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PERFORMANCE ANALYSIS OF A THERMOSIPHON CHARGED WITH DEIONIZED WATER/ ETHYLENE GLYCOL MIXTURE BASED GRAPHENE NANO PLATELET NANOFLUID

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ABSTRACT: The thermosiphons are wickless heat pipes which work under gravity force. Different working fluids like water, engine oil, ethylene glycol are used in this equipments. Nanofluids including various nano particles are also used in the thermosiphons. In this study, deionized water (DW)/ ethylene glycol (EG) mixture based graphene nano platelet (GNP) nanofluid was charged in a thermosiphon and thermal performance analysis was performed. The mixing rate of DW:EG was 95:5 while the particle concentration was 1 %. Triton X-100 was added to the mixture as surfactant. To specify the effect of GNP, a set of experiments for both DW+EG and DW+EG+GNP nanofluid were carried out at the same operating conditions. The results show that GNPs had a positive effect on the performance of the thermosiphon. The presence of GNP in the base fluid was decreased the thermal resistance while it was increased the thermal efficiency of the thermosiphon. The maximum efficiency value was reached as 57.1 % when the nanofluid used. At the same condition, the efficiency was 49.5 % when the working fluid was DW+EG mixture.

Keywords: *Thermosiphon, Ethylene glycol, Graphene, Nanofluid, Efficiency*

Deiyonize Su/ Etilen Glikol Karışımı Bazlı Grafen Nano Plaka İçeren Nanoakışkan ile Şarj Edilen Bir Termosifonun Performans Analizi

ÖZ: Termosifonlar yer çekimi altında çalışan fitilsiz ısı borularıdır. Bu ekipmanlarda su, motor yağı, etilen glikol gibi farklı çalışma akışkanları kullanılmaktadır. Termosifonlarda çeşitli nano parçacıklar içeren nano akışkanlar da kullanılmaktadır. Bu çalışmada, deiyonize su/etilen glikol karışımı bazlı grafen nano plaka içeren bir nano akışkan termosifona şarj edildi ve ısıl performans analizi yapıldı. Deiyonize su/etilen glikol karıştırma oranı 95:5 iken partikül konsantrasyonu %1 idi. Karışıma yüzey aktif madde olarak Triton X-100 ilave edildi. Grafenin etkisini belirlemek için, aynı çalışma koşullarında hem DW+EG hem de DW+EG+GNP nanoakışkanı için bir dizi deney yapılmıştır. Sonuçlar grafenin termosifon performansı üzerinde olumlu bir etkiye sahip olduğunu göstermiştir. Baz akışkanda grafen bulunması, termosifonun ısıl verimini artırırken ısıl direncini azaltmıştır. Nanoakışkan kullanıldığında maksimum verim değerine % 57.1 olarak ulaşılmıştır. Aynı durumda, çalışma akışkanı DW+EG karışımı olduğunda verim % 49.5 olmuştur.

Anahtar Kelimeler: *Termosifon, Etilen Glikol, Grafen, Nano akışkan, Verimlilik*

1. INTRODUCTION

Improving of nano technology in last decades has come up with different types of nano particles which have various usage areas like food processing and packing, coatings, drug delivery, adsorption, photocatalytic and thermal processes (Ghorabaee et al., 2021). Nanofluids which were first mentioned in

1995 by Choi and Eastman (Choi & Eastman, 1995) are the suspension of nano particles and some base fluids. The nanofluids have unique thermal properties while the base fluids don't have. Two main techniques are widely used in preparing of nanofluids in literature. One of them is "one step method" and the other is "two step method" which was mostly preferred. In one step method, nano particles and nanofluid were simultaneously produced. In two step method, nano particles are produced first. Than nano particles are added to base fluid (Ghorabaee et al., 2021).

Different types of base fluids such as ethylene glycol, water, engine oil and different nano particles such as graphene, metals, carbon nanotubes, metal oxides were utilized in nanofluid preparation in literature. These nanofluids generally positively affected the thermal properties of base fluids. Some of the studies about nanofluids are listed in Table 1.

In general, there are some parameters which affect the thermal properties of a nanofluid such as nano particle, nanofluid concentration, base fluid, temperature and surfactant type (Ghorabaee et al., 2021). Among these parameters, the base fluid and nano particle have the most important effect on the heat transfer performance of nanofluid. While the base fluid can be a single liquid or the mixture of more than one liquid, different nano particles can be used with these base fluids (Martin & Boran, 2021), (Filiz & Yetişken, 2021), (Sun et al., 2021), (Kakavandi & Akbari, 2018), (O. Soltani & Akbari, 2016), (Dong et al., 2022). In this experimental study Graphene Nano Platelet (GNP) was utilized as nano particle. The base fluid of the nanofluid was the mixture of deionised water (DW) and ethylene glycol (EG). DW: EG mixing rate was 95:5 by weight. Prepared nanofluid was performed in a thermosiphon heat pipe for different experimental conditions. Evaporation temperature of EG is higher than DW. Although the use of ethylene glycol and water in the thermosiphon is included in some studies in the literature, the use of graphene nanoplatelets with these two fluids mixing ratio of 95:5 is not included. This is the novelty of current study. The aim of this study is to investigate the working temperature range of the thermosiphon heat pipe in case of the presence of 5% EG in DW. It was also investigated how the presence of GNP in the DW-EG mixture affects the thermal performance of the heat pipe.

2. MATERIAL AND METHOD

GNPs having unique properties (i.e. thermal conductivity of 3000 W/mK and specific heat capacity of 1528 J/kgK), have a great potential of using in heat transfer applications. GNPs are also good at preparing nanofluids.

2.1. Nanofluid Preparation

The nanofluid whose nano particle and base fluid were GNP and DW-EG mixture respectively was utilized in a thermosiphon type heat pipe. DW-EG mixing rate was 95:5 by weight. Two step method was performed to prepare the nanofluid. Particle concentration was 1% by weight. The surfactant Triton X-100 with a concentration of 0.2 % by weight was added to the mixture to prevent agglomeration. The mixture was detained in an ultrasonic bath for 5 hours before the experiments. Therefore a more stable nanofluid could be obtained. Preparation steps of the nanofluid can be seen in figure 1.

Table 1. Summary of some studies about nanofluids prepared various base fluids and nano particles

Researchers	Base Fluid	Nano Particle	Application	Results
Arif et al. (Arif et al., 2021)	Engine Oil	Molybdenum Disulphide and Graphene oxide	Oscillating Vertical Cylinder.	The heat transfer rate improved up to 23.17 %
Aberoumand and Jafarimoghaddam (Aberoumand & Jafarimoghaddam, 2017)	Engine Oil	Cu	Thermal Conductivity and Viscosity Analysis	Viscosity and thermal conductivity improvements of 37% and 49% were procured respectively.
Vasheghani et al. (Vasheghani et al., 2013)	Engine Oil	TiO_2	Thermal Conductivity and Viscosity Analysis	Thermal conductivity and viscosity values increased about % 57 and % 8 respectively
Soltani et al. (F. Soltani et al., 2020)	Engine Oil	Tungsten Oxide and Multi Walled Carbon Nano Tube	Thermal Conductivity Analysis	The maximum increasing rate of thermal conductivity was procured as 19.85 %
Sundar et al. (Sundar et al., 2021)	Water	Nanodiamond	Plate Heat Exchanger	Heat transfer coefficient and Overall heat transfer coefficient enhanced up to 55.47% and 32.50 % respectively
Nfawa et al. (Nfawa et al., 2021)	Water	MgO and CuO	Thermal Conductivity Analysis	The maximum enhancement in thermal conductivity was reached as 16 %
Cruz et al. (Cruz et al., 2022)	Water	CuO	Shell and Tube Heat Exchanger	The biggest increasing rate in heat transfer was achieved as 48 %
Sözen et al. (Sözen et al., 2021)	Water	Graphene	Air-to-Air Heat Exchanger	The biggest enhancement value in thermal efficiency was reached as 87.7 %
Yashawantha and Vinod (Yashawantha & Vinod, 2021)	Ethylene Glycol and Water	CuO, Al_2O_3 and TiO_2	Thermal Conductivity Analysis	Thermal conductivity improvements of 3.59 %, 4.87% and 6.34 % was achieved
Aydın et al. (Aydın et al., 2020)	Ethylene Glycol	Dolomite	Heat Pipe	The thermal efficiency value was increased from 44% to 65% thanks to the nanofluid
Suganthi et al. (Suganthi et al., 2014)	Ethylene Glycol and Water	ZnO	Heat Transfer Performance Analysis	Thermal conductivity improvement of 33.4%
Sundar et al. (Sundar et al., 2013)	Ethylene Glycol and Water	CuO and Al_2O_3	Thermal Conductivity Analysis	The maximum thermal conductivity enhancement was reached as 24.56 %

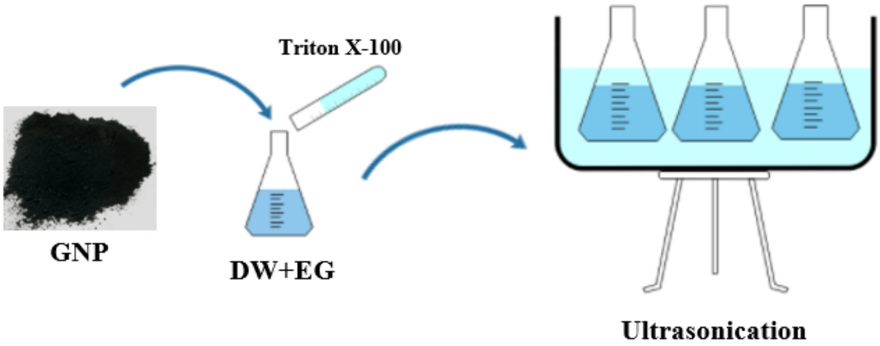

Figure 1. Nanofluid preparation steps

GNPs and Triton X-100 surfactant were procured from "Nanografi Company". SEM image and particle size distribution of the GNPs were shown in figure 2 and figure 3 respectively. GNP is a 2D nano structure as can be seen in fig. 2. It can be understood from fig.3 (Blue line) that GNPs are thinner than 5 nm. Fig 3 also shows that the average particle size of the GNPs are 3 nm. Other properties of GNPs were as follows:

- Purity: 99.9%
- Surface Area: 800 m^2/g
- Density: 2267 kg/m^3

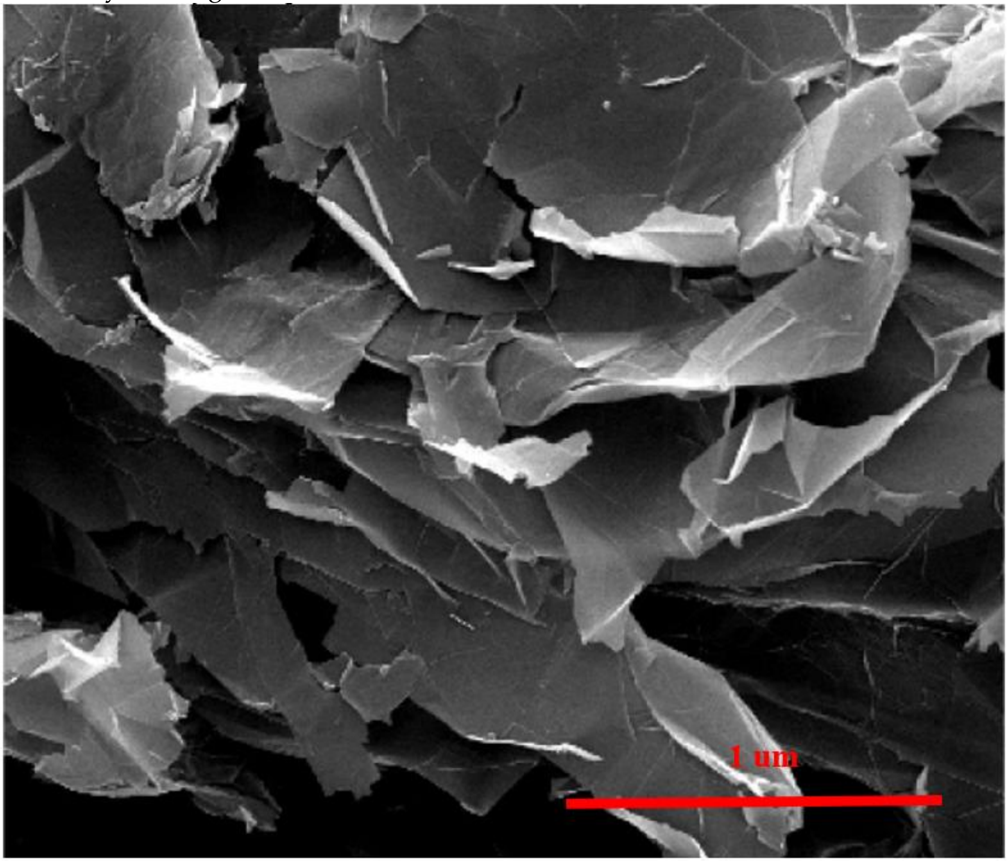

Figure 2. SEM image of GNPs

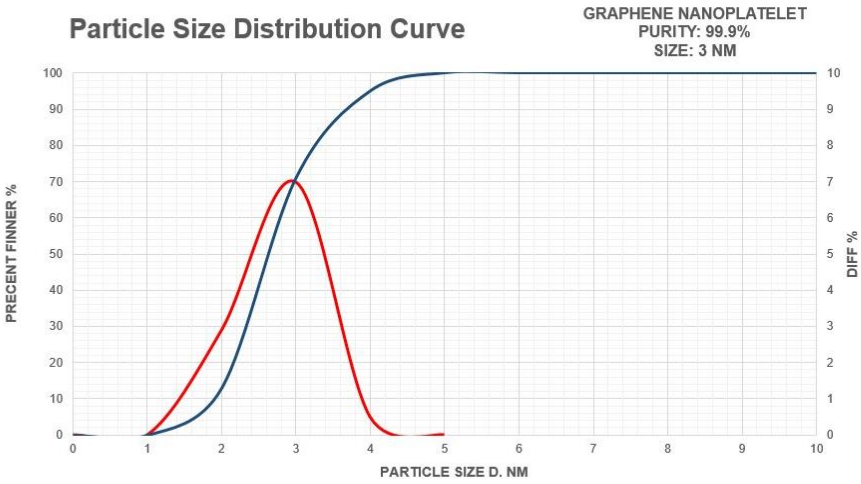

Figure 3. Particle size distribution of GNPs

2.2. Experimental Setup

Prepared nanofluid was charged to the thermosiphon which was made of copper. Its length and inner diameter were 1 m and 13 mm respectively. It consisted of 3 main part named as condenser, adiabatic and evaporator sections whose lengths were 400 mm, 200 mm and 400 mm respectively. The thermosiphon was well isolated by using glass wool to eliminate the heat losses. The evaporator section was heated by an electrical resistance while condenser section was cooled by water passing through the jacket around it. The wall temperatures of the thermosiphon were measured by the K-type thermocouples located in eight different point as seen in fig. 4. Besides, two more thermocouples were utilized to measure inlet and outlet temperatures of the cooling water.

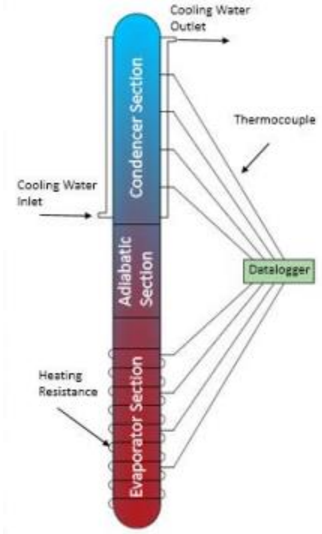

Figure 4. Schematic view of the thermosiphon

44.2 ml nanofluid, which was corresponded to 1/3 of the total volume of the thermosiphon, was charged into it. The experiments were performed with different heating powers (200 W, 300 W and 400 W) and flow rates (3 g/s, 6 g/s and 9 g/s) to see working range of the thermosiphon. Three working fluids (DW, DW+EG (95:5) and DW+EG+GNPs) were tried separately and the results were compared.

3. RESULTS AND DISCUSSIONS

Thermal efficiency, wall temperature distribution and thermal resistance can be considered as performance indicators of a thermosiphon. These parameters which were mostly affected by working fluid, cooling water mass flow rate and heating power were calculated as follow.

Thermal efficiency was calculated as the ratio of heat transfer rate in condenser to heating power changing from 200 W to 400 W.

$$\eta = \frac{\dot{Q}_c}{\dot{Q}_e} \tag{1}$$

Here, $\dot{Q}_c$ was the heat transfer rate in condenser section while $\dot{Q}_e$ was the heating power supplied from the heating resistance in evaporator section. Thermosiphon was well isolated so heat transfer rate to the atmosphere was negligible. $\dot{Q}_c$ was calculated by using equation 2.

$$\dot{Q}_c = \dot{m}_{water} c_{p,\ water} \Delta T_{water} \tag{2}$$

The heat was transferred from thermosiphon wall surface to cooling water in condenser section. In eq.2, $\dot{m}_{water}$ corresponded to mass flow rate of cooling water while $c_{p,water}\ and\ \Delta T_{water}$ corresponded to specific heat capacity and temperature difference between inlet and outlet temperatures of cooling water respectively.

Average temperature difference between condenser and evaporator sections and thermal resistance of the thermosiphon were calculated using equation 3 and 4 respectively. In eq. 3, T_e values were the wall temperatures of evaporator section measured from 4 different point. Similarly, T_c values were the wall temperatures of condenser section measured from 4 different point. In eq. 4, R was the thermal resistance of the thermosiphon.

$$\Delta T = \left(\frac{T_{e1}+T_{e2}+T_{e3}+T_{e4}}{4}\right) - \left(\frac{T_{c1}+T_{c2}+T_{c3}+T_{c4}}{4}\right) \tag{3}$$

$$R = \frac{\Delta T}{\dot{Q}_e} \tag{4}$$

The tests were done for various working conditions for each working fluid (DW, DW+EG and DW+EG+GNP). The results were illustrated as graphics to see the effect of working fluid and test conditions to the performance of thermosiphon.

The temperature difference between evaporator and condenser sections specify the thermal resistance of thermosiphon (Eq. 4). Fig. 5, 6 and 7 show the wall temperature distribution along the thermosiphon at 200 W, 300 W and 400 W respectively. Here, the heat pipe length from 0 to 40 cm corresponded to evaporator section, 40 to 60 cm corresponded to adiabatic area and 60 to 100 cm corresponded to condenser section. Higher evaporator temperature means higher thermal resistance. It is wanted that the thermosiphon has low thermal resistance so it would have high efficiency value. When the graphs examined, it can be seen that the presence of EG in the DW increased the evaporation temperature of the fluid. This is because EG has a higher boiling temperature than DW. The aim of this study is to see the effected of GNPs in DW+EG base fluid. The temperature distribution of DW was added to the graph to show the difference of working temperature between DW and EG on thermosiphon. On the other hand, the presence of GNP in the DW+EG mixture decreased the evaporation temperature. It means that adding of GNPs to DW+EG mixture decreased the thermal resistance of thermosiphon and improved the thermal efficiency.

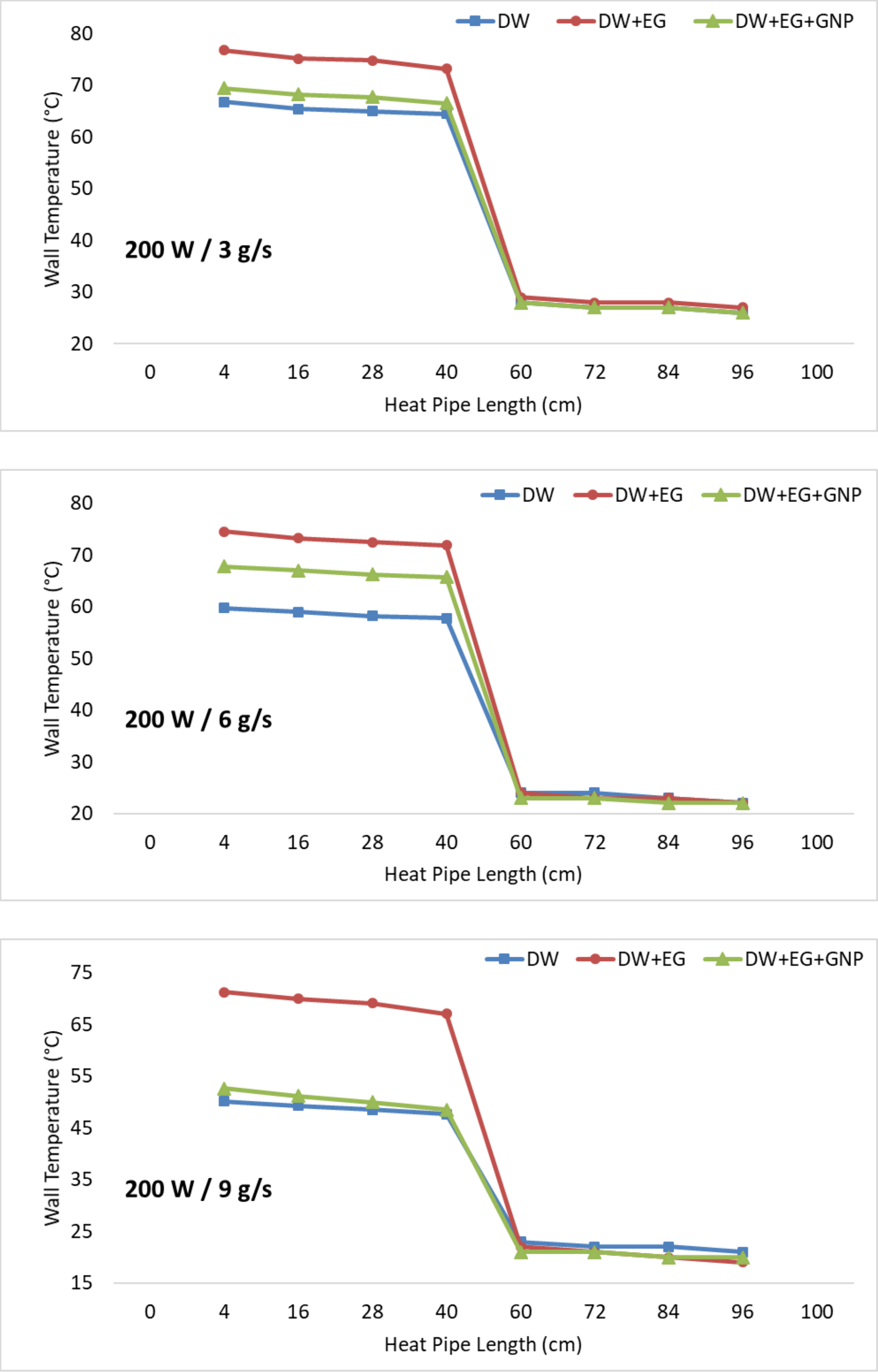

Figure 5. Wall temperature distribution of the thermosiphon under 200 W heating power

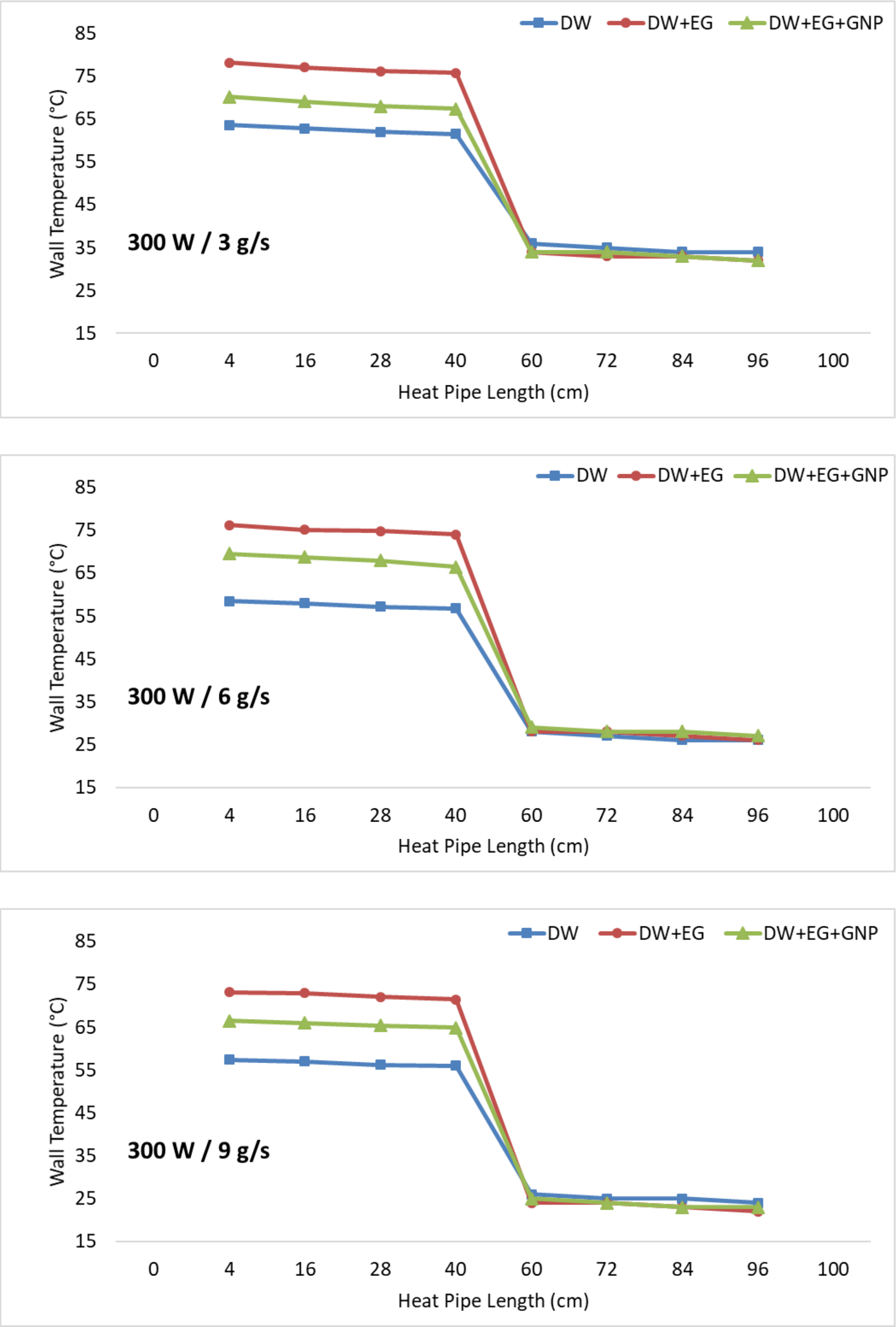

Figure 6. Wall temperature distribution of the thermosiphon under 300 W heating power

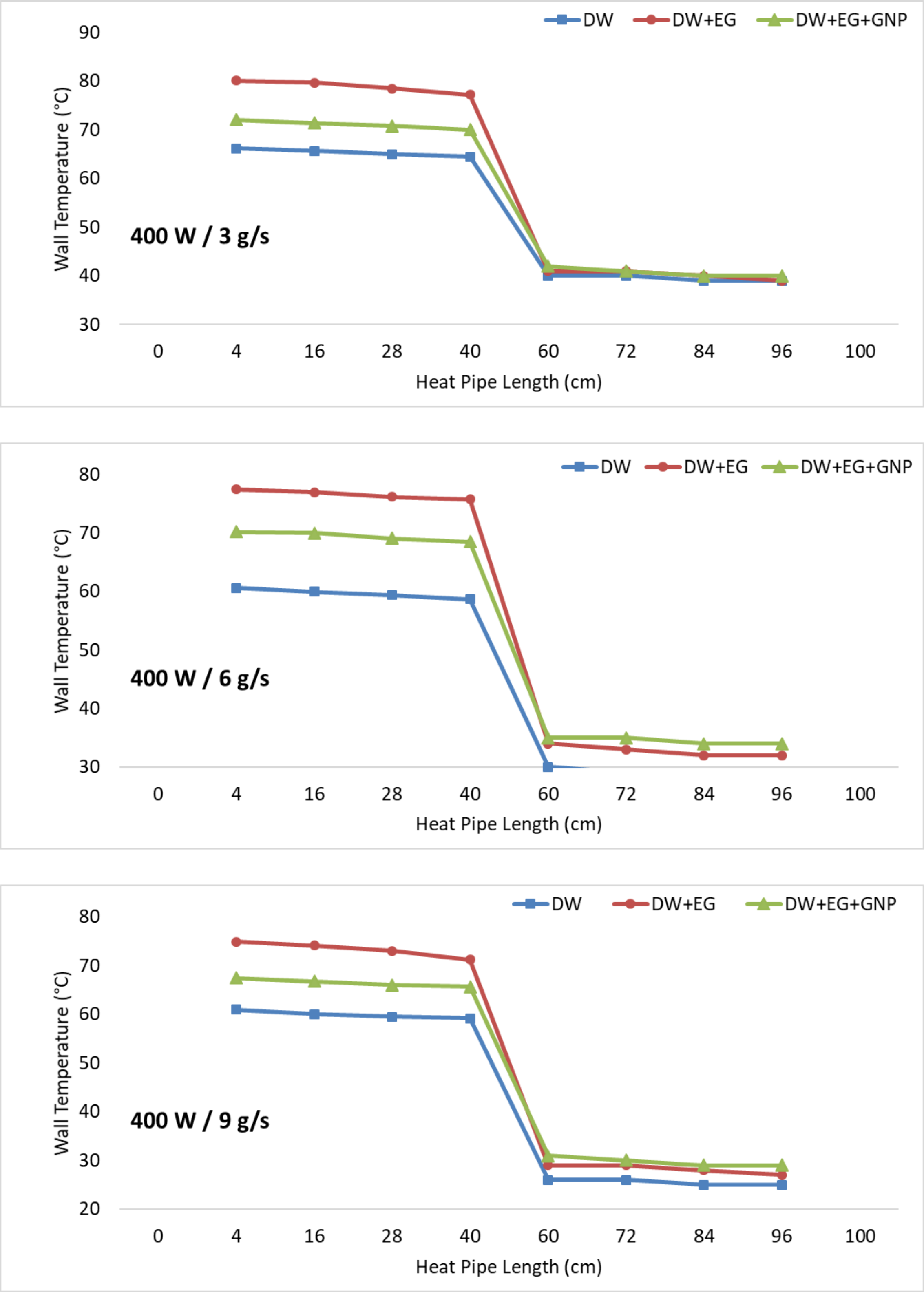

Figure 7. Wall temperature distribution of the thermosiphon under 400 W heating power

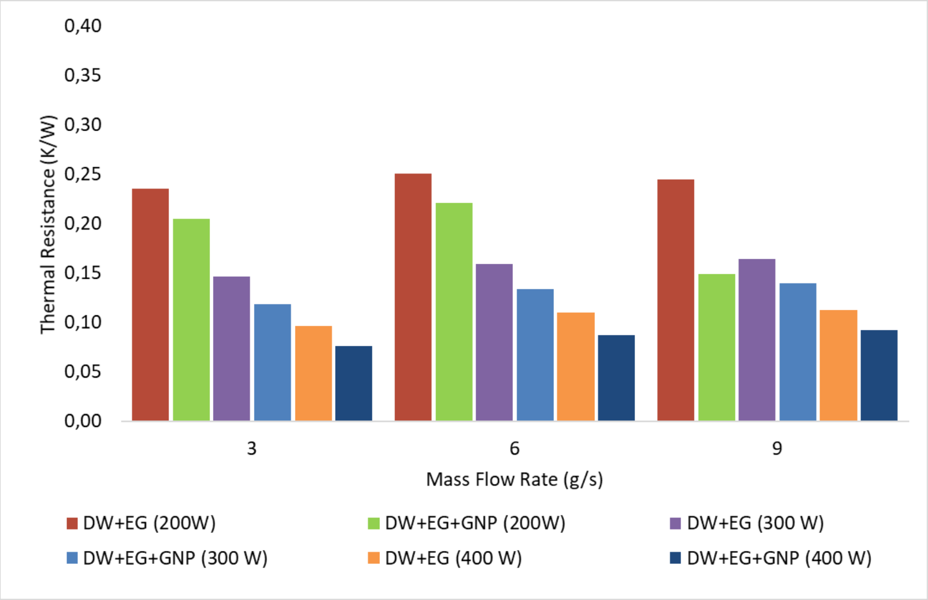

Figure 8. Thermal resistance values of thermosiphon in different mass flow rates

Thermal resistance of a thermosiphon directly affects the thermal performance of it. It is desirable that the heat pipe has low thermal resistance. The graphic in figure 8 shows the effect of working fluid on thermal resistance of thermosiphon at different heating powers and mass flow rates. When the graph analysed, it is seen that using of GNPs in base fluid decreased the thermal resistance value of thermosiphon for all heating powers and mass flow rates. For example when the heating power and mass flow rate were 200 W and 3 g/s respectively, thermal resistance was decreased from 0.24 K/W to 0.21 K/W by adding GNPs to DW+EG. The minimum thermal resistance value was reached as 0.076 K/W when the working fluid was DW+EG+GNP nanofluid at the conditions of 400 W heating power, 3 g /s mass flow rate. At the same mass flow rate, increasing of heating power value decreased the thermal resistance for each working fluid. For instance, when the working fluid and mas flow rate were DW and 6 g/s respectively, while heating power increased from 200 W to 400 W, the thermal resistance values decreased from 0.25 K/W, 0.11 K/W.

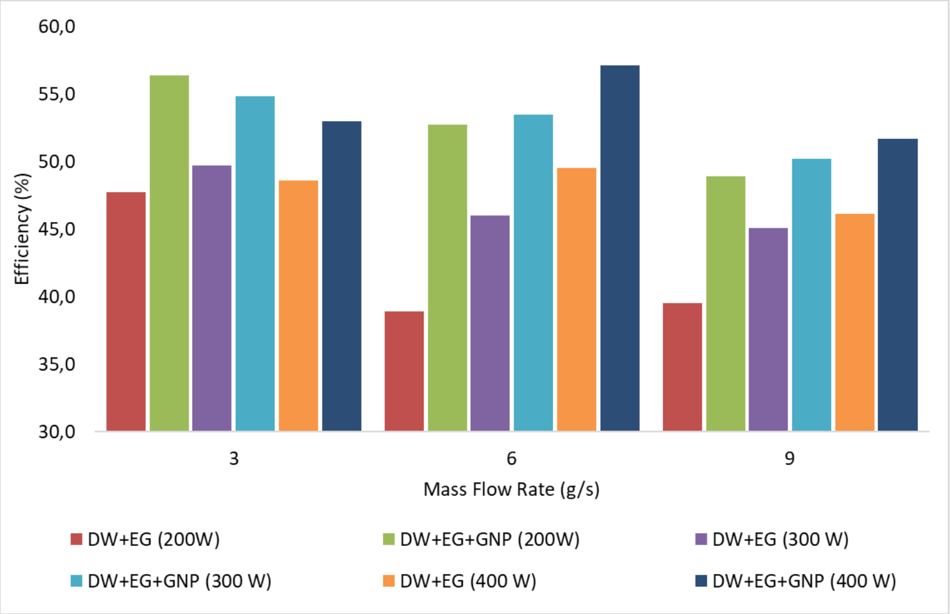

Figure 9. Thermal efficiency values of thermosiphon in different mass flow rates

The presence of GNPs in DW+EG mixture had a positive effect on efficiency of the thermosiphon for all experimental conditions as seen in fig. 9. For example, in the experiments which DW+EG+GNP nanofluid used and the mass flow rate was 3 g/s, maximum efficiency values were 56.4 %, 54.8 % and 53 % at the heating powers of 200 W, 300 W and 400 W respectively. The maximum efficiency value was reached as 57.1 % when the working fluid, heating power and mass flow rate were GNP+DE+EG, 400 W and 6 g/s respectively. The best improvement rate in efficiency was achieved as 35.5 % in condition of mass flow rate of 6 g/s and heating power of 200 W. Besides, increasing of the mass flow rate from 3 to 9 had a negative effect on the efficiency values for almost all working fluids and heating powers. The minimum efficiency values were reached in the mass flow rate of 9 g/s.

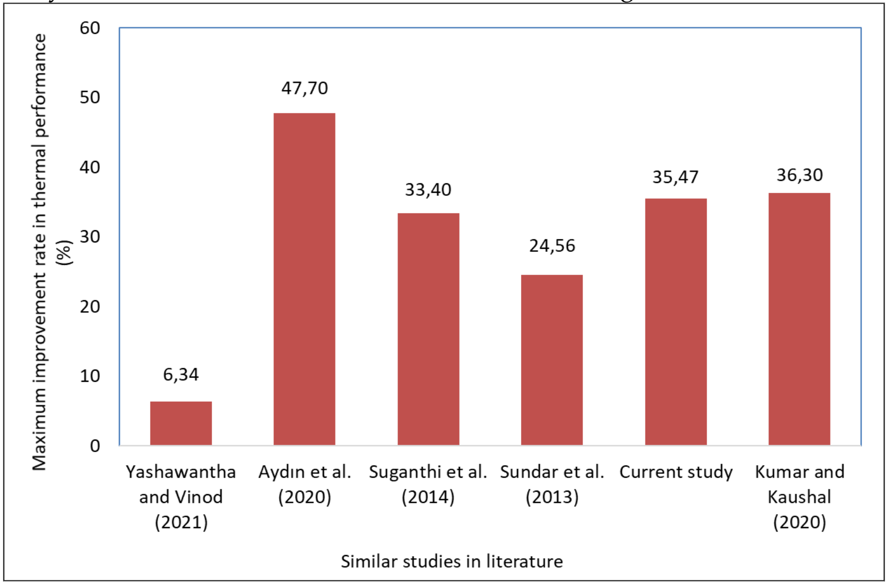

Figure 10. Comparison of the results with similar studies in literature

Figure 10 shows the comparison of the results with similar studies. It indicates the maximum improvement rates in thermal performance of the systems. When the graphic analysed it can be clearly seen that the result of current study was very close to other studies. For example while Aydın et al (2020) and Kumar & Kaushal (2020) had improvement rates as 33.4 % and 36.3 % respectively, the current study had an improvement rate as 35.47%. Therefore figure 10 shows that the obtained results are in agreement with other studies in the literature.

4. CONCLUSIONS

The usage of GNPs in thermal systems is rising nowadays. In this study thermal performance of the thermosiphon type heat pipe charged with nanofluid including GNPs was investigated. The base fluid was DW+EG (95:5) mixture. The results had a good agreement with other studies in the literature as mentioned below:

- Adding of the GNPs to DW+EG mixture decreased the evaporating temperature. Therefore thermal resistance of the thermosiphon was decreased.
- For the same mass flow rate, increasing in heater power decreased the thermal resistance.
- The lowest resistance value was reached as 0.076 K/W when the nanofluid, heating power and mass flow rate were DW+EG+GNPs, 400 W, 3 g/s respectively.
- GNPs had a significant effect on thermal efficiency of the thermosiphon.
- The best value of thermal efficiency was achieved as 57.1 % when the working fluid was DW+EG+GNP nanofluid at the conditions of 400 W heating power and 6 g/s flow rate.
- In further studies, effect of different mixing ratio of DW and EG can be investigated. The usage of different nano particles and particle concentrations can be analysed as well.

NOMENCLATURE

DW: Deionized Water
EG: Ethylene Glycol
GNP: Graphene Nano Platelet
SEM: Scanning Electron Microscope
η: Thermal Efficiency
$\dot{Q}_c$:Heat Transfer Rate (Condenser)
$\dot{Q}_e$:Heating Power
$\dot{m}_{water}$: Mass Flow Rate of Water
$c_{p,water}$: Specific Heat Capacity of Water
ΔT_{water}: Temperature Difference
T_e: Wall Temperature of Evaporator
T_c: Wall Temperature of Condenser
R: Thermal Resistance

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