70% filling ratio and 0.9% mass fraction.

Yulong Ji et al. [29] experimentally investigated the Al_2O_3 particle effect on the heat transfer performance of an oscillating heat pipe (OHP). Average diameter of 50 nm, 80 nm, 2.2 μm, and 20 μmwere studied. Experimental results confirmed that, the Al_2O_3 particles added in the OHP significantly affect the heat transfer performance & it depends on particle size. When the OHP was charged with water & 80 nm Al_2O_3 particles, the OHP can achieve the best heat transfer performance among four particles investigated. It is found that all particles added in the OHP can improve the start-up performance of the OHP even with 20 μm Al_2O_3 particle.

4.5. Two-phase closed thermosyphon

Gabriela Huminic et al. (2011) [30] presents an experimental investigation regarding the use of solid nanoparticles added to water as a working fluid. Tests were made on a thermosyphon heat pipe. The experiment was performed in order to measure the temperature distribution and compare the heat transfer rate of the thermosyphon heat pipe with nanofluid and with DI-water. The iron oxide nanoparticles were obtained by the laser pyrolysis technique. The tested concentration level of nanoparticles is 0%, 2%, and 5.3%. Results show that the addition of 5.3% (by volume) of iron oxide nanoparticles in water presented improved thermal performance compared with the operation with DI-water.

Zhen- Hua Liu et al. (2010) [31] carried an experimental study was performed to investigate the thermal performance of an inclined miniature grooved heat pipe using water-based CuO nanofluid as the working fluid. This study focused mainly on the effects of the inclination angle and the operating pressure on the heat transfer of the heat pipe using the nanofluid with the mass concentration of CuO nanoparticles of 1.0 wt.%. The experiment was performed at three steady sub-atmospheric pressures. Experimental results show that the inclination angle has a strong effect on the heat transfer performance of heat pipes using both water and the nanofluid. The inclination angle of 45° corresponds to the best thermal performance for heat pipes using both water and the nanofluid. The investigation indicates that the thermal performance of an inclined miniature grooved heat pipe can be strengthened by using CuO nanofluid.

5. HEAT TRANSFER CHARACTERISTICS OF NANOFLUIDS IN HEAT PIPE.

5.1. Experimental results

Many researchers have reported experimental studies on the thermal conductivity of nanofluids in heat pipes, thermal resistance & thermal efficiency of heat pipe. The results from all the available experimental studies indicated that nanofluids have substantially higher thermal conductivity than those of base fluids & increase in thermal efficiency of heat pipe.

Zhen- Hua Liu et al. (2012) [32] reviews and summarizes the research done on heat pipes using nanofluids as working fluids in recent years. The research results describe 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. For the majority of micro-grooved heat pipes, mesh wick heat pipes, oscillating heat pipes and most closed two-phase thermosyphon, adding nanoparticles to the working liquid can significantly enhance the heat transfer, reduce the total heat resistance and increase the maximum heat removal capacity.

Naphon et al. [33] investigated the enhancement of heat pipe thermal efficiency with TiO_2 alcohol nanofluids. In this, straight copper tube with outer diameter 15 mm & length 600 mm, the working fluid of heat pipe such as DI water, alcohol & nanofluids are tested. The parameters considered are the effects of percentage charge amount of working fluid, nanoparticle volume concentrations & heat pipe tilt angle on the thermal efficiency of heat pipe. The nanoparticles added with the base fluid have a significant effect on the enhancement of thermal efficiency of heat pipe. The maximum heat pipe thermal efficiency is attained at the optimum condition of 45° tilt angle &

66% charge amount of alcohol. The thermal efficiency of heat pipe is 10.60% higher than the base working fluid with 0.10% nanoparticle volume concentration.

M. G. Mousa [34] experimentally studied the effect of Al_2O_3- water based nanofluid concentration on the performance of a circular heat pipe. The operating parameters considered are working fluid filling ratio, volume fraction of nanoparticles in the base fluid & heat input. Thermal resistance decreases with increasing Al_2O_3-water based nanofluid compared to that of pure water. The results showed that, filling ratio of charged fluid in heat pipe was about 0.45 to 0.50 for both pure water & Al_2O_3- water based nanofluid.

5.2. Theoretical investigation

Maryam Shafahi et al (2016) [35] investigated the thermal performance of cylindrical heat pipe using nanofluids. In the analysis, three different types of water based nanofluids namely Al_2O_3, CuO, and TiO_2 are considered as the working fluid. In this work a reasonable concentration was chosen for different particle sizes & the performance of the cylindrical heat pipe were investigated for different heat inputs. 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 nanofluids are utilized as the working fluid. It is shown that the thermal resistance decreases as the concentration increases or as the particle diameter decreases.

Kyu-Hyung Do et al. [20] numerically investigated the effect of water based Al_2O_3 nanofluid as working fluid on the thermal performance of a flat micro heat pipe with a rectangular grooved wick in their work titled effect of nanofluids on the thermal performance of a flat micro heat pipe with a rectangular grooved wick. The axial variations of the wall temperature & the evaporation and condensation rates are considered by solving the one-dimensional equation for the wall & the augmented Young- Laplace equation for the phase change process. The thin porous coating layer formed by nanoparticles suspended in nanofluids is a key effect of the heat transfer enhancement for the heat pipe using nanofluids.

6. CONCLUSION

This review describes the research results of heat transfer characteristics of various types of heat pipes using nanofluids as working fluids. From the literature results it is concluded that the heat transfer coefficient increases with the increase in heat input & thermal resistance decreases as heat input increases. As the angle of inclination increases, the thermal resistance decreases & the heat transfer coefficient of heat pipe increases. For the majority of micro grooved heat pipes, mesh wick heat pipes, oscillating heat pipes & most closed two- phase thermosyphon, adding nanoparticles to the working liquid fluid can significantly enhance the heat transfer, reduces the total heat resistance & increase the maximum heat removal capacity. Application oriented research in nanofluid is in its infancy & is expected to grow at a faster rate in the future, only this will define the future of nanofluids & its present promises.

REFERENCES

1. Omer A. Alawi, Nor AzwadiCheSidik, H. A. Mohammed, S. Syahrullail, Fluid flow and heat transfer characteristics of nanofluids in heat pipes: A review, International communication in heat & mass transfer 56 (2014) 50-62.
2. Min-Sheng Liu, Mark Ching-Cheng Lin, I-Te Huang, Chi-Chuan Wang, Enhancement of thermal conductivity with carbon nanotube for nanofluids, Int. Commun. Heat Mass Transf. 32 (9) (2005) 1202–1210.
3. S.U.S. Choi, Z.G. Zhang, Wu. Yu, F.E. Lockwood, E.A. Grulke, Anomalous thermal conductivity enhancement in nanotube suspensions, Appl. Phys. Lett. 79 (14) (2001) 2252–2254.
4. HuaqingXie, Hohyun Lee, WonjinYoun, Mansoo Choi, Nanofluids containing multiwalled carbon nanotubes and their enhanced thermal conductivities, J. Appl. Phys. 94 (8) (2003) 4967–4971.
5. Bao Yang, Z.H. Han, Thermal conductivity enhancement in water-in-FC72 nanoemulsionfluids, Appl. Phys. Lett. 88 (26) (2006) (261914-261914).
6. X. Zhang, H. Gu, M. Fujii, Experimental study on the effective thermal conductivityand thermal diffusivity of nanofluids, Int. J. Thermophys. 27 (2) (2006) 569–580.
7. HuaqingXie, Jinchang Wang, Tonggeng Xi, Yan Liu, Fei Ai, Wu. Qingren, Thermal conductivity enhancement of suspensions containing nanosized alumina particles, J. Appl. Phys. 91 (7) (2002) 4568–4572.

8. S.M.S. Murshed, K.C. Leong, C. Yang, Enhanced thermal conductivity of TiO_2-water based nanofluids, Int. J. Therm. Sci. 44 (4) (2005) 367–373.

9. XieHuaqing, Wang Jinchang, Xi Tonggeng, Liu Yan, Study on the thermal conductivity of SiC nanofluids, J. Chin. Ceram. Soc. 29 (4) (2001) 361–364.

10. Hrishikesh E. Patel, Sarit K. Das, T. Sundararajan, A. Sreekumaran Nair, BeenaGeorge, T. Pradeep, Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: manifestation of anomalous enhancement and chemical effects, Appl. Phys. Lett. 83 (14) (2003) 2931–2933.

11. YiminXuan, Qiang Li, Heat transfer enhancement of nanofluids, Int. J. Heat Fluid Flow 21 (1) (2000)58–64.

12. Haitao Zhu, Canying Zhang, Shiquan Liu, Yaming Tang, Yansheng Yin, Effectsof nanoparticle clustering and alignment on thermal conductivities ofFe_3O_4aqueous nanofluids, Appl. Phys. Lett. 89 (2) (2006) (023123-023123).

13. Tae-Keun Hong, Ho-Soon Yang, C.J. Choi, Study of the enhanced thermal conductivity of Fe nanofluids, J. Appl. Phys. 97 (6) (2005) (064311-064311).

14. J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles, Appl. Phys. Lett. 78 (6) (2001) 718–720.

15. Min-Sheng Liu, Mark Ching-Cheng Lin, C.Y. Tsai, Chi-Chuan Wang, Enhancementof thermal conductivity with Cu for nanofluids using chemical reduction method, Int.J. Heat Mass Transf. 49 (17) (2006) 3028–3033.

16. Amir F. (2014). Heat Pipes: Review, opportunities and challenges. Frontiers in Heat Pipe (FHP), 5.

17. Wei-Chiang Wei, Sheng-Hong Tsai, Shih-Yu. Yang, Shung-Wen Kang, Effectofnanofluid concentration on heat pipe thermal performance, IASME Trans. 2 (8) (2005) 1432–1439.

18. Shung-Wen Kang, Wei-Chiang Wei, Sheng-Hong Tsai, Shih-Yu. Yang, Experimental investigation of silver nano-fluid on heat pipe thermal performance, Appl. Therm. Eng. 26 (17) (2006) 2377–2382.

19. Zhen-Hua Liu, Yuan-Yang Li, Ran Bao, Compositive effect of nanoparticle parameter on thermal performance of cylindrical micro-grooved heat pipe using nanofluids, Int. J. Therm. Sci. 50 (4) (2011) 558–568.

20. Do K.H., Jang S.P., Effect of nanofluids on the thermal performance of a flat micro heat pipe with a rectangular grooved wick, International Journal of Heat and Mass Transfer, Vol. 53, 2010, pp. 2183-2192.

21. Nandy P; Wayannataseptiadi (2013). Thermal performance of screen mesh wick heat pipes with nanofluids, Experimental Thermal and Fluid Science, 40, 10-17.

22. Ramachandran R. N., et al.: The role of hybrid nanofluids in improving the thermal characteristics of screen mesh cylindrical heat pipes, Thermal Science, Year 2016, Vol.20, No. 6, pp. 2027-2035.

23. Kole M. &Dey T. K., "Thermal performance of screen mesh wick heat pipes using water – based copper nanofluids. Applied thermal engineering, 2012, (50), 763-770.

24. Asirvatham L.G., Nimmagadda R., Wongwises S., Heat transfer performance of screen mesh wick heat pipes using silver–water nanofluid, International Journal of Heat and Mass Transfer, Vol. 60, 2013, pp. 201-209.

25. M. Ghanbarpour, N. Nikkam, R. Khodabandeh, M. S. Toprak, "Thermal performance of inclined screen mesh heat pipes using silver nanofluid", International Communications in heat and mass transfer, 67 (2015) 14-20.

26. Kang, S., Wei, W., Tsai, S., and Huang, C., 2009, "Experimental Investigation of Nanofluids on Sintered Heat Pipe Thermal Performance," Applied Thermal Engineering, 29(5–6), 973–979.

27. Fumin Shang, Dengying Liu, Haizhen Xian, Yongping Yang, Xiaoze Du, Flow and heat transfer characteristics of different forms of nanometer particles in oscillating heat pipe, J. Chem. Ind. Eng. China 58 (9) (2007) 2200.

28. Yu-Hsing Lin, Shung-Wen Kang, Hui-Lun Chen, Effect of silver nano-fluid on pulsating heat pipe thermal performance, Appl. Therm. Eng. 28 (11) (2008) 1312–1317.

29. Qu. Jian, Wu. Hui-ying, Ping Cheng, Thermal performance of an oscillating heat pipe with Al_2O_3–water nanofluids, Int. Commun. Heat Mass Transf. 37 (2) (2010) 111–115

30. Yulong Ji, Hongbin Ma, Su. Fengmin, Guoyou Wang, Particle size effect on heat transfer performance in an oscillating heat pipe, Exp. Thermal Fluid Sci. 35 (4) (2011) 724–727.

31. Gabriela H, Angel H, Ion M, Florian D (2011). Experimental study of the thermal performance of thermosyphon heat pipe using iron oxide nanoparticles. International Journal of Heat and Mass Transfer, 54, 656-661.

32. Zhen-hua Liu, Xue-fei Yang, Guo-san Wang, Guang-liangGuo, Influence of carbon nanotube suspension on the thermal performance of a miniature thermosyphon, Int. J. Heat Mass Transf. 53 (9) (2010) 1914–1920.

33. Zhen-Hua Liu, Yuan-Yang Li, A new frontier of nanofluid research—application of nanofluids in heat pipes, Int. J. Heat Mass Transf. 55 (23–24) (2012) 6786–6797.

34. Paisarn Naphon, Pichai Assadamongkol, Teerapong Borirak, Experimental investigation of titanium nanofluids on the heat pipe thermalefficiency, Int. Commun. Heat Mass Transf. 35 (10) (2008) 1316–1319.

35. M.G. Mousa, Effect of nanofluid concentration on the performance of circular heat pipe, Ain Shams Eng. J. 2 (1) (2011)63–69.

36. Maryam Shafahi, Vincenzo Bianco, Kambiz Vafai, Oronzio Manca, An investigationof the thermal performance of cylindrical heat pipes using nanofluids, Int. J. Heat MassTransf. 53 (1) (2010) 376–383.

