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Experimental investigation of graphene oxide nanofluid on heat transfer enhancement of pulsating heat pipe

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ABSTRACT

Pulsating heat pipes (PHPs) are heat transfer devices which are widely utilized in electronic devices and energy systems. Improvement in thermal performance of PHPs will lead to higher heat transfer capacity and enhancement in the efficiency of systems which PHPs are applied. In this study, an experimental investigation was performed on the thermal performance of a pulsating heat pipe by applying graphene oxide nanofluid as working fluid. Four concentrations of graphene oxide (0.25, 0.5, 1, and 1.5 g/lit) in water as base fluid were used in the PHP. Results indicate that adding graphene oxide sheets increased thermal conductivity and viscidity of the base fluid. Moreover, utilizing graphene oxide can decrease thermal resistance of PHP up to 42%. In addition, high concentration (1.5 g/lit) of the nanofluid worsen thermal performance of the PHP in comparison with pure water which is attributed to increase in dynamic viscosity of nanofluid. Finally, a regression model is proposed in order to compare effects of heat input and concentration of nanofluid on thermal resistance mathematically.

1. Introduction

Heat pipes are two-phase heat transfer devices which are widely used in various applications due to their high effective thermal conductivity [1,2]. There are different types of heat pipe which are categorized based on their structure [3,4,5]. Pulsating heat pipes (PHPs) are the most compact of them. Effective thermal conductivity of PHPs is much higher in comparison with metals due to their two-phase heat transfer mechanism. PHPs consist of a capillary tube which is bent into several turns and filled by degrees with a fluid [6]. If two ends of capillary tubes are connected to each other, the PHP is closed loop PHP, while when the ends are separated, the PHP known as open loop PHP. The main parts of PHPs are evaporator, condenser sections. In addition, adiabatic section exists in the cases there is distance between condenser and evaporator. The working fluid in the PHP evaporates by receiving heat in evaporator section. The vapor converts into liquid by heat dissipation in the condenser [7]. These two-phase heat transfer mechanism is the main factor of heat transfer in PHPs. PHPs are passive heat transfer devices since the pressure instabilities in tubes is the main reason of fluid motion.

Pulsating heat pipes have several applications. For instance, PHPs can be used in heat recovery systems [8] very efficiently compared with other heat transfer devices due to their high heat transfer capability. In addition, PHPs are used in renewable energy systems such as solar desalination systems [9], solar water heater [10] and thermal storage systems [11]. Moreover, pulsating heat pipe has reliable performance in solar combined heat and power generation systems [12]. By applying fluids with specific properties, PHPs are able to work efficiently at very low temperatures [13].

Several parameters affect thermal performance of PHPs such as geometry [14,15], inclination angle, operating condition [16], and working fluid [17]. Ebrahimi et al. [18] experimentally investigated a flat plate PHP with interconnecting channels. Results indicated that interconnecting channels can improve thermal performance of the PHP due to consolidation in flow circulation in the channels. Xue et al. [19] investigated the effect of inclination angle on the thermal performance of a PHP and concluded that lower thermal resistance is obtainable by increasing inclination angle. Sun et al. [16] conducted a study on a PHP filled with water and HFE-7000. It was observed that for evacuation pressure of 0.01 Torr, at 80 w heat input, the PHP filled with water had better thermal performance; while at increased evacuation pressure (over 100 Torr), the PHP filled with HFE-7000 had lower thermal resistance [16]. Working fluid has the most important role in thermal performance of PHPs. Fluid with special thermophysical properties such

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as higher thermal conductivity and lower dynamic viscosity can perform better in PHPs [20]. Lower dynamic viscosity leads to easier fluid motion in tube and higher thermal conductivity increase heat transfer of PHPs.

There are different methods to change thermophysical properties of fluids and obtain more appropriate working fluids such as adding surfactants [21], and nanofluids [20,22,23,24]. Nanofluids consist of a base fluid and particles or sheets which are in nanometer scale [25]. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes [26]. Common base fluids include water, ethylene glycol and oil. Adding surfactant to the based fluid mainly influences on surface tension, while adding nano particles and sheets to the working fluid, improve thermal conductivity of fluid and heat transfer ability [27,28].

In this study, effects of adding grapheme oxide sheets on the thermal performance of a PHP filled with graphene oxide nanofluid as working fluid is experimentally investigated. Thermophysical properties of nanofluid with concentration 0.25, 0.5, 1 and 1.5 g/lit graphene oxide are measured. Thermal performance of a two-turn PHP at different heat inputs is investigated. Finally, a regression model is proposed in order to get better inside into the effects of heat input and nanofluid concentration on thermal resistance of the PHP mathematically.

2. Experimental set-up

In order to investigate the thermal performance of PHP, the graphene oxide nanofluid was used in a 2-turn PHP. The inner diameter and outer diameter of the PHP are 2 mm and 4 mm, respectively. Ni-Cr heater wires were used as heating elements in evaporator section. The ends of the element were connected to Micro power supply. The glass wood with 30 mm thickness was used as insulation in the evaporator and adiabatic sections to prevent heat transfer with ambient. In order to achieve different heat inputs, the voltage of power supply changed in each step. Two K-type thermocouples were used in evaporator section and two same thermocouples were located in condenser section in order to measure temperatures. Thermocouples were connected to temperature data logger model 4208SD. Temperatures were recorded with 0.5 Hz frequency. The thermal resistance was defined as = = $\Delta T/q$, where ΔT and q are temperature difference between evaporator and condenser, and heat input, respectively.

Firstly, the PHP was evacuated with a vacuum pump and the pressure inside the PHP reached approximately 50 Pa. In the next step, the PHP filled with the working fluid. The filling ratio in all tests was 50% of the total volume of the PHP. The schematic of the PHP is shown in Fig. 1.

2.1. Methodology of nanofluid preparation

The graphene oxide was prepared by modified Hummer method. 1 g of graphite powders was mixed with 46 mL sulfuric acid in 80 °C on a hotplate stirrer. Afterwards, the solution was cool down to 25 °C and put in an ultrasonic bath for 1 h. In next step, 1 g NaNO3 with 1:1 ratio was added to the solution and mixed for 10 min on the stirrer. After that, KMnO4 with 6:1 ratio was added to the solution and mixed on the stirrer. The obtained solution was mixed on the stirrer for more than 1 h in 37–40 °C. Afterward, 40 mL DI water was added and mixing procedure was done for 30 min at 85–90 °C. Subsequently, 100 mL DI water added to the solution and after that 5 mL, H_2O_2 was added. The solution was filtered and then washed by HCl acid with 10% concentration and DI water, till the PH of the solution reached in the range 4–5. In this study, four concentrations of graphene oxide, 0.25, 0.5, 1, and 1.5 g/lit, in water as base fluid were used in the PHP. In order to investigate the effects of thermal conductivity and dynamic viscosity of nano fluid on thermal performance of PHP, these parameters were measured by KD2 PRO THERMAL PROPERTIES METER and Lauda viscometer, respectively.

In order to evaluate synthesized graphene oxide, X-Ray diffraction (XRD) was conducted on copper as anode. Obtained result is shown in Fig. 2. As shown in Fig. 2, the 2θ position of the graphen oxide peak was 10.99°, which is in the range obtained in other studies [29].

3. Results and discussion

Thermophysical properties of fluid have specific role in thermal performance of PHPs [20,30]. In this study the effect of thermal conductivity and dynamic viscosity on thermal performance of a PHP is investigated. Measured thermal conductivity of different working fluids is shown in Table 1.

As shown in the Table 1, the effective thermal conductivity of nanofluid promotes by increasing concentration, since graphene oxide nano sheets have higher thermal conductivity compared with pure water. Therefore, adding these nano sheets will improve thermal conductivity of the fluid [32].

Another thermophysical property which affects thermal performance of PHP is dynamic viscosity of working fluid. Measured dynamic viscosities of different working fluids are shown in Table 2.

As shown in Table 2, dynamic viscosity increases by increment of concentration. However, it has unfavorable effect on the fluid pulsation in PHP. Lower dynamic viscosity leads to easier fluid motion in the tube and more appropriate thermal performance of the PHP.

In this study, effects of heat input and concentration of graphene oxide were investigated experimentally. Fig. 3 shows the thermal resistance of the PHP for different concentration of graphene oxide nanofluid.

As shown in Fig. 3, thermal resistance reduced by increasing the

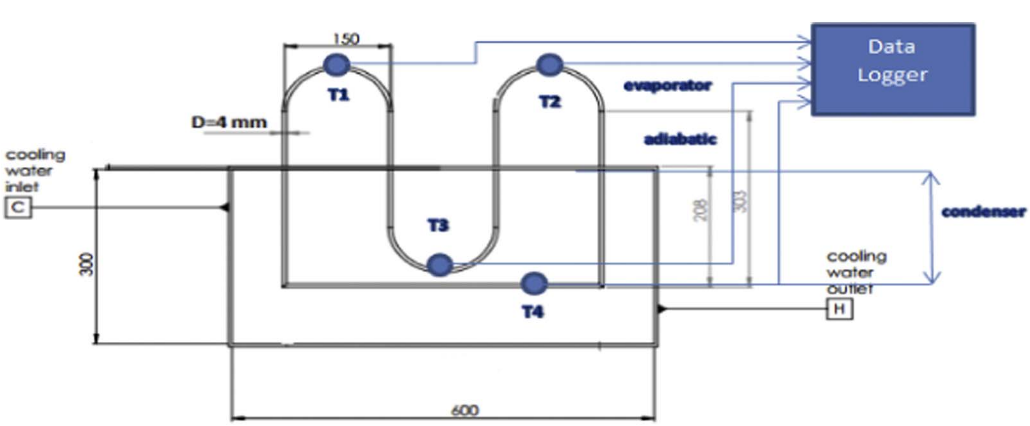

Fig. 1. Schematic of the PHP.