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Research Article

Thermal Performance Improvement of the Heat Pipe by Employing Dolomite/Ethylene Glycol Nanofluid

Duygu Yılmaz Aydın[a], Metin Gürü[a], Adnan Sözen[b] and Erdem Çiftçi[b,*]

[a]*Chemical Engineering Department, Gazi University, Ankara, Turkey*

[b]*Energy Systems Engineering Department, Gazi University, Ankara, Turkey*

ABSTRACT. In heat transfer applications, heat pipes are widely- preferred because of some characteristics such as low cost, being able to be produced in any size and low maintenance cost make them superior. Moreover, the working fluid to be employed substantially affects the heat transfer characteristics of a heat pipe. In this paper, effects of nanoparticle addition into the ethylene glycol on heat pipe's thermal performance were analysed experimentally. Every test was done using two variant working fluids, ethylene glycol and dolomite nanoparticles-doped ethylene glycol, respectively. Dolomite nanoparticles (2% by weight) and Sodium Dodecyl Benzene Sulfonate (0.5% by weight) were doped into the ethylene glycol while preparing the dolomite/ethylene glycol nanofluid. After filling in the heat pipe, experiments were realized under changing working conditions. Using experimental data, efficiency and thermal resistance of the heat pipe were examined. Viscosity of the each working fluid was determined. The contact angle –wettability measurements were also performed to specify the effects of surface active agent addition. The obtained findings revealed that nanoparticle inclusion inside the base fluid, i.e. ethylene glycol, improved the thermal performance (efficiency) and decreased the heat pipe's thermal resistance substantially.

Keywords: Ethylene glycol, dolomite, nanofluid, efficiency, thermal resistance

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1. Introduction

Heat transfer is one of the most encountered phenomenon in industry required essentially for heating or cooling. This process is frequently put into practice by means of such devices as heat exchanger, heat pipe and so on. It is incontrovertible fact that heat pipes, used for transferring the heat in an efficient way and swift, are the most favoured one, because they are of a wodge of profits. For example, they can be manufactured in needed sizes, they require no extra equipment to operate, and their costs are not too high. Predominantly deionized water, some alcohols or oils were employed in heat pipes as working fluid. The working fluid used inside a heat pipe directly impacts thermal performance of the heat pipe. Consequently, thermophysical properties of the working fluid have tried to being developed day by day. There is a rising inclination in employment of nanoparticle-including working fluid, named as nanofluid. A nanofluid includes nanoparticles of a material (metal oxides like alumina, fly ash etc.), a base fluid in which nanoparticles are doped and a surface-active agent (surfactant) to prevent agglomeration of nanoparticles. It was observed in latest studies that nanofluids have been successfully employed as working fluid in various systems (Chen *et al.* 2013, Ghanbarpour *et al.* 2015, Kim and Bang 2015, Sözen *et al.* 2016, Khanlari *et al.* 2019, Baïri and Laraqi 2019, Ozdemir and Ergun 2019, Dagdevir *et al.* 2019, Sözen *et al.* 2019a, Sözen *et al.* 2019b) more in particular in heat pipes (Huminic and Huminic 2013, Venkatachalapathy *et al.* 2015, Tharayil *et al.* 2015, Sözen *et al.* 2018, Gürü *et al.* 2019). To illustrate; Hassan et al. (2015) analysed influence of accumulation on the heat pipe wick porosity following the alumina (Al_2O_3) nano fluid usage as the working medium. They set up a test rig and mounted temperature sensors to different locations of it. They realized the tests under various operating conditions. They employed the Scan Electron Microscope (SEM) images to illustrate the wicks after the repetitive usage of nanofluid solutions. They observed from these images that a nanoparticle layer takes place onto the wick surface. They found out that this particle accumulation entails critical capillary and thermal resistance effects that influence the heat pipe's thermal performance (efficiency) affluently. They inferred that a new design which diminishes the solid particles from the wick must be performed if a nanofluid solution is employed as working fluid in a heat pipe. Lin *et al.* (2015), in a turbulent pipe, implemented a number of numerical analysis of aqueous ZnO nanofluids including rod-like nanoparticles. They

* Corresponding author: erdemciftci@gazi.edu.tr

estimated the Nusselt numbers for discrete Reynolds numbers. They figured out that the Nusselt number for water and each nanofluid mixture increases as the Reynolds number ascends and also they reported that heat transfer rate could be improved by nanofluid utilization. Sadeghinezhad *et al.* (2016) experimentally analysed the thermal performance of the sintered heat pipes. They used a sintered heat pipe that contains a wick structure and water-based graphene nano platelets nanofluids or deionized water as working fluid. In their experiments, they utilized two different tilt angle, namely 0^0 and 60^0, and four varied heating power, that is 20, 40, 60 and 80 W. The pipe was charged with 0.1 wt% of graphene nano platelets nanofluid as the working fluid. In this study, they concentrated on not merely the graphene nano platelets' concentration, but inclination angle and input heating power effects on the heat pipe's thermal performance as well. The maximum decline they obtained in thermal resistance was 48.4% compared with deionized water. Furthermore, the maximum thermal conductivity improvements they achieved were 23.4; 29.8; 37.2 and 28.3 % for 60^0 tilt angle and 20, 40, 60 and 80 W heating powers, respectively. Ma *et al.* (2016) performed an experimental study to specify the nanofluid impact on heat transport capacity in an oscillating heat pipe. The nanofluid they prepared composed of HPLC grade water and diamond nanoparticles at the rate of 1.0% (vol.) and 5–50 nm in-size. Their experimental findings display that the heat transport capability of the oscillating heat pipe remarkably ascended when it was filled with the nanofluid at half filling ratio (50%). They also reported that the heat transport capacity of the oscillating heat pipe based upon the working temperature. At a heat input of 336 W, the oscillating heat pipe they analyzed could reach 0.03°C/W thermal resistance value. Malekan et al. (2019) investigated thermal resistance of a closed cyle oscillating heat pipe by using experiment-based results and artificial intelligence procedures. They prepared the nanofluid solution by doping cFe_2O_3 and Fe_3O_4 nanoparticles inside the base fluid. They also developed some intelligent models that depends upon the heat input applied to evaporator section, the working fluids' thermal conductivity and the ratio of the internal diameter to heat pipe length tested with the aim of forecasting the oscillating heat pipe's thermal resistance. Obtained results illustrated that nanofluids' utilization as working fluid in the oscillating heat pipe diminished the thermal resistance. The root-mean-square error for their intelligent models are 0.0508, 0.0556, and 0.0569 (C/W for MLFFNN, ANFIS, and GMDH, in turn.

Metal oxides and deionized water have been widely used for nanofluid preparation thus far (Das *et al.* 2003, Bang and Chang 2005). The purpose of this study was to investigate novelly effects of nanofluid prepared using dolomite nanoparticles and ethylene glycol on heat pipe efficiency. In addition, temperature distributions throughout the heat pipe wall and thermal resistance of heat pipe were investigated. In order to illustrate nanoparticle-addition effects, experiments were conducted filling the heat pipe with ethylene glycol and dolomite-ethylene glycol nanofluid consecutively.

2. Materials and Method

Thanks to their prominent heat transfer properties like high heat transfer ratio, low thermal resistance and high thermal conductivity, heat pipes enable efficient heat transfer. In Figure 1, the schematic diagram and a general view of the experimental set up were illustrated.

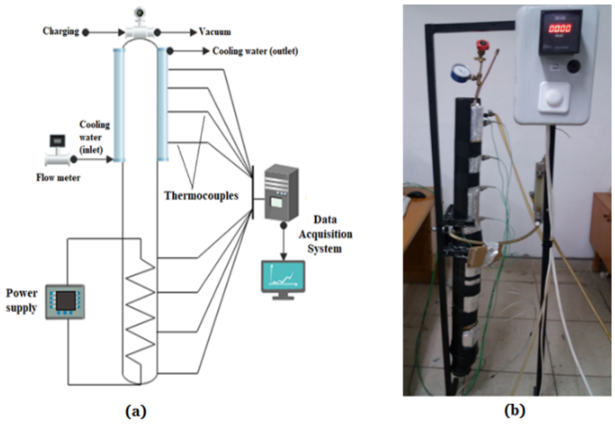

Fig. 1 The schematic (a) and general representation (b) of the experimental setup

A plain tube made of copper with an internal and external diameters of 13 mm and 15 mm, in turn, was utilized as the heat pipe. The heat pipe had also 100 cm in-length. Evaporator and condenser sections of the heat pipe had 400 mm in-length whilst remaining 200 mm constituted the adiabatic section situated on central span. In order to constitute a temperature difference between evaporator and condenser sections, evaporator section was warmed up through an electrical heat source that is of 1500 W nominal power. The experiments were carried out at 200 W, 300 W and 400 W heating power conditions and input power was gauged and tracked via a wattmeter. Condenser section of the experimental setup was wrapped by a cooling jacket in which water circulates to extract the heat transported. In a similar way, cooling water mass flow rates were set up as 5 g/s, 7.5 g/s and 10 g/s. In addition, K type 10 thermocouples were mounted on different locations along the heat pipe wall to track the temperature alterations (Figure 2). Each experiment was carried out thrice and average of all measured data was employed in theoretical analysis.

Dolomite, $CaMg(CO_3)_2$, is a mineral in the combination of calcium and magnesium carbonate. It is a fragile mineral and has specific gravity of 2.8 g/cm^3 and a hardness of 3.5-4. It is usually used iron-steel and glass industry. The composition of dolomite used in preparation of nanofluid is provided in Table 1.

Dolomite nanoparticles at the rate of 2% and SDBS at the rate of 0.5% were doped into ethylene glycol base fluid to prepare the nanofluid. Prepared nanofluid was detained inside the ultrasonic bath roughly 3 hours before each experiment to ensure homogeneity and stability of mixture.

Table 1
The materials composing the dolomite

Constituent	Ca	Mg	SiO_2	$CaCO_3$	HCl
% (m/m)	>23.50	>12.07	<0.90	>86.52	<1.00

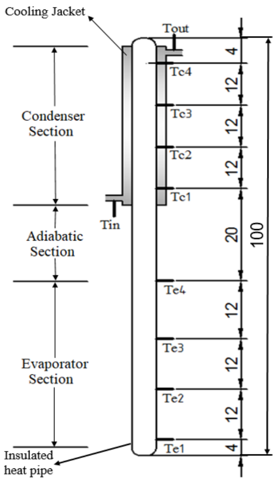

Fig. 2 Thermocouple locations on the heat pipe wall

3. Results and Discussion

By using the average values of the experimental results, heat transfer rate ($\dot{Q}_e$) was computed by using Eq. (1):

$$\dot{Q}_e = \dot{m}c(T_{out} - T_{in}) \quad (1)$$

In Eq. (1), $\dot{Q}_e, \dot{m}, c, T_{out}, T_{in}$ represent the heating power applied to evaporator section, mass flow rate, specific heat, output temperature, input temperature, respectively. Also, the temperature difference(ΔT) was calculated as follows:

$$\Delta T = \left(\frac{T_{e1}+T_{e2}+T_{e3}+T_{e4}}{4}\right) - \left(\frac{T_{c1}+T_{c2}+T_{c3}+T_{c4}}{4}\right) \quad (2)$$

T_e and T_c indicate temperatures of evaporator and condenser section depending on location in heat pipe, respectively. Heat pipe efficiency (η) was computed by using the ratio of dissipating heat by condensation ($\dot{Q}_c$) to the receiving heat by evaporation ($\dot{Q}_e$) as is seen in Eq. [3].

$$\eta = \frac{\dot{Q}_c}{\dot{Q}_e} \quad (3)$$

Thermal resistance of heat pipe (R) was also calculated by the equation below:

$$R = \frac{\Delta T}{\dot{Q}_e} \quad (4)$$

Temperature distributions throughout the heat pipe wall were recorded and they were used for theoretical calculations. Wall temperatures were provided for the experiments performed under 200 W, 300 W and 400 W heating powers and 5 g/s, 7.5 g/s and 10 g/s cooling water mass flow rates in Figure 3.

It can be seen from the figure that a gradual decline was observed in the wall temperature of the heat pipe in the evaporator-condenser direction. Nanofluid employment instead of ethylene glycol as working fluid significantly decreased the mean temperature of the heat pipe wall. The highest difference in the temperature was observed as about 35^{0}C under the test circumstances input of power of 200 W and cooling water flow rate of 7.5 g/s. The obtained figures also showed that dolomite-based nanofluid made easy not merely the heat drawn from the condenser, but also the heat acquisition from the evaporator section. While dolomite/ethylene glycol nanofluid was employed as working fluid in the heat pipe, average temperatures of evaporator and condenser sections became lower.

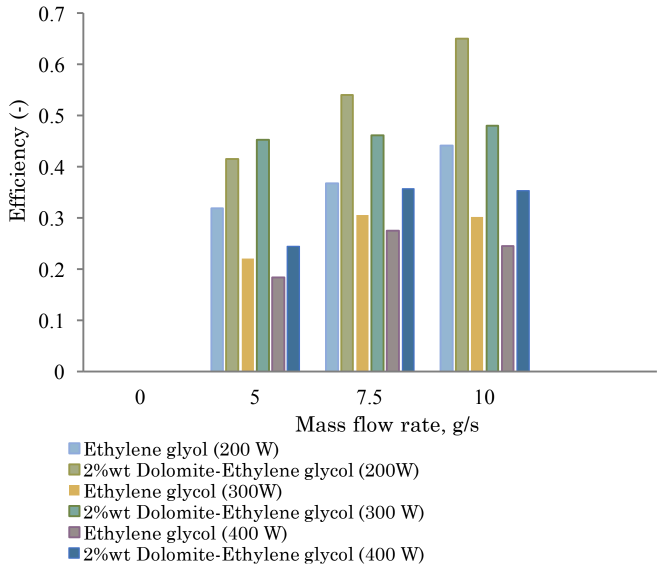

Fig. 4 Efficiency of the heat pipe under varying operating conditions

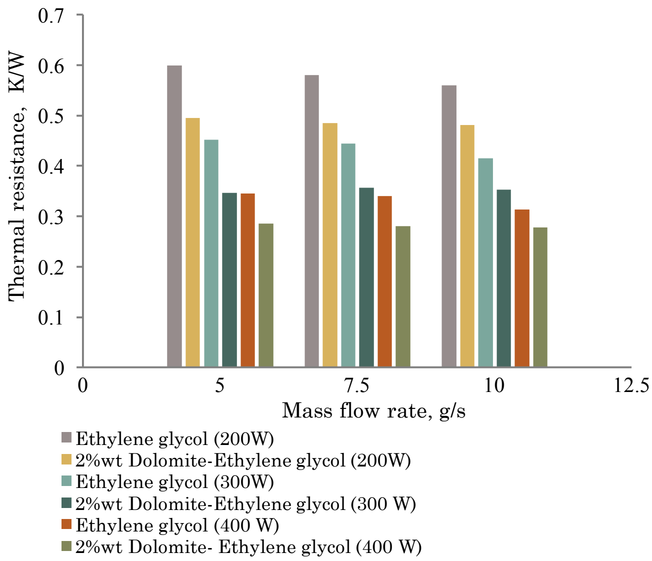

Fig. 5 Thermal resistance of the heat pipe under varying operating conditions

Figure 4 represents the heat pipe efficiency for 200 W, 300 W and 400 W heating powers and 5 g/s, 7.5 g/s and 10 g/s cooling water mass flow rates. Nanofluid utilization as working fluid considerably increased the heat pipe efficiency for all test conditions. The maximum increment, from 44% to 65%, in efficiency was observed under 200 W heating power and 10 g/s cooling water mass flow rate conditions However, when the heating power was increased, the increment in efficiency became lower.

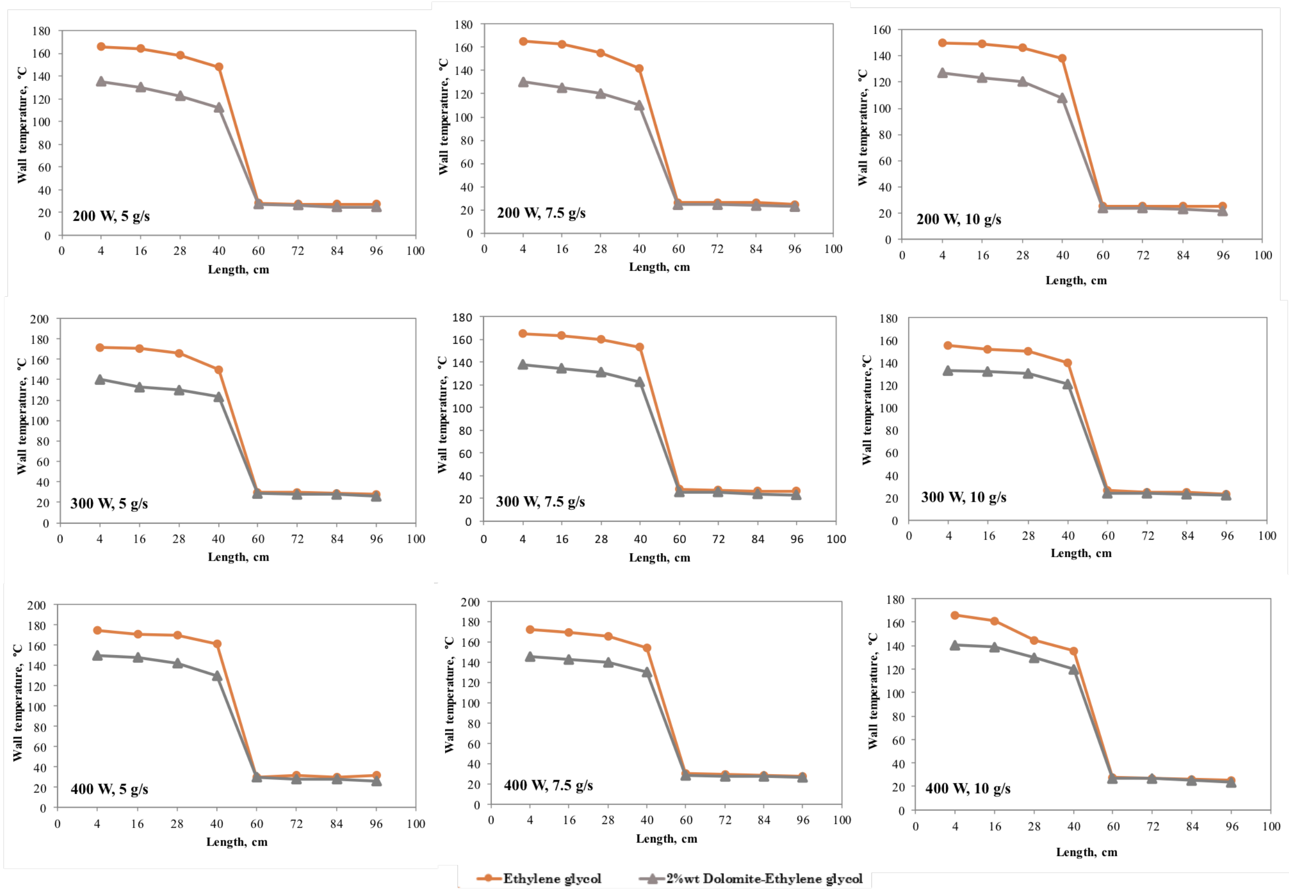

Fig. 3 Temperature distributions throughout the heat pipe wall under various working circumstances

The thermal resistance of the heat pipe is given in Figure 5 for varying heat input power, respectively. It can be overtly seen from this figure that heat pipe's thermal resistance could be remarkably reduced with the usage of dolomite-ethylene glycol nanofluid for all operating conditions. Optimum decline in thermal resistance was observed in lower heating powers as well.

Viscosity is an important thermophysical feature in heat transfer applications for nanofluids. Because the pumping force and pressure drop depend on this property of nanofluids. The viscosity of the dolomite/ethylene glycol nanofluid was determined by a viscometer (Brookfield) under varying temperatures as 20^{0}C, 40^{0}C, 50^{0}C, 60^{0}C, 70^{0}C, respectively. The obtained results were presented in Figure 6. It can be understood from the figure that nanofluid has more viscous than ethylene glycol in every temperature. Ultimately, contact angle-wettability measurements were done for both working fluids to exhibit the effects of surfactant addition (Fig. 7). As the contact angle decreases, wetting capability of the fluid increases. Surface tension of the base fluid, ethylene glycol, could be declined by doping surfactant into the mixture. Surface tension diminished in proportion to increment in wettability. As the contact angle decreases, wetting capability of the fluid increases. Surface tension of the base fluid, ethylene glycol, could be declined by doping surfactant into the mixture. Surface tension diminished in proportion to increment in wettability.

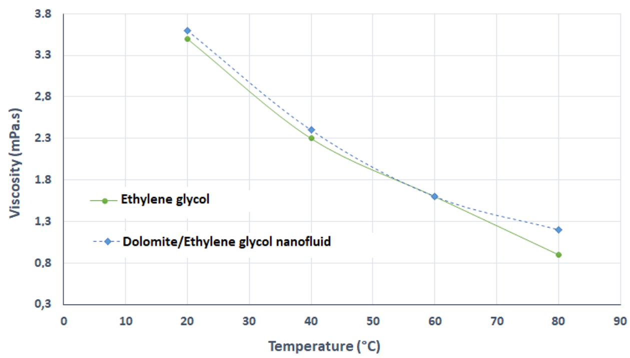

Fig. 6 Viscosity of the ethylene glycol and prepared nanofluid

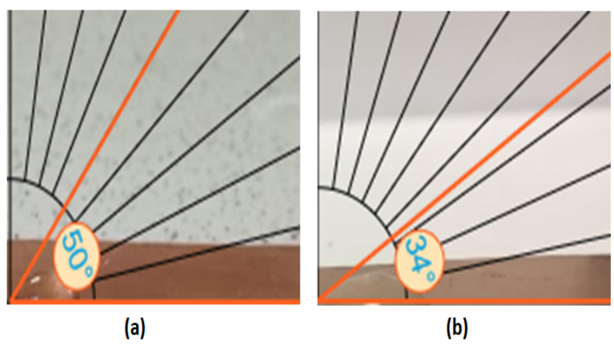

Fig. 7 Contact angle values of (a) ethylene glycol and (b) dolomite/ethylene glycol nanofluid

4. Conclusion

With the aim of improving the heat transfer aptitude of the heat pipe, dolomite nanoparticles-containing working fluid was prepared and investigated in a test rig. Heat pipe was charged by each working fluid at the rate of 1/3 of the overall volume (44.2 mL). Experiments were accomplished under changing working circumstances using ethylene glycol and dolomite/ethylene glycol nanofluid and then experimental results were compared to each other. The findings acquired from this study on the assessment of heat pipe's performance of a give rise to the consequent remarks:

- ✓ Distribution of the wall temperature was constrained to a limited span when dolomite nanoparticles-containing working fluid was used instead of ethylene glycol. The difference between the wall temperature of the evaporator and the condenser sections was smaller when employing the nanofluid as the working fluid instead of ethylene glycol.
- ✓ The evaporation temperature of the dolomite-including nanofluid was specified to be lessen in the evaporator than that of ethylene glycol. This outcome displays that the movement of heat from the low temperature hot sink would be permitted along the heat pipe.
- ✓ The maximum enhancement in efficiency was obtained under 200 W heating power and 10 g/s cooling water mass flow rate conditions.
- ✓ Surface tension of the base fluid could be declined with the addition of nanoparticles inside it.
- ✓ It is found out that heat pipe's thermal resistance was diminished notably with the nanofluid employment as working fluid.

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