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Heat transfer mechanisms in heat pipes using nanofluids – A review

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ABSTRACT

Heat pipes are compact and efficient heat exchangers which are widely used in a large number of thermal devices. Researchers were attracted towards the application of nanofluids in heat pipes due to its superior thermo physical properties. They used nanofluids as working fluid in heat pipes and noticed significant changes in thermal performance. In present study authors summarize the research outcomes of various experimental and numerical studies. It also provides an overview of heat transfer mechanisms responsible for the change in thermal performance of heat pipes. Heat transfer mechanisms depend upon, type of heat pipes, nanofluids characteristics, design and operating parameters of heat pipes, etc. All the parameters have their own individual as well as the combined effect on thermal performance. Authors have drawn the attention of research community to explore the dependency of all parameters on each other.

1. Introduction

In the age of technological advancement, the efficiency and effectiveness of the engineering applications are becoming more prominent. Continuous improvements are required to sustain the technology itself. Technology is being upgraded continuously by adopting new innovative ideas and strategies for efficient utilization, storage and transfer of energy. Nanotechnology is the most vibrant area that attracts the research community due to its higher potential, enabling a significant improvement in the performance of various devices. In last two decades, significant work has been done to apply nanotechnology in heat transfer applications. Nanofluids are the new advancement in thermo-fluidics, obtained by stirring nano particles in conventional fluids [1]. Researchers have taken nanoparticles of different metals, metal oxides, carbides, nitrides, and different types of carbon with different base fluids such as water, ethylene glycol (EG) and engine oils. Nanofluids can be prepared by two methods: One step method and two step method. The main purpose of these methods is to prepare a homogeneous and stable solid-liquid mixture and to avoid the agglomeration, possible erosion & clogging, etc. In one step method, the nanoparticles are made and dispersed into the base fluid simultaneously. While in a two-step method, the nanoparticle is produced in the first step & dispersed into host fluids in the second step. It can be observed in the literature that nanofluids with oxide nanoparticles and carbon nanotubes are prepared by two step method. Two step methods are not suitable for metallic nanoparticles. Under specific conditions, nanofluids exhibit superior thermo physical properties which result in improved efficacy of the thermal application.

In the last few years, several researchers have proposed mechanisms of enhancement in heat transfer through nanofluid like the effect of Interface, Brownian motion, Ballistic transport of energy carriers and thermophoresis. Chandrasekar et al. [2] reviewed the mechanisms which were responsible for the enhancement in thermal conductivity of nanofluids. Researchers discussed various mathematical models to identify different factors and their limitations. Murshed et al. [3] concluded that nanoparticles shape, size and volume fraction were the main parameters to decide the thermal conductivity of nanofluids. Saidur et al. [4] summarized the applications and challenges of nanofluids.

Heat Pipe (HP) is a device used in transferring the heat from one place to another (Fig. 1a). There are different types of HP, widely used in different applications such as micro grooved, mesh wick, sintered wick, oscillating, and thermosyphon, etc. In its simplest form (Thermosyphon HP) it is a hollow, closed, evacuated pipe containing a working fluid. It is divided into three sections: evaporator, adiabatic, and the condenser section. The working fluid absorbs the heat in evaporator section, gets converted into the vapour phase, which travels towards the condenser section due to the pressure difference, rejects heat to the cooling media through the condenser section and finally gets converted into the liquid phase. Due to gravity, the condensed working fluid returns to the evaporator section. Therefore, the heat is absorbed continuously through the evaporator section and released by the condenser section

Thermal resistance network of HP is shown in Fig. 1b. It shows that

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Nomenclature

HP	heat pipe
OHP	oscillating heat pipe
LHP	loop heat pipe
MWCNT	multiwall carbon nanotubes
Vol.	volume
Wt.	weight
PG	propylene glycol
EG	ethylene glycol
DEG	di ethylene glycol

R_2, & R_3 are the conductive thermal resistance, R_1 & R_4 are the convective thermal resistance at evaporator section. Similarly, R_9 & R_{10} are the conductive resistance; R_8 & R_{11} are the convective resistance at condenser section. R_5 & R_6 are the conductive resistance; R_7 is the convective resistance at the adiabatic section. Thermal resistance network is used to understand the heat transfer process and make the analysis simple and effective. In a composite system, the thermal analogy is very useful to calculate the heat transfer rate and the interfacial temperatures of the system.

Researchers have used nanoparticles of different metals (Cu, Ag, and Gold, etc.), metal oxides (Al_2O_3, CuO, MgO, ZnO, TiO_2 and SiO_2, etc.) and several other materials suspended in water, EG, ethanol, R-11and R-141b, etc. Different experimental studies, including the effect of various types, size, shape and concentrations of nanoparticles and other operating parameters of HP such as heat input, charging volume of working fluid and inclination angle on thermal efficiency have been done. Moreover, the main objective of the experimental studies was to obtain the most suitable combination of the different design and operating parameters corresponding to the maximum thermal performance of HPs. Presently HPs are widely used in different thermal devices due to their high heat transfer capability and compact size. The thermal performance depends on the thermo physical properties of working fluid. Therefore the selection of suitable working fluid becomes more essential. Owing to the higher thermal conductivity of nanofluids, many researchers have used various nanofluids as the working fluids to improve their thermal performance.

Some researchers have summarized the published work on nanofluids application in HPs. Liu and Li [5] discussed the reduction in thermal resistance using nanofluids as working fluid as compare to D.I. water. Authors discussed the mechanism of heat transfer and existing issues regarding the nanofluids application in HPs. Sureshkumar et al. [6] presented an overview regarding the heat transfer enhancement and reduction in thermal resistance. Authors have concluded that enhancement in critical heat flux, the effective conductance of liquid and effective thermal conductivity of wick structure play the main role in the enhancement of thermal performance. Buschmann et al. [7] summarized the recent experimental research work using nanofluids as a working fluid in thermosyphon and HPs. Authors have gone through 38 experimental studies and 4 modelling approaches. Review article concluded that several questions regarding gadget parameters may be answered but many questions regarding nanofluids characteristics, mechanism of heat transfer and optimization of heat transfer capability are still unanswered. Alawi et al. [8] reviewed the recent experimental and theoretical investigations. Authors remarked that available experimental/theoretical investigations are limited, so more studies will require in future.

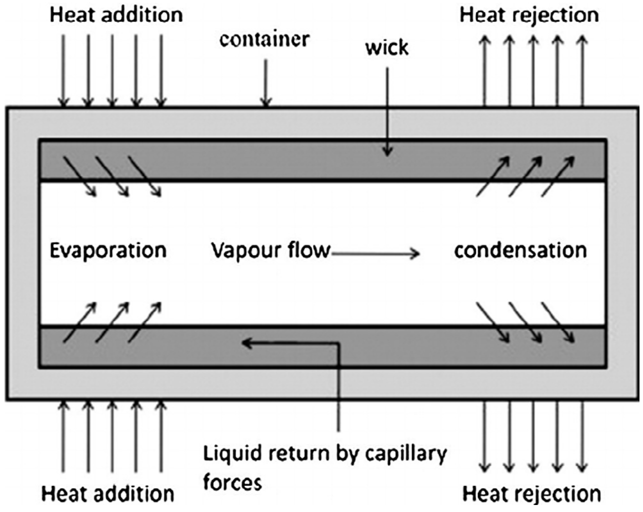

Fig. 1a. Schematic diagram of heat pipe [6].

The objective of the present paper is to summarize the research outcomes of different experimental and numerical studies. Authors aimed to provide an overview of the heat transfer mechanisms responsible for the change in thermal performance of HPs using nanofluids as working fluids.

2. Fundamental studies of nanofluid applied in heat pipe

2.1. Experimental studies

HPs are very compact and effective category of heat exchangers. They were used in different size and shape depending upon the application requirement. Most popular types are Micro-grooved, Mesh wick, Sintered wick, Oscillating, Thermosyphon, etc. In experimental/theoretical studies researchers used different types of nanofluids such as Al_2O_3 [14,17,18,26,27,37,39,41,46,47,49,51,53,54,56,72,75,76,86], CuO [9–11,13,19,23,28,29,38,43,47,77,81], Cu [13,16,20,24,59,62,64,77,84], MgO [48], Fe_2O_3 [42,58,67–69,79], SiO_2 [45,51,55,60,63], TiO_2 [51,81,83,85] and ZnO [22] to obtain the enhanced thermal performance. Thermal performance includes thermal efficiency, thermal resistance, the effective thermal conductivity of HP, surface temperature gradient, convective heat transfer coefficient at evaporator and condenser section, etc.

2.1.1. Experimental studies of nanofluid application in heat pipes

2.1.1.1. Micro-grooved heat pipes. Micro-grooved HPs are widely used in the different area of application. Grooves are provided on the inner surface of HPs for facilitating the condensed working fluid to return back to the evaporator section through capillary force. In a wide range of evaporator heating, the evaporation rate of working fluid varies accordingly. Similarly, coolant temperature, mass flow rate, specific heat, etc. controls the condensation rate of working fluid. Evaporation rate, condensation rate and condensate flow rate (from the condenser to evaporator section) should be in proper balance with each other for efficient working of HP. If evaporation rate is higher than condensation rate there will be a dry out condition. Lower evaporation rate would lead to the lower efficiency. To avoid the dry out condition, proper flow of condensate from the condenser to the evaporator is required. So grooves or wick must be capable of producing the sufficient capillary force to arise the required condensate to evaporator section under a wide range of different operating parameters. Researchers have used different nanofluids in micro-grooved HPs and noticed a significant enhancement in thermal performance (Table 1).

Wang et al. [9] examined the thermal performance of HP charged with aqueous CuO nanofluid as the working fluid. In unsteady state condition, the startup time was reduced when aqueous CuO nanofluid was used as the working fluid. Significant enhancement of 40% in heat