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Effect of Nanofluids on Heat Pipe Thermal Performance: A Review of the Recent Literature

P M Sonawane, M D Shende, V P Baisane

***Abstract*— Normally conventional fluids are used in heat pipes to remove the heat based on a temperature range for its particular operating conditions [1] (see Fig.2). The addition of the nano particles to the base fluid is one of the significant issues to enhance the heat transfer of heat pipes. The purpose of this review is to summarize the research done on heat pipes using nanofluids as working fluids in recent years (2012 to 2013). This review article provides additional information for the design of heat pipes with optimum conditions regarding the heat transfer characteristics of nanofluids in heat pipes. Moreover, this paper identifies several important issues that should be considered further in future works.**

***Index Terms*— Heat pipes, Nanofluids, Thermal resistance, Heat transfer.**

I. INTRODUCTION

Nowadays heat pipes find numerous applications such as in solar energy, air conditioning systems, waste heat recovery to save energy and prevent global warming, designing compact electronic components, space applications, telecommunications, food industries, geothermal systems, etc. Based on these applications, "lightweight" and "high performance" becomes the key goals for current heat pipe design, especially for applications in the electronic industries.

A heat pipe is a simple device used to transfer the heat from one place to the other. The advantage of using a heat pipe over the other ordinary methods to heat transfer is that a heat pipe can have an extremely high thermal conductance in steady state operation, and hence known as "super thermal conductors". The heat pipe consists of evaporator section, adiabatic section and condenser section (Fig.1). The heat is transferred as latent heat energy by evaporating the working fluid in the evaporator (hot side) and condensing the vapor in the condenser (cool side), the circulation is completed by the forces, such as capillary force, gravitational force (in the thermosyphon heat pipes), electrostatic force, or other forces directly acting on the liquid flow. Adiabatic section is fully insulated. Because the middle region of the heat pipe is regarded as an adiabatic zone, the amount of heat transfer to ambient is low. Regardless of the classifications of heat pipes, which might depend on the geometries, applications, and so on, the basic principles are the same.

P M Sonawane, Mechanical, Dr.BAMU/ SYCET, /Aurangabad, India, 7875383793

M D Shende, Mechanical, Dr.BAMU/ SYCET, /Aurangabad, India

V P Baisane, Mechanical, Dr.BAMU/ PESCOE, /Aurangabad, India

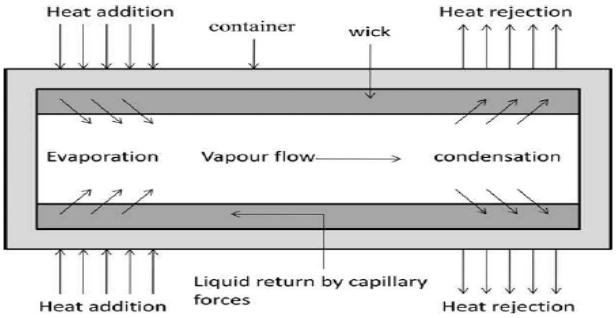


Figure 1.Schematic diagram of heat pipe.

The lower thermal conductivity of these working fluids limits the thermal performance enhancement of the heat pipes. Nowadays, nanofluids play an important role in heat pipes to increase the heat transfer compared to conventional fluids. The research on application of nanofluids in heat pipes was firstly published in 2003 [2].

Recently, many researchers have presented the heat transfer characteristics of heat pipe using nanofluids. Most of the research works are carried out experimentally to focus on finding out the key factors affecting the reliable application of nanofluids in the heat pipes. The type, size of heat pipes and operating conditions of heat pipes, the kind of the base fluids, the material and size of nanoparticles all varied in very wide ranges among these experiments.

The observations based on the reviewed literature showed that the theoretical investigations on nanofluids in heat pipes are very few and hence validating the experimental findings is difficult [3-6]. However, many issues such as the transfer of nanoparticles by the vapour phase during heat pipe operation can be investigated only with adequate experiments.

This paper compiles the recent researches on the heat transfer characteristics of nanofluids in heat pipes and identifies many issues that are open or even not commenced to investigate.

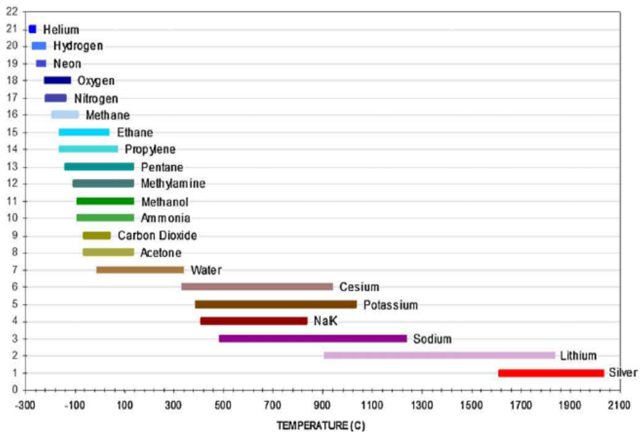


Figure 2. Operating temperature range of common working fluids [1]

II. LITERATURE REVIEW

The objective of this paper is to present an overview of literature dealing with recent developments in the study of heat transfer using nanofluids in heat pipes and some important inferences from the various papers are also highlighted by the following studies.

In recent years, researchers have given much attention on thermal conductivity rather than heat transfer characteristics. Because the thermal conductivity is an important parameter in enhancing the heat transfer performance of a heat transfer fluid. Nanofluids as a novel strategy to increase the thermal conductivity of base fluids by the addition of solid particles with diameters below 100 nm was proposed by Choi [7] and his team. Choi et al. [8] observed 160% thermal conductivity enhancement with carbon nano tubes dispersed in engine oil. The similar trend is also observed by Lee et al. [9], Eastman et al. [10, 11], Das et al. [12] and Naik and Sundar [13]. The nanoparticles suspended in conventional fluids have superior heat transfer capability due to improved thermal conductivity.

Asirvatham et al. [14] experimentally investigated the effects of using silver water nanofluid on the heat transfer performance of a heat pipe and showed a substantial reduction in thermal resistance of 76.2% and an enhancement in the evaporation heat transfer coefficient of 52.7% for 0.009% silver nanofluid. Their results demonestrated that the use of nanoparticles enhances the operating range of heat pipe by 21% compared with that of DI(De-Ionized) water.

Hung et al. [15] experimentally demonstrated the enhancement of the thermal performance of a heat pipe charged with Al2O3/water nanofluid. The heat pipe in this study was a straight copper tube with an outer diameter of 9.52 mm and different lengths of 0.3 m, 0.45 m, and 0.6 m. Their results showed that at a heating power of 40 W, the optimal thermal performance of heat pipes measuring 0.3 m, 0.45 m, and 0.6 m with Al_2O_3/water nanofluid was 22.7%, 56.3%, and 35.1%, respectively, better than that with heat pipes using distilled water as the working fluid. They also stated that the thermal performance of the heat pipe decreases with nanoparticle volume concentration at the concentrations higher than the optimum. It is due to the fact that the high concentrations of nanoparticles lead to high water absorption, which in turn facilitates forming a coating layer through the sedimentation of nanoparticles on the surface of the evaporation section.

Kole and Dey [16] prepared surfactant-free and fairly stable Cu-distilled water nanofluids and observed an enhancement of ~ 15% in the thermal conductivity for 0.5% copper nanofluid at room temperature. In their experiment, the thermal resistance of the vertically mounted heat pipe with the addition of 0.5% copper nanoparticles in distilled water was reduced by ~ 27% and also the average wall temperature of the evaporator was reduced to 14°C at an input power level of 100 W.

Liu et al. [17] experimentally showed that the solar collector integrated with open thermosyphon has a much better collecting performance compare with the collector with concentric tube and the solar collecting efficiency could be improved using 1.2% CuO/water nanofluid as the working fluid instead of pure water. They reported that the air outlet temperature of the collector using nanofluid as the working fluid has reached 174°C at noon, while the air outlet temperature of the collector using water as the working fluid of open thermosyphon has reached 155°C at noon.

Aboutalebi et al. [18] experimentally investigated the effects of rotational speed on thermal performance of a rotating closed loop PHP (Pulsating heat pipe), RCLPHP, by changing input power in the evaporator (from 25 W to 100 W) and filling ratio (25%, 50% and 75%) for different rotational speeds (from 50 rpm to 800 rpm). The study highlighted the advantages of using RCLPHP system as a novel kind of heat pipes in comparison to blade cooling passages for gas turbine blade cooling. They pointed out that a very encouraging issue to direct future researches is to investigate effects of using nanofluids, as the operating fluid, on thermal performance of RCLPHP. However, this issue needs further investigations on performance of RCLPHPs under different working modes.

Saleh et al. [19] experimentally showed that the temperature distribution and the thermal resistance decreased with the increasing volume concentration and the size of the ZnO nanoparticles for a conventional screen-mesh wick heat pipe. In their experiment, ZnO nanoparticles were synthesized using a co-precipitation method and were dispersed in ethylene glycol at concentrations from 0.025 to 0.5 vol.% and also the as-synthesized ZnO particles had average crystallite sizes of 18 or 23 nm.

Yousefi et al. [20] experimentally investigated the effects of inclination angle and nanofluids on the performance of a heat pipe used for CPU cooling. With the CPU in the horizontal position, the heat pipe was capable of cooling the CPU. Their results indicated that using 0.5% Al2O3-water nanofluid as the heat pipe’s working fluid, the thermal resistance can be decreased by 15% and 22%, when the heat generated at the CPU was at 10 W and 25 W respectively.

Moraveji et al. [21] experimentally investigated the effect of using 35nm Al_2O_3/water nanofluid on the thermal efficiency enhancement of a heat pipe. The heat pipe was made of a straight copper tube with an outer length of 8 and 190 mm and a 1 mm wick-thickness sintered circular heat pipe. They highlighted the influences of the nanoparticle concentration level on the temperature difference between the evaporator and condenser (JT) under various input powers in Fig. 3.

From this figure it can be seen that the temperature difference decreased by increasing the nanofluid concentration. Also an increase and then sudden decrease can be seen by increasing the heat load due to the fact that the value of vapor and rate of transnational speed between condenser and evaporator improved. They reported that by using nanofluid as a working fluid, the heat pipe can be operated under a larger heat load. They observed that the thermal resistance of the heat pipe decreased with volume fraction for different concentration of Al_2O_3 as shown in Fig. 4. They explained one of the main reasons for reducing the heat pipe thermal resistance as follows. The suspended nanoparticles tend to bombard the vapor bubble during bubble formation to create a smaller bubble nucleation size with a lower thermal resistance.

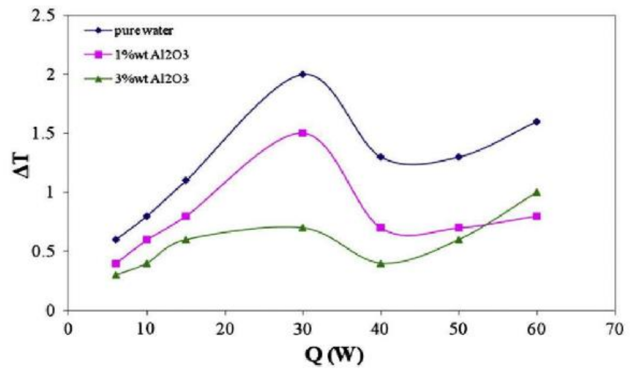


Figure 3. The effect of different nanoparticle concentrations and input powers on the temperature difference of heat pipe [21].

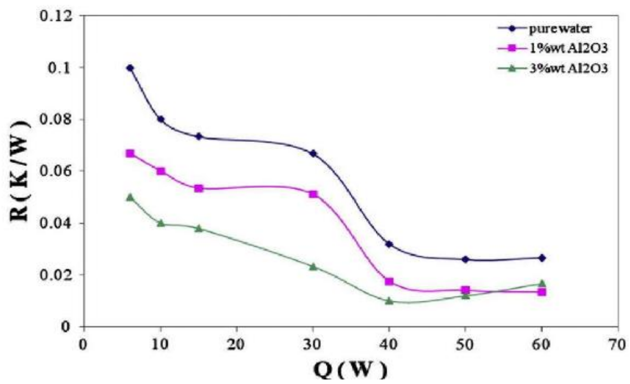


Figure 4. The effect of different nanoparticle concentrations and input powers on the heat pipe thermal resistance [21].

Hajian et al. [22] experimentally investigated the transient and steady thermal performance of a medium-sized cylindrical stainless steel meshed heat pipe utilizing DI-water/silver nanofluid at various concentrations. In this study, nanofluids were prepared without surfactant at various concentrations of 50, 200 and 600 ppm. Thermal resistance and response time were used in this study for describing the steady state and transient behavior of the heat pipe. The definition of response time was based on the variation of heat pipe outside surface temperature because the thermal resistance or temperature gradient of the heat pipe may reach to a constant value but the surface temperature is still rising. In their experiment, an appropriate point on the midpoint of the adiabatic section was selected due to its distance from evaporator and condenser for specifying the state of the heat pipe operation. They obtained the temperature of midpoint at the response time (TRT) based on the initial and final temperatures of maid point (Ti and Tf) as TRT=0.9×(Tf-Ti)+Ti and plotted the response time at various heat rates (300-500 W) for various working fluids as shown in Fig. 5. Their results showed that the heat pipe with 50 ppm nanofluid (dilute nanofluid) had better performance than the other fluids so that the response time of the heat pipe, at higher heat rates, decreased about 20% compared to DI-water. They ascribed this main conclusion to both enhancements of thermal conductivity and boiling in the evaporator section. As seen in Figs. 5 and 6, the study's conclusions showed that the use of Ag nanofluids with high solid volume fraction (200 ppm and 600 ppm) had negative effects on thermal performance of the heat pipe in both transient and steady states, mainly because of these reasons: (a) by reduction of suspended nanoparticles due to the probability of particles conglomeration and sedimentation in high concentration nanofluids without any surfactant, the Brownian motion of nanofluid and consequently its thermal conductivity is decreased.(b) Reduction in boiling heat transfer rate due to decrease in frequency of bubble formation and departure by covering the heat pipe wall with a layer of nanoparticles.

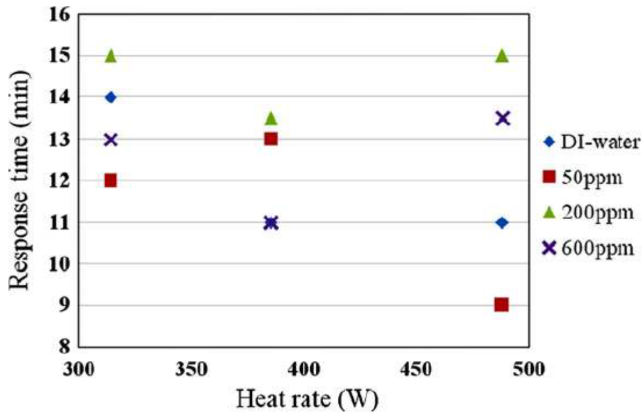


Figure 5. Response time of the heat pipe [22].

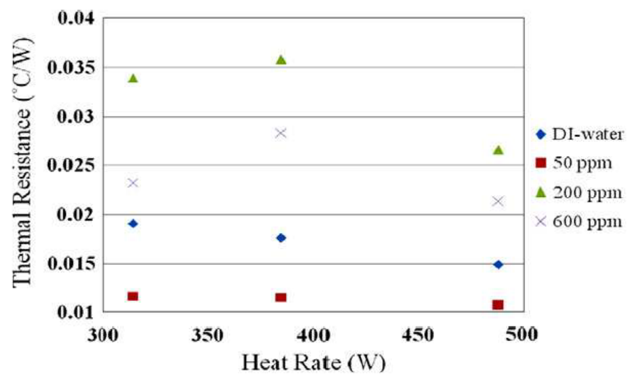


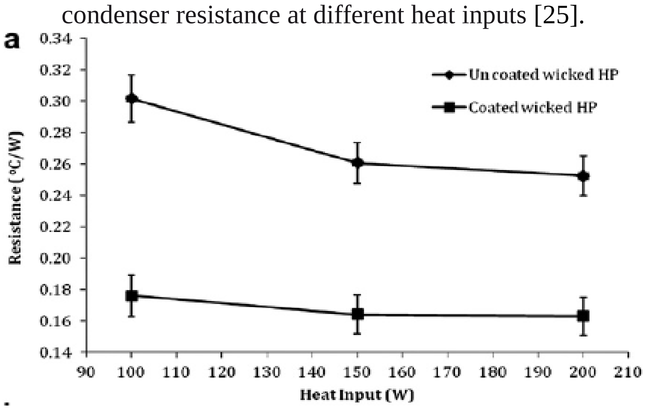
Figure 6. Steady state thermal resistance of the heat pipe [22].

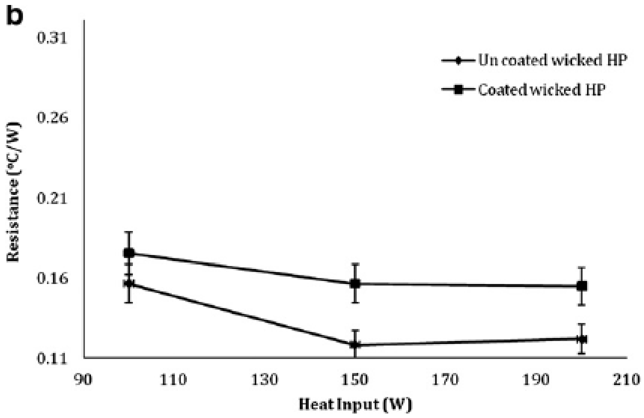
Wang et al. [23] performed an experiment concerning an inclined miniature mesh heat pipe. The working fluid was 50nm-CuO/ DI-water nanofluid that prepared by oscillating CuO nanoparticles for 10 h in an ultrasonic water base without any surfactant. The length, outer diameter and wall thickness of the heat pipe were 350 mm, 8 mm and 0.6 mm, respectively. The evaporator section, adiabatic section and condenser section of the heat pipe were 100 mm, 100 mm and 150 mm long, respectively. They showed the existence of an optimal concentration of 1.0 wt% for all inclination angles that takes a balance between the capillary force and the flow drag force. They observed that the thermal performance of an in162 clined miniature mesh heat pipe can be strengthened with increasing nanoparticles loading in the base fluid up to an optimum concentration.

Senthilkumar et al. [24] discussed about the thermal efficiency enhancement of the heat pipe based on the ratio of cooling capacity rate of condenser fluid at the condenser section and the supplied power at the evaporator section regarding 40nm-Cu/DI-water nanofluid as the working fluid (40 ml). Experimental procedure was repeated for different heat inputs (30, 40, 50, 60 and 70 W) and different inclinations (0°, 15°, 30°, 45°, 60°, 75° and 90°). The evaporator temperature was controlled at a temperature of 30°C. The following conclusions can be drawn from this study: (a) by using nanofluid as working fluid in the evaporator section, the temperature of the working medium increases and hence more amount of heat can be removed in the condenser section. (b) The thermal efficiency of the heat pipe enhances about 10% when copper nanofluid is utilized as the working fluid. (c) The heat pipe thermal efficiency increases with increase in inclination of the heat pipe up to 30° for DI water and 45° for copper nanofluid. It is attributed to the fact that the heat transfer rate increases with an increase in inclination angle by using nanofluid because of the increase in domination of gravitational forces. The authors stated that the higher rate formation of liquid film inside the condenser at larger inclination angles Led to the increase of the thermal resistance.

Solomon et al. [25] coated a wick with nanoparticles by simply immersing the wick into a nanofluid and drying it afterwards. The nanofluid was prepared by directly dispersing 1 g of copper nanoparticles in the size range of 80-90 nm into 1 L of DI water by ultrasonication. The following conclusions can be drawn from this study: (a) the evaporator thermal resistance of the heat pipe with coated wick is less than that of the same with uncoated wick. The main reason for reduction in thermal resistance is a significant increase of the heat transfer from the wall of the evaporator to the working fluid due to surface area improvement of the coated wick. (b) Thermal resistance decreases with heat load in the heat pipe operated with uncoated wick whereas the effect of heat input on the thermal resistance of the heat pipe operated with coated wick is negligible (see Fig. 7(a)). (c) Thermal resistance in the condenser section of heat pipe operated with coated wick is higher than that of the conventional heat pipe because of the increase in roughness of the wick due to the coating (see Fig. 7(b)). (d) The total resistance of heat pipe operated with coated wick is lower than that of conventional heat pipe because the reduction in the thermal resistance of the evaporator is higher than the increase in the thermal resistance of the condenser (see Fig. 8). (e) According to Fig. 8, the authors compared their work with Shukla et al. [26]'s study and shown that the thermal resistance of the heat pipe operated with nanoparticle coated wick is higher than that of heat pipe operated with Cu-water nanofluid, especially for higher heat inputs. An analytical model based on the startup model presented in Zhu and Vafai [27] for investigating the impact of using different types and concentrations of nanofluids on reducing the size and thermal resistance of the flat-shaped heat pipes under a given imposed load was proposed by Alizad et al. [5]. Their model indicated a clear effect of the nanoparticle material on the decrease of the thermal resistance. The results obtained in this work were in agreement with the experimental results.

Figure 7.(a) Thermal resistance at the evaporator (b) condenser resistance at different heat inputs [25].





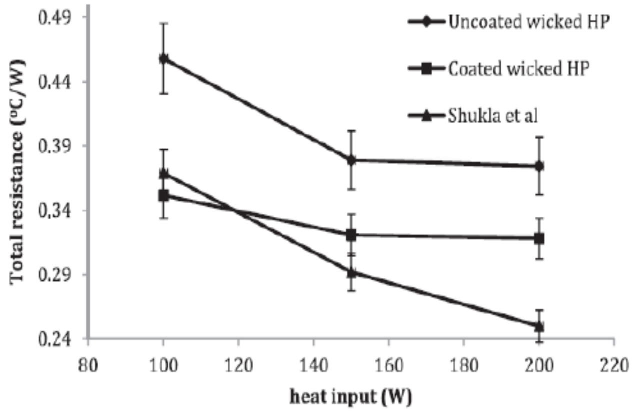


Figure 8. Total resistance of heat pipes [25].

III. Conclusion

1) At the present time, few studies have been published based on theoretical models; most of research works that have investigated the use of nanofluids in heat pipes are experimental.
2) Further theoretical and experimental investigations are needed to understand the heat transport properties of nanofluids in heat pipes and to optimize their concentration.
3) It is needed to do investigations to find ways for nanofluids' stability except surfactants in the future.

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