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Fluid flow and heat transfer characteristics of nanofluids in heat pipes: A review☆

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ABSTRACT

Comprehensive research work on heat transfer in heat pipe using traditional working fluids has been carried out over the past decade. Heat transfer in heat pipes using suspensions of nanometer-sized solid particles in base fluids have been experimentally and theoretically investigated in recent years by various researchers across the world. The suspended nanoparticles effectively enhance 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 recent developments in the study of heat transfer using nanofluids in heat pipes and some important inferences from the various papers are also highlighted. It also discusses the mechanism of heat transfer enhancement or degradation, the existing problems for various heat pipes utilizing nanofluids, and explores the possible application prospects.

Contents

1. Introduction

With the increase of work frequency and heat flux of electronic components, the dissipation problem of the high heat flux components becomes one of the key technologies of the electronic device design. Up to now, heat pipe technology has been widely applied in the field of microelectronics cooling, as the improved construction of the general heat pipes, flat heat pipe has now become a hotspot technology of heat pipe research and development [1,2] and has been widely applied in many fields, such as spacecraft thermal control, high heat flux electronic equipment cooling, medical and health undertakings, and household appliances. Heat pipe is a device used to transfer the heat from one place to the other. The heat pipe consists of evaporator section, adiabatic section and condenser section (Fig. 1). Heat absorption takes place in the evaporator section and heat rejection at the condenser section. Adiabatic section is fully insulated. The heat pipe is evacuated using a vacuum pump and is filled up with the working fluid. The working fluid absorbs the heat at one end of the heat pipe called evaporator and releases the heat at the other end called condenser. Due to the capillary action, the condensed working fluid through the mesh wick structure returns to the evaporator, on the inside wall of the pipe. Normally conventional fluids are used in heat pipes to remove the heat [3].

For the time being, nanofluids play an important role in heat pipes to increase the heat transfer compared to conventional fluids.

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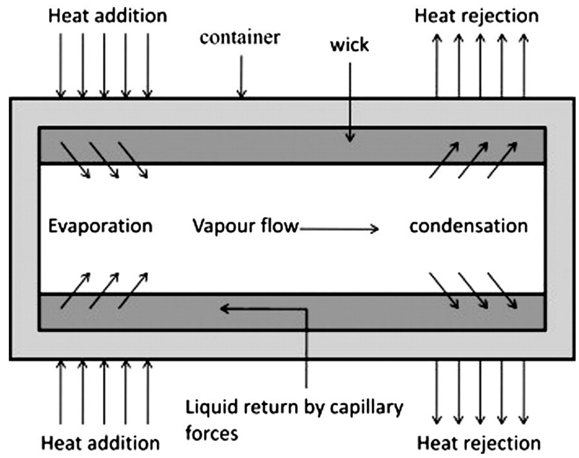

Fig. 1. Schematic diagram of heat pipe [3].

Thermal conductivity is an important parameter in enhancing the heat transfer performance of a heat transfer fluid. Researchers have also tried to increase the thermal conductivity of base fluids by suspending nanometer-sized solid particles in fluids since the thermal conductivity of solid is typically higher than that of liquids, as seen from Table 1. Many researchers have presented the heat transfer characteristics of heat pipe using nanofluids [3]. The concept of "nanofluid" has firstly proposed by Choi and Eastman [4]. That is, adding nanoscale metal or metal oxide particles in the liquid with a certain way and proportion, which forms a new class of heat transfer and cooling working fluid. Because of its stability and high thermal conductivity, the nanofluid shows a promising prospect in the heat transfer enhancement. Keblinski et al. [5] made an interesting review to discuss the properties of nanofluids and future challenges. Weerapun and Somchai [6] summarized the published experimental and numerical investigations of forced convective heat transfer of nanofluids. Bahrami et al. [7] provided an overview on the effective thermal conductivity of nanofluids. Cheng et al. [8] carried out an overview on the studies of nanofluids boiling and two phase flow. The application of nanofluid research in heat pipes was firstly published by Chien et al. [9]. Over 20 relevant articles have been published since then, involving mesh wicked heat pipes [10,11], micro-grooved heat pipes [9,12–17], sintered metal wicked heat pipes [18] and so on.

An experiment concerning a cylindrical mesh wicked heat pipe was performed by Tsai et al. [10]. The working fluid was an aqueous suspension of various-sized gold nanoparticles. The inner diameter and the length of the tested copper tube were 6 mm and 170 mm, respectively. A 200 mesh screen was distributed on the inner wall. The experimental results showed that the total thermal resistance of the heat pipe reduced a lot due to the addition of nanoparticles under the same cooling condition. The experiment also found that the best way to use nanofluids in the heat pipe was using a well dispersed nanofluid. The mechanism of the heat transfer enhancement was explained as follows: a major thermal resistance of heat pipe was caused by the formation of vapor bubbles at the liquid–solid interface; the suspended nanoparticles tended to bombard the vapor bubbles during the bubble formation; therefore, it was expected that the nucleation size of vapor bubbles was much smaller for the fluid with suspended nanoparticles than that without them. Chen et al. [11] studied the performance of axially flat mesh wicked heat pipe (FHP) using water-based silver nanofluids with different nanoparticle concentrations under the input power of 20–40 W. The average diameter of nanoparticles was 35 nm. The height and the length of the FHP used in the experiment were 3 mm and 200 mm, respectively. It was found that the total thermal resistance of the heat pipe using nanofluids was reduced compared with that of the heat pipe using deionized water under the same cooling condition. In the volume concentration range tested, the larger the volume concentration of nanoparticles was, the more reduction of the thermal resistance could be. The mechanisms of heat transfer enhancement were given by authors as: (1) the increase of the wettability increased the critical heat flux; (2) the mutual increases of the liquid thermal conductivity and the wick conductivity increased the heat transfer.

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. Water-based CuO nanofluids and water-based carbon nanotubes without dispersant were used as the working fluids [15]. All experiments show that adding nanoparticles into the base liquid can enhance both the heat transfer performance and the maximum input power of heat pipes [9,12–17].

Analytical models carried out to investigate the thermal performance of rectangular and disk-shaped heat pipes using nanofluids. Some of the more widely utilized nanoparticles, such as Al_2O_3, CuO and TiO_2 with a range of nanoparticle diameters were considered. Results show that the presence of nanoparticles in the working fluid leads to a reduction in the speed of the liquid, smaller temperature difference along the heat pipe and the possibility of reduction in size under the same operational conditions. It is similar to what has been observed experimentally that using a nanofluid will reduce the thermal resistance of the flat-shaped heat pipe. The maximum heat removal capability of the flat-shaped heat pipe was displayed for a range of wick thicknesses and nanoparticle concentration levels. The existence of an optimum nanoparticle concentration level and wick thickness in maximizing the heat removal capability of the flat-shaped heat pipe was established [19]. Alizad et al. [20] studied the thermal performance, transient behavior and operational start-up characteristics of flat-shaped heat pipes using nanofluids. Three different nanofluids (CuO, Al_2O_3, and TiO_2) were utilized in their analysis. A comprehensive analytical model, which accounts in detail the heat transfer characteristics within the pipe wall and the wick within the condensation and evaporation sections, was utilized. The results illustrate the enhancement in the heat pipe performance while achieving a reduction in the thermal resistance for both flat-plate and disk-shaped heat pipes throughout the transient process. It was shown that a higher concentration of nanoparticles increases the thermal performance of either the flat-plate or disk-shaped heat pipes. The study has also established that for the same heat load a smaller size flat-shaped heat pipe can be utilized when using nanofluids.

The papers presented on the study of heat transfer and flow characteristics of the heat pipe with nanofluids have rarely been reported. 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.

Table 1
Thermal conductivities of various solids and liquids [3].

Thermal conductivity (W/m-K)	Material
401	Metallic solid copper
237	Aluminum
148	Nonmetallic solid silicon
40	Alumina (Al_2O_3)
72.3	Metallic liquid sodium (644 K)
0.613	Nonmetallic liquid water
0.253	Ethylene glycol (EG)
0.145	Engine oil (EO)

2. Preparation of nanofluids

The powder form nanoparticles which disperse in host liquids are called nanofluids. Nanofluids can be produced by two techniques; the two-step (double-step) method, and one-step (single-step) method.

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