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Research Article

Heat Transfer Augmentation of Heat pipe using Nanofluids

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Abstract

A new way to enhance the heat transfer rate of heat pipe by going above the already existing heat transfer rate is the use of Nanofluids. This talks about the various researches done on heat pipes with the aid of nanofluids inside it as working fluids. The high impact of characteristics and mass concentrations of nanoparticles on the thermal behaviour and enrichment in various types of heat pipes with various base fluids under number of operating conditions have been studied. In the tested heat pipes the impact of enhancement as well as degradation is explained. A comparative study of the newly designed system with the earlier system by showing the relative degradation is mentioned.

Keywords: *Nanoparticles, nanofluid, heat transfer, thermal conductivity, thermal resistance, volume concentration.*

1. Introduction

A new way of enriching and enhancing the thermal performance is ultimately with the use of nanofluids. Heat pipes are already known for their constructional simplicity and mode of operation in two phases simultaneously in evaporation and condensation respectively. The heat transfer occurs from the evaporator to the condenser part in heat pipes. (E.g. laptop). Nanofluids can be made by using the mixture of nanoparticles with the base fluids (e.g. nano-sized silver particles) (e.g. water, ethyl glycol). The main purpose of this study from literature is to study the effect of nanoparticles on thermal performance of heat pipes and relative decrease in thermal resistance. The outcomes from literature have found that when particle conductivity and concentrations are high in case of nanoparticles there is decrease in the overall thermal resistance of the heat pipe wall, hence the thermal performance of heat pipes gets enhanced. It can be concluded that there are some limitations in synthesis of these nanoparticles and thereby the nanofluids, the filling ratios as well as the concentration levels of nanoparticles because of which there are some limitations in commercialization of these fluids as working fluids. Hence there is a future scope in finding the optimum processes in the synthesis, concentration, morphologies of these nanoparticles many researches are carried out for the heat transfer performance of heat pipes using nanofluids. For e.g. copper oxide nanofluids (CuO) with base fluid being water.

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2. Nanofluids

With the rapid growth in IT and new technology computer hardware, heat transfer of these electronic components is one of the bottle neck problems. Hence to avoid this heat pipe using nanofluids can be one of the options to cope up with the management of all these electronic components.

This paper focuses on the following topics.

1) Concept of a nanofluid
2) Synthesization of nanoparticles
3) Parameters affecting a nanofluid
4) Working of heat pipe
5) Effect of nanofluids on different parameters of heat pipes

Fluids that are being used as a working fluid for cooling of engine oils, ethylene glycol and water. Thermal conductivity of these liquids is lower than metals and ionic components such as: copper, silver, silicon carbide and copper oxide. The characteristics of these metals and ionic components has given a rise to a fluid that consists of a mixture of a base fluid and metals (Maxwell). This idea of a suspension of nanofluid led to the improvement in one of the highly important parameters in a working fluid: thermal conductivity (Behi and Mirmohammadi, 2012).

Fluids that are being used as a working fluid for cooling purposes include engine oil, ethylene glycol and water. Above mentioned liquids have lower thermal conductivity than that of the other metals and oxides like copper, silver, copper oxide and silicon oxide. By examining the characteristics of all these metals and metal oxides, a new idea raised that is of the use of suspension of these metal's nanoparticles in the base fluid being water or any suitable conventional working fluid like ethyl glycol, or some chemicals. Thus named it as a nanofluid. This idea worked very well and the performances of heat pipes were considerably high. (Behi and Mirmohammadi, 2012).

2.1 Nanoparticle synthesis

In order to achieve better results in thermal properties of Nanofluids, the preparation procedure is one of the difficult tasks as well as the synthesis is also one of the hurdles. For this purpose the suspension of nanoparticles in the base fluid must be homogeneous to get better optimization of thermal as well as physical properties of Nanofluids. In the current scenario of research, more impact is given on the effectiveness parameters of the thermal conductivity and their behaviour as well. (Behi and Mirmohammadi, 2012).

The distinguishing of the production procedure is mainly into two groups: top down approach and bottom up approach. In the top down approach, involves the process into which the bulk material is broken down into nano sized structures and particles. This stage is somewhat more difficult or extensive to the making of micro sized particles. This method is more suitable in creation of cohesive structure. Grinding and milling procedures are carried out in order to mechanical size reduction of particles. But in case of the bottom up technique , the material is built up atom by atom in a very controlled manner. Or in some case it is built up molecule by molecule. This approach is economical and can be prioritized for atomic precision while creating same structures. (Das *et al*., 2007a, b, c, d, e).

Because of the thermo physical limitations that are already there in a working fluid, it also affects the performance of the heat pipe. Higher effectiveness in the heat transfer capability can only be achieved with a good margin of thermal conductivity (Iborra Rubio, 2012).

For enhancement of the thermal conductivity, solid nanoparticles are added to a base fluid (Shafahi *et al*., 2010a) pump oil, ethyl glycol, water. (Behi and Mirmohammadi, 2012). Solid particles having size less than 100 nanometers which are colloidal in nature. Table 1 shows the numbers representing the thermal conductivity of nanoparticles, which are 100 times more conductive. (Iborra Rubio, 2012).

Table 1–thermal conductivity of different solids and liquids

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 (Al_2O_3)	40
Metallic liquids	Sodium @ 644K	72,3
Non-metallic liquids	Water	0,613
	Ethylene glycol	0,253
	Engine oil	0,145

The building blocks of thermal conductivity

Following diagram illustrates various factors that affect the thermal conductivity of nanoparticles.

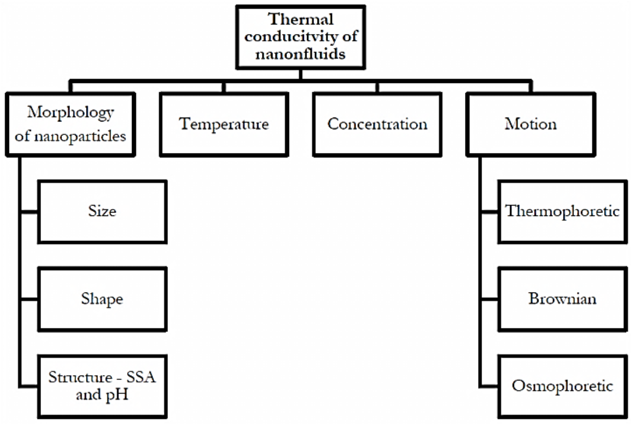

Fig 1 parameters affecting thermal conductivity

3.1 *Morphology of Nanoparicles*

The structure of organism including shape and size and their relation is called the morphology (Britannica, 2014).

The thermal conductivity of nanofluid is size dependent, i.e. smaller is the size better is the performance. In the experiment carried by Li *et al*. the diameter of aluminium particles was 36 and 47 nanometer. The temperature range selected for this experiment between 27-37 ^{0}C. The volume fraction of these was 0.5-6%. The result so obtained was higher thermal conductivity about 8%. The nanoparticles were 36 nm in size. (Sankar *et al*., 2012).

Xie *et al*., studied the influence of shape, in which he stated spherical or cylindrical nanoparticles that were made up of silicon carbide nanofluids. (SiC).Murshad *et al*., simultaneously investigated the performance of rod shaped as well as spherical shaped nanoparticles of TiO_2. Experimental results showed effectiveness in the thermal conductivity for rod shaped nanoparticles.

The specific surface area (SSA) is used to calculate the structure of nanoparticles. In which the relation between volume of particle and surface area. (Rice University, SSA).Xie.et.al., announced that the thermal conductivity can be increased with increased amount of SSA of nanoparticles. (Xie *et al*., 2002). The SSA and PH value have a common relation. Force of hydration is is induced amongst the particles with the increase in pH from isoelectric point. Therefore there is ultimate increase in thermal conductivity due to the mobility of particles with higher SSA.(Das *et al*., 2007a, b, c, d, e).

3.2Temperature

In the experiment of Yu *et al*. aluminium oxide (Al_2O_3) with base fluid being ethyl glycol and propylene with ten percent of volume concentration. With the increase in temperature from 10 to 60 ^{0}C, there he found a rise in thermal conductivity about 1 to 4%. But the limitation found is that there is reduction in the thermal conductivity with increased temperature. Because the temperature of the range of 1000^0 C affect the thermal conductivity of solid metals.

3.3 Concentration

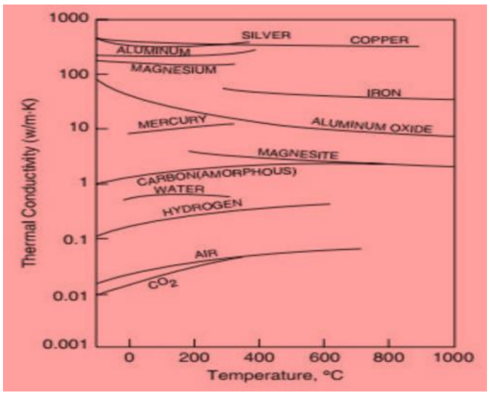

Fig 2. Temperature affecting thermal Conductivity

To increase the thermal efficiency of the nanofluids the important consideration is the concentration of nanofluids. In the experiment of Eastman et. al., in ethyl glycol he added the nanoparticles of copper of the size 10nm diameter thus resulting in 0.3 % rise in thermal conductivity. (Eastman *et al*., 2001b).

3.4 Motion

A temperature gradient is developed in the fluid because of the thermophoetic motion, thus one can say that the the thermal conductivity is affected by the motion of nanofluids. When predicted the thermal performance in analytical model the thermal conductivity was found to be less than that of the actual. Brownian motion is one of the most effective quality of nanofluids that leads to increase the thermal conductivity of nanofluids. It happens because of the collision of nanoparticles with the base fluid. Thereby increasing the particle velocity.

A concentration gradient is developed due to motion of particles called the osmophoretic motion. The effect of the thermophoretic and osmophoretic motion is insignificant compared to the Brownian motion (Behi and Mirmohammadi, 2012).

4. The increasing effect of nanofluids in heat pipes

The thermal efficiency is the ratio of heat rejected at the condenser section to the heat input at evaporator section (Senthilkumar *et al*., 2011). The parameters considered in thermal efficiency are the following (Naphon *et al*., 2008):

- Chargeof nanoparticles in working fluid
- Inclination angle
- Concentration of nanoparticles with respect to base fluid (Volumetric concentration)
- Thermal resistance

4.1. Thermal network in model

The heat pipe is shown in axial cross section orientation where there are eleven thermal resistances in Fig 3. $R2,3$,$R4$,$R8$,$R9$,$R10$ have a radial effect and $R1$,$R5$,$R6$,$R7$,$R11$ have an axial effect on the heat pipe for heat transfer. $R1 and R11$ can be evaluated using the surrounding conditions which contact with heat pipe wall as well as the three basic types of heat transfers.

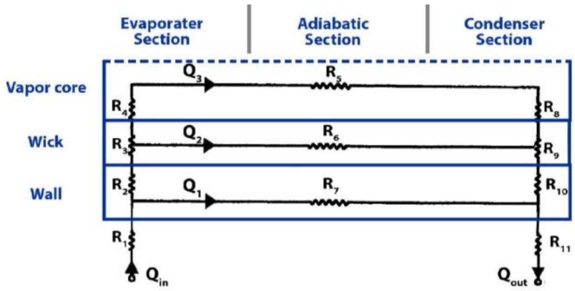

Fig. 3 Thermal resistance networks in a heat pipe

4.2 Differentnanofluid but same concentration

When the difference in temperature of evaporator and condenser is studied the thermal efficiency can be evaluated. The heat transfer rate gets increased without increase in the heat pipe wall temperature is by use of nanofluids. (Shafahi *et al*., 2010a).

In the given fig 4 base fluids used is the water and nanofluids used are aluminum oxide *(Al2O3)*, silicon carbide *(SiC)*, and silver *(Ag)*With 10% concentration by volume.

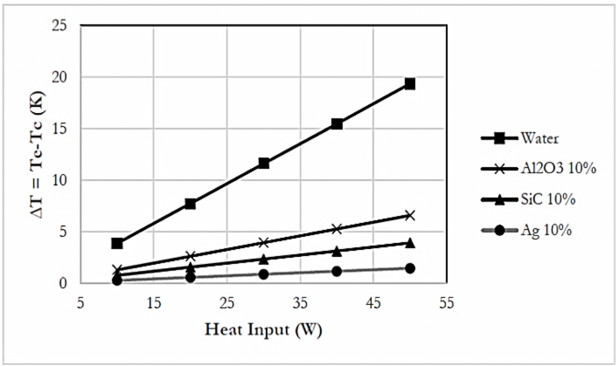

Fig.4 Temperature difference between evaporator and condenser for different nanofluids

4.3 Different concentrations but same nanofluid

Because of the nanofluid concentration of silicon carbide (SiC) there exists temperature. These results are compared with water and the mixture with nanofluid is found to be more efficient. On the aid of heat input the temperature difference acts in a linear manner. That is, with the increased concentration of nanoparticles there is decrease in temperature. Each of the working fluid there is increase in heat flux. Due to high inclination water cannot operate under the impact of heat load as that of SiC. Below are the graphs showing different concentration details versus temperature difference.

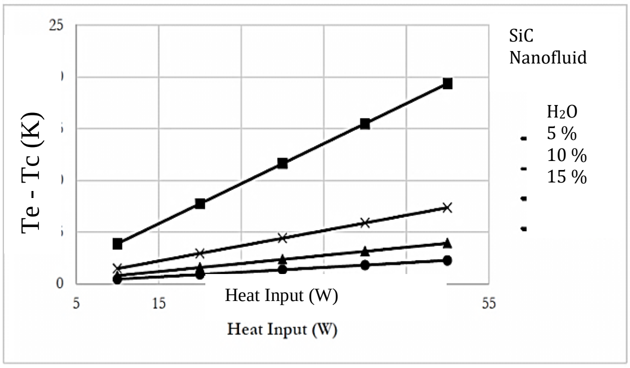

Fig.5 Temperature difference between evaporator and condenser based on concentration and heat supplied.

4.4 Analysis of results

A large scale variation is found in overall behaviour of SiC nanofluids having concentrations of 5%, 10% and 15% by volume. While the heat supplied was 50W. Resulting in a considerable temperature difference in evaporator and condenser. Thus it again proved that on increase in the concentration there is rise in thermal conductivity of heat pipes. (Eastman *et al.*, 2001a).
But still it can be concluded that the resistances as labelled$R1$, $R2$, $R10$ and $R11$ are constant in allmanners throughout the experimentation. The affected resistances are 3and $R9$ only. Hence one can say that there is considerable effect of morphology on thermal conductivity. hence reduction in overall thermal resistance.

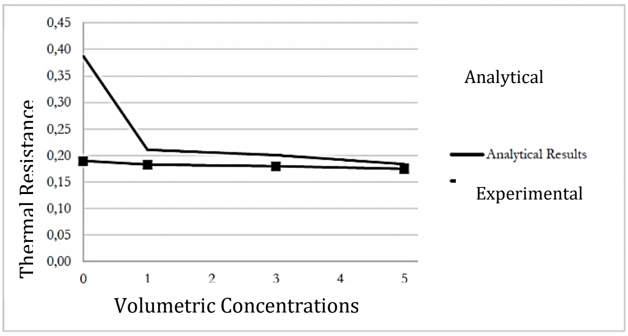

Fig.6 Thermal resistance aluminum oxide under different concentrations

4.5 Analysis of thermal resistance with increasing concentration

As per The results there is decrease in overall thermal resistance as the volumetric concentration gets increased. On studding the analytical results it can be seen that there is around 46% to 53% decrease in thermal resistance because of 1% to 3% of Al_2O_3 nanofluid. This is due to the fact that there are a range of uncertainties in experimental results showing very small influence on thermal resistance due to concentration. Considering solely the experimental results: by using 1%, 3% and 5% water-based aluminum oxide nanofluid, the thermal resistance is found to be decreased with 4%, 5% and 8% respectively. This is due to the fact that there are a range of uncertainties in experimental results showing very small influence on thermal resistance due to concentration.

The morphology and motion processes inside the heat pipe e.g. Brownian force are not considered. Such a model requires though detailed knowledge about the nanoparticle in aspect of thermo physical data (e.g. viscosity and size of particles) and motion process in the working fluid e.g. Brownian force, By the experimental results it is notable that there is no significant decrease of thermal resistance with higher concentration. Thus indicating that the nanofluid reaches a saturation point resulting in a minimal thermal resistance. Higher concentration demands larger amount of nanoparticles and it has no economic increased value for continuous increase in the nanoparticle concentration when reaching this saturation point in aspect of thermal resistance.

4.6 Temperature at evaporator section

The incremental effect on the temperature at the evaporator section by increasing a depending parameter value with 20 % can be seen in figure 8. There are three important factors illustrated such as: bulk temperature, heat pipe inner radius and heat pipe vapor core radius. It can be observed that the bulk temperature and the heat pipe inner radius have the largest positive impact on the temperature of the evaporator section.

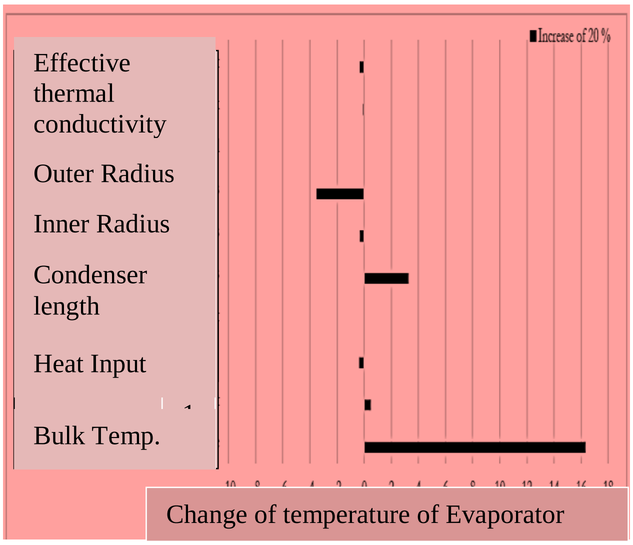

Fig.7 Parameters affecting temperature of evaporator section

The Numbers indicate following parameters:

1) Bulk Temperature
2) Heat Input
3) Length of condenser
4) Inner radius of Heat pipe
5) Outer radius of Heat pipe
6) Effective thermal conductivity of heat pipe

4.7 Temperature at condenser section

The incremental effect on the temperature at the condenser section can be seen by increasing a depending factor value with 20 %. It is observed from Fig.8 that there are four factors affecting the condenser temperature: bulk temperature, heat input, length of condenser and heat pipe outer radius. A 20 % increase of heat input gives a lead to increase the temperature with 4 % on the other hand the condenser length and heat pipe outer radius decrease the temperature about 3.4 %.

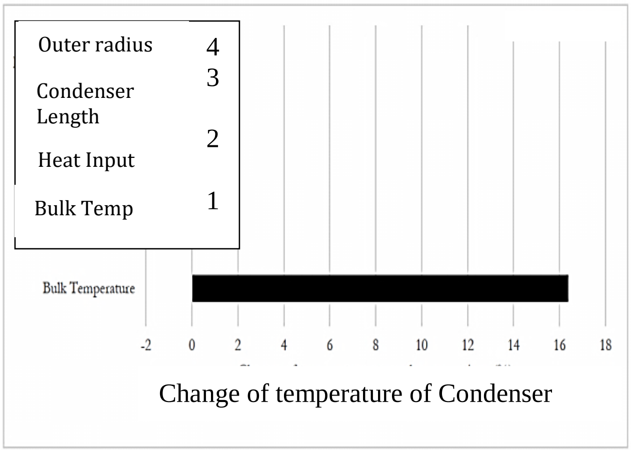

Fig.8 Temperature affecting condenser section

5. Production difficulties of nanofluids

The production process of nanofluids is an important parameter that has hindered regarding the usage as coolant in heat exchanging devices (Saidur *et al*., 2011). The production process of nanofluids has employed two methods: 1) one-step method, that consists of the nanoparticle synthesis and dispersion of the nanoparticles at same time 2) two-step method that consists of synthesis of nanoparticles and subsequently dispersing them into a base fluid (Shafahi *et al*., 2010b). However the base fluid usually consists of other ions and reactions that are not easy and sometimes impossible to separate from the fluids (Saidur *et al*., 2011). These difficulties and procedures cause vast production costs. Since optimum filling and concentration levels have not been decided for several heat pipes, from economical angle, the unknown optimal filing and concentration levels can lead to consumption of nanofluids more than the limit, thus resulting in the revenue not being able to cover the cost of application of nanofluids in heat pipes.

6. Challenges for nanofluid based heat pipes

Recent researches and studies have showed positive effects of applying nanofluids in heat pipes by augmenting the heat transfer characteristics of heat pipes. It is found from the results of this study and other studies that the thermal conductivity in heat pipes increases with nanofluids when applied as working fluids.

Experiments have found that a sediment layer on the wick after being heated. This affects the thermal performances of heat pipes both in positive and negative ways. (Liu and Li, 2012). Current studies are focused on how the thermal performance will be impacted if the sediment layer becomes thicker and if the sediment layer will maintain a well-defined thickness during the entire operation since this has a noticeable impact on the practical engineering applications of nanofluids in heat pipes (Liu and Li, 2012).

7. Future research suggestions and sustainability

A micro level or in other words a deep research and effort is required in the field of nanofluids where there is a lot of variety of issues, such as synthesis, thermo physical properties, characterization, filling ratio and concentration level of nanoparticles needs to be studied. A multidisciplinary or interdisciplinary approach comprising researches in different field is required. A necessary intensified focus in the development of nanofluids could be solving the key energy transport mechanism in nanofluids.

When sustainability is the main issue, a challenging way for future applied research in the field of heat pipes and nanofluids is to pursue ecofriendly designs by choosing biodegradable and nonhazardous nanoparticles (Gupta *et al*., 2012). This gives a conclusion regarding the direction to commercialization of nanofluids towards a low cost, high volume production of stable and sustainable nanofluids.

Conclusions

Based on the findings extracted from literature studies and the discussion the following conclusion can be made:

- A higher particle conductivity of nanoparticles gives rise to the thermal conductivity of the nanofluid, thereby increasing the effective thermal conductivity of the heat pipe, on the other hand decreasing the thermal resistance in the heat pipe. Thereby there is augmentation of the thermal performance.
- A higher concentration of nanoparticles increases the thermal conductivity of the nanofluid, which in

turn increases the effective thermal conductivity of the heat pipe, ultimately decreasing the thermal resistance in the heat pipe and enhancing the thermal performance.

- There are problems associated with the production process, and working e.g. high production cost, of nanofluids, sedimentation of nanoparticles in wick structure.
- A detailed study must be put on research in the field of nanofluids concerning synthesis, thermo physical properties, filling ratio and level of concentration of nanoparticles.

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