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Effect of electric field on thermal performance of thermosyphon heat pipes using nanofluids

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ABSTRACT

In the present study the effect of electric field on thermal performance of two-phase closed thermosyphon as external modifications has experimentally investigated. Internal modifications applied by using two different water based nanofluids as working fluids. Nanofluids prepared by adding Al_2O_3 and CuO nanoparticles into the pure water using ultrasonic vibration system without adding any dispersant or stabilizer to prevent any possible change of chemical properties of the nanofluid. Results show that the thermal performance, and the Nusselt number ratio of thermosyphon gradually increase by increase in electric field intensity and nanofluids concentration. These values decrease by increasing in input power. Results also show that Al_2O_3/water nanofluid improves thermal performance of thermosyphon more than CuO/water nanofluid. Also, the experimental results indicate that the effect of nanoparticles on thermosyphon thermal performance is higher than the electric field. Maximum enhancement of Nusselt number ratio is about 43% that observed at 60 W input power and 2.5% by volume of Al_2O_3 nanoparticles in the work fluid under 20 V electrical field strength. Enhancement value is 39% for CuO/water nanofluid.

1. Introduction

From operating point of view, there are different types of heat pipes such as wick based heat pipes, oscillating heat pipes, loop heat pipes, and thermosyphon. Thermosyphon, which operates according to gravity, is the most common type. Thermosyphon has very high heat transfer capability compared to other types of heat pipes. Operating temperature ranges from triple point to critical point of base work fluids [1–5]. Thermosyphon loop can be divided into three parts: evaporator, adiabatic, and condenser. Heat source can be a bath or an electrical heating element and working fluid is a saturated fluid [6,7]. Thermosyphon is capable of transmitting large amount of heat with a small heat transfer area that makes it one of the most efficient heat recovery devices [7–10].

Heat transfer enhancement is the most interesting topic in design of heat transfer devices. Generally the heat transfer enhancement techniques are classified into two major groups, active and passive heat transfer enhancement techniques. The active techniques use external forces such as the electric field. The passive techniques use additives into fluid or special surface geometry. Applying an electric field on heat transfer media is a useful method of heat transfer enhancement that introduced as electrohydrodynamic (EHD). Electric field has substantial effect on boiling and condensation processes and improves the heat transfer coefficient [11–16]. The effect of electric field on the heat transfer enhancement was reported by Senflleben for the first time [17].

Poulter and Miller [18] investigated the heat transfer enhancement in a shell and tube heat exchanger. An Applied electric field causes the heat transfer to increase up to 500% compared to the same condition without electric field. Chen et al. [19] studied the effect of electric field on the heat transfer enhancement in condensation of a dielectric liquid on the horizontal enhanced tube. Heat transfer increased up to 260% in an electric field. Omidvarborna et al. [11] represented the influence of electric field on condensation of R-134a. Results showed an improvement of condensation heat transfer coefficient. Existence of non-condensable gas has a contrary effect on heat transfer coefficient. Wangnipparnto et al. [14] studied the effect of electric field on the air side performance of thermosyphon heat exchanger in low Reynolds number. Low strength electric field had a trivial impact on heat transfer coefficient. In addition, the effects of electric field disappeared by increase in Reynolds number. Applying electric field results in 15% increase in heat transfer coefficient for low

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Nomenclature

C_p [J/(kg °C)]	heat capacity of water
d [m]	thermosyphon diameter
e_{xi}	measurement error
I [A]	electric current
L [m]	thermosyphon length
$\dot{m}$ [kg/S]	water mass flow rate
Nu_E	Nusselt number in the presence of electrical field
Nu_o	Nusselt number in the absence of electrical field
Q_{in} [W]	input heat at condenser section
Q_{out} [W]	output heat at condenser section
T_i [°C]	water inlet temperature
T_o [°C]	water outlet temperature
V [v]	electric voltage
η	thermal efficiency
$\Delta\theta$ [°C]	difference between evaporator and condenser section surface temperatures

Reynolds number. Alamgholilou and Esmaeilzadeh [20] mentioned considerable enhancement of heat transfer, using electric field.

The inclusions of nanoparticles into a conventional fluid promise the generation of a novel class of heat transfer fluids. James Clerk Maxwell (1881) was the first one who proposed the idea of dispersing solid particles in fluids in order to enhance the heat transfer rate. Nanofluids are emerging as alternatives to conventional heat transfer fluids. The term 'Nanofluid' is used to indicate a newly introduced special class of heat transfer fluids that contain nanoparticles (<~100 nm) that are uniformly and stably suspended in a conventional heat transfer liquid [21]. Thermal conductivity of fluid increases as a result of adding nanoparticles. Increasing nanoparticles concentration also improves thermal properties of nanofluid [8,22–26]. Among the advantages of nanofluids their capability of transmitting a large amount of heat, provision of smaller heat transfer area, better stability, and rheological properties can be mentioned [7,8,27].

Particle volume fraction, particle thermal conductivity, particle size, interface layer, and temperature are parameters that affect the thermal conductivity of nanofluid. Changing nanofluid properties, such as thermal conductivity, has only a minor effect on thermal performance of thermosyphon and there exist other parameters that affect the thermal performance of thermosyphon [11,28,29]. The heat transfer performance of nanofluid in natural convection was improved at low concentration of nanoparticles, but high concentration of nanoparticles had a contrary effect on nanofluid thermal performance [23,30]. Huminic et al. investigated the effect of iron oxide nanofluid and stated important enhancement in thermal characteristics of thermosyphon [24,27].

General advantages of two-phase closed thermosyphon in processes are a high rate of effectiveness and reliability, high efficiency, cost effectiveness, and capability of work at small temperature differences between the heat source and the heat sink. Thermosyphons have no moving part, thus they have fewer maintenance problems [6,31–33].

There are two approaches to improve performance of heat pipe or thermosyphon. The first approach is using more efficient fluids due to their properties (mainly thermal conductivity, surface tension), the second approach focused on mechanical, surface, and external modifications [34–37].

The objective of present investigation is identification of the effect of electric field and nanofluids on the heat transfer performance of thermosyphon experimentally. Experiments conducted using of Aluminum oxide/water nanofluid and copper oxide/water nanofluid, under the influence of different intensities of electric field in two phase closed thermosyphon. Effects of various parameters such as nanoparticles type, electrical field strength, heat power, and nanofluid concentration on the thermal performance of thermosyphon were investigated and discussed.

2. Materials and methods

2.1. Experimental

Experimental setup has been designed and constructed to study the influences of electric field and nanofluids on the thermal performance of two-phase closed thermosyphon. Tube length of thermosyphon is 40 cm. The condenser section is the first 15 cm of the tube from the top, next 5 cm is the adiabatic section, and the other 20 cm is the evaporator section. To apply the electric field to thermosyphon, the evaporator and condenser sections act as two different electrodes and are connected to a high voltage power supply. Electrical conductance of work fluid was the major concern when electric field applied. The key to solve the problem was a nonconductor Teflon tube that separate the evaporator section and condenser section. Teflon ring act as the adiabatic section of the thermosyphon. Evaporator and condenser utilize as electrodes that applied electric field. After the determination of the electrical discharge voltage, the tests are performed in voltages below the discharge voltage. The electric field strength performed in voltages below the discharge voltage. Initial vacuum process continues until the gage pressure reaches −0.9 bar in each experiment. In order to prevent heat loss the thermosyphon is well insulated. Thermometers with precision of ±0.1 °C were used to measure temperature.

The effect of electric field with different strengths on thermal performance and Nusselt number ratio were investigated. Different voltages of 5, 10, 15, and 20 kV were applied to create an electric field. Applying electrical fields higher than 20 kV lead to electrical discharge. In order to heat the working fluid in evaporator section, two electric heaters made of nickel–chrome wire were wrapped around the evaporator section, which was connected to a DC power supply. To prevent heat loss, the electric elements were insulator (Rock Wool) having a thickness of 20 mm for vaporization and adiabatic section and 10 mm for condenser section. The experiments showed that about 30–45 min was needed for the system to reach the steady state condition. All data was recorded at steady state condition. Experiments conducted with different constant input powers of 60, 80, 100, and 120 Watts to evaporator. DI water and different nanoparticle concentrations of 1.5, 2, and 2.5 volume percent used as the work fluid. Fig. 1 shows a schematic of experimental setup.

3. Data analysis

Heat input to evaporator section of thermosyphon by electric heaters is calculated as follows [1]:

$$Q_{in} = VI \quad (1)$$

where V is applied as voltage and I is the established current that produced input power. The output heat from the condenser section could be calculated as follows [1]:

$$Q_{out} = \dot{m}C_p(T_o - T_i) \quad (2)$$