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Thermal performance and efficiency of a thermosyphon heat pipe working with a biologically ecofriendly nanofluid☆

M.M. Sarafraz [a,*], F. Hormozi [a], S.M. Peyghambarzadeh [b]

[a] Faculty of Chemical, Petroleum and Gas Engineering, Semnan University, Semnan, Iran
[b] Department of Chemical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran

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ABSTRACT

Thermal performance of a wickless thermosyphon heat pipe charged with a biologically-produced ecofriendly working fluid is experimentally studied. Biologically dependable process is a cheap and promising way for obtaining the high quality nanoparticles. Thus, in the present work, using the green synthesis, silver nanoparticles are produced from the aqueous silver nitrate and the fresh tea leaf extract. The formation of Ag nanoparticles was observed by the change of color from colorless to dark brown by the addition of silver nitrate into the leaf extract and proved by SEM, TEM and XRD quality tests. Performing the two-step method, nanofluids at different weight concentrations were prepared, stabilized and used as working fluid inside the thermosyphon. The heat pipe was fabricated from the smooth copper tube with inner and outer diameters of 10.7 and 12 mm respectively and total length of 280 mm. Uniform heat flux was applied into the evaporator section using electrical cartridge heater and the condenser section was constantly cooled using ethylene glycol/water cooling jacket. Influence of different operating parameters such as applied heat flux to the evaporator section, filling ratio of working fluid, heat pipe inclination, nanoparticle concentration and response time on the thermal performance and efficiency of heat pipe was also experimentally studied and briefly discussed. Results showed that using the nanoparticles leads to the reduction in temperature distribution and enhances the thermal performance of heat pipe.

1. Introduction

Although heat pipes are new to the world of heat transfer, they can open the new horizon toward the economic heat transfer strategies and passive cooling systems as well as process intensification. In fact, heat pipes are the innovative product for saving, transferring and storing the thermal energy. Generally, heat pipes (HPs) are passive devices which can work in a two-phase heat transfer mode and have a higher energy-saving capability and superior thermal performance in comparison with other heat transfer devices and are widely utilized for cooling the electronic chipsets such as CPU, GPU and VGA. The wickless gravity-assisted thermosyphon HPs are one of the simplest and efficient types of HPs which can widely be employed in micro-device cooling, computers, solar energy collectors, aeronautics sciences, missiles, spacecraft thermal control, micro-transportation systems, cooling loops, fuel cells, heat recovery systems and car batteries in form of parallel or bundle arrangements. Effective thermal conductivity coefficient of a heat a thermosyphon heat pipe can be orders of magnitude higher than that of highly conductive metals and conductive materials, such as aluminum or copper. Generally, thermosyphon HPs consist of three main sections: 1) Evaporator section in which heat is absorbed from the heating source (e.g. electronic chipset or processor) and is transferred to the working fluid, 2) adiabatic section (usually isolated) which navigates the working fluid to the condenser section, and 3) condenser which delivers the absorbed heat to the cold environment (e.g. to a heat sink). Therefore, working fluid has an important role in heat transfer mechanism of HPs. For the first time, the idea of dispersing the solid particles inside the fluid was introduced by Maxwell and utilization of particles in size of nanometer was first studied by a research group at the Argonne National Laboratory and officially introduced by Choi [1] as nanofluid is a stable solid–liquid suspension created by dispersing the nanoparticles within the traditional working fluid which is called base fluid. They also showed that the striking feature of nanofluids is their superior thermal conductivity which sometimes is ten times larger than base fluids. Since then, numerous articles have been published that mainly focused on the prediction and measurement techniques in order to evaluate the thermal conductivity and performances of nanofluids in cooling systems and heat transfer devices particularly for thermosyphon heat pipes [2–12]. Applying nanofluids as working fluids in HPs is a novel, but phenomenal idea that can be found only in the recent literatures. For example Kang

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* Corresponding author.
E-mail addresses: mohamadmohsensarafraz@gmail.com (M.M. Sarafraz), fhormozi@semnan.ac.ir (F. Hormozi), peyghambarzadeh@gmail.com (S.M. Peyghambarzadeh).

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Nomenclatures

A	heat transfer area, m^2
D	diameter of heat pipe, m
e_s	uncertainty error due to instruments
e_r	uncertainty error due to repeatability of results
h	heat transfer coefficient, $W \cdot m^{-2} \cdot °C^{-1}$
I	current, A
k	thermal conductivity, $W \cdot m^{-1} \cdot °C^{-1}$
L	length of heat pipe, m
q''	heat flux, $W \cdot m^{-2}$
Q	heat load, W
R	thermal resistance, °C/W
T	temperature, °C
t	time, min
V	voltage, volt

Subscripts

a	adiabatic section
c	condenser section
e	evaporator section

Greek symbols

Δ	difference
τ	time constant
Ψ	constant
ϕ	weight fraction

Abbreviations

HP	heat pipe (wickless type)

et al. [13] investigated the influence of silver nanofluids on grooved heat pipe with circular cross section and 200 mm length and 6 mm diameter. Results demonstrated that thermal resistance of the heat pipe decreases 10–80% in comparison with water. Noie et al. [14] employed a two-phase closed thermosyphon (TPCT) with alumina/water nanofluid as the working fluid and nanoparticle volume concentrations ranging from 1% to 3%. Their experimental results indicate that for different input powers, the efficiency of the TPCT increases up to 14.7% when using alumina nanofluid instead of pure water. There are many parameters which influence the thermal performance of a HP. Shafahi et al. [15] studied the thermal performance of a cylindrical heat pipe containing different nanofluids (alumina, copper oxide, and titanium oxide). In fact, they mainly studied the influence of type of nanofluid on the thermal performance of HP. The nanoparticles in the liquid enhanced the thermal performance of the heat pipe by reducing the thermal resistance and enhancing the maximum heat load. Smaller particles have a more pronounced effect on the temperature gradient along the heat pipe. Liu et al. [16] investigated the thermal performance of an inclined miniature grooved heat pipe using CuO/water nanofluid as the working fluid. They focused on the effects of the inclination angle and the operating pressure on the heat transfer of the heat pipe using nanofluid with a 1.0 wt.% mass concentration of CuO nanoparticles. An inclination angle (tilt angle) of 45° corresponds to the best thermal performance for heat pipes using both water and nanofluid. Hajian et al. [17] experimentally investigated the thermal resistance and response time of a heat pipe, showing them to be the characteristics of steady states and transient states, respectively. They prepared Ag–water nanofluids with various nanoparticle concentrations of 50, 200 and 600 ppm at heating rates ranging from 300 to 500 W. The thermal resistance and response time of the heat pipe with nanofluids decreased up to 30% and 20% respectively, in comparison with water as a base fluid. In some references, thermosyphons and heat pipes have been studied in details. They are known as highly efficient heat transfer media due to the utilized phase change. Design, operation principles and thermal performance are discussed in detail in several textbooks such as Reay and Kew [18] or Faghri [19]. There are still researches which belong to the enhancement of thermal performance of thermosyphon heat pipes working with Ag nanofluids that can be found in the literatures [20–23].

In the present work, an experimental investigation employing Ag nanoparticle dispersed in water is performed in order to study the thermal performance of a thermosyphon heat pipe. Unlike the previous studies, a biological, ecofriendly method for producing the nanoparticle is employed which is cost-effective way to manufacture the Ag nanoparticles. Using the two-step method, nanofluids then were prepared, stabilized and utilized as working fluid. Thermal performance of HP is evaluated in case of using nanofluids. Likewise, influence of different operating parameters such as heat flux, inclination of heat pipe, working fluid concentration and HP response time is experimentally investigated and briefly discussed.

2. Experimental

2.1. Biological synthesis, preparation and stabilization of Ag nanofluids

In the present work, for producing the nanoparticles, biological method introduced by Yu et al. [24] was used. As a reducing agent, tea leaf extract was used. About 14.8 g of green tea leaves was dried in microwave-assisted oven and after milling was added to 100 mL deionized water in a flask. The mixture was boiled for 7–10 min, quenched, screened, and filtered. Although Yu et al. suggested that the filtrate should be kept in 4 °C, we stored the filtrate at 10 °C as the stock solution. Using TOC analyzer, total organic carbon (TOC) content of tea extract was evaluated and analyzed (TOC—Dohrmann, Teledyne), which was approximately 18.97 g/L. 750 mL silver nitrate (10 mM) was added drop wise into the 15 mL tea extract working solution while it was agitated using magnetic stirrer with speed of 800 rpm for 120 min at 30–50 °C. Ag nanoparticles were concentrated and purified by centrifugal ultrafiltration and then rinsed and dried. Noticeably, formation of Ag nanoparticles was indicated by the appearance of signature brown color of the solution which is in a good agreement with observations carried out by Yu et al. [24]. To prepare the nanofluids, obtained particles were dispersed into the DI water as base fluid using the method we introduced in our previous publications [25–28]. Nanofluids were prepared at different weight concentrations of 0.1–0.4%. PH control, sonication as well as surfactant were performed for stabilizing the nanofluids. Table 1 shows the stability condition for Ag/water nanofluids.

Quality tests were also performed to ensure about the size, shape, purity and uniform dispersion of nanoparticles into the base fluids. SEM and TEM images can be seen in Fig. 1(A–B).

As can be seen in Fig. 1(A), nanoparticles have uniform spherical shape and almost have an identical mean size that ranged from 40 to 50 nm which was also proved by particle size-count test. As Fig. 1(B) demonstrates, nanoparticles are well-dispersed within the base fluid. As can be seen, neither agglomeration nor clustering is formed inside the bulk of nanofluid.

To check the purity and morphology, we examined the produced nanoparticles with XRD tests. XRD pattern depicted in Fig. 2(A) demonstrates the single-phase Ag nanoparticles with a monoclinic structure which implies on this fact that there is no impurity other than Ag; however, a small peak due to existence of AgO_2 was also observed which is negligible. Accordingly, no significant peaks of impurities are found in XRD pattern. XRD diffraction pattern gives information on symmetry size and shape of the particle and purity of particles from peak positions.