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Heat Transfer Coefficient in a Copper Pipe Flow System Using a 40/60 Volume Ratio Ethylene Glycol/Water (EG/H2O) Blended Fluid

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ABSTRACT

This study discusses the performance of Ethaline Glycol/water (EG/H2O) fluids at a volume ratio of 40/60. EG/H_2O fluids are widely used as basic fluids in cooling and heating system applications. The discussion of EG/H_2O fluid performance is focused on the analysis of the heat transfer coefficient and pressure drop. The study used an experimental method using a suction test made of pure copper with an inner diameter, outer diameter and length of 16 mm, 19 mm and 1500 mm respectively. The EG/H_2O volume ratio at 40/60 was selected as the input parameter. Other input parameters are variations in the fluid flow rate which are regulated using a control valve at fluid flow rates of 4, 6, 8, 10.12, 14.16 and 18 liters/minute. A 2-unit tubular heater with a total capacity of 2000 W was installed on the sides of the copper pipes. A voltage regulator with a capacity of 3000 W is used to regulate the electric power by regulating the supplied voltage. Ampere pliers are used to measure amperage at the setting used. The experimental results show that the performance of the EG/H_2O fluid on the heat transfer coefficient increases as the fluid flow rate increases. The highest heat transfer coefficient rate was obtained at a fluid flow rate of 18 L/minute, while the lowest value was obtained at a fluid flow rate of 4 L/minute. Pressure drops fluctuations occur as the fluid flow rate increases. Even though there is a fluctuating pressure drop, this condition does not significantly affect the friction factor, because the fluid flow characteristics occur in a turbulent manner.
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Keywords: *Ethaline Glycol/water, Friction factor, Heat transfer coefficient, Pressure drops, Reynolds number*

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1. INTRODUCTIONS

Technological advances have rapidly increased, especially in automobile cooling systems. The performance of an internal combustion engine is closely related to heat transfer efficiency. A cooling system that can transfer heat effectively in a car will prevent the engine from overheating, improve engine performance, reduce fuel consumption, and produce lower emissions [1]. An efficient cooling system design is required to achieve high heat transfer efficiency. In a car cooling system, a mixture of EG and water flows through the radiator to absorb excess heat from the engine. Then, the mixture flows inside back to the engine to cool the engine temperature. This process repeats continuously to keep the engine temperature stable and prevent overheating [2].

Ethylene glycol (EG) and water based fluids are mixtures composed of ethylene glycol and water. These fluids are commonly used as coolants or heat transfer fluids in various applications, including automotive engines, HVAC systems, and industrial processes. The performance of EG/water based fluids can be influenced by the ratio of ethylene glycol to water, commonly referred to as the concentration or percentage of EG in the mixture. Different concentrations may be selected depending on the specific application requirements, such as the desired freeze protection or the operating temperature range.

The heat transfer coefficient is a fundamental parameter that quantifies the rate of heat transfer between a surface and a fluid medium [3][4]. It represents the ability of a fluid to conduct heat and is a crucial factor in determining the efficiency of heat transfer processes [5][6]. The heat transfer coefficient depends on several factors, including the physical properties of the fluid, the flow conditions, and the nature of the surface [7][8]. It is influenced by parameters such as fluid velocity [9][10], temperature [11], viscosity [12], density [13], thermal conductivity [14], and the presence of any additives or nanoparticles in the fluid [15][16]. Accurate knowledge of the heat transfer coefficient is essential for designing and optimizing heat exchangers[17], cooling systems [18] , and other heat transfer equipment, as it directly affects the overall heat transfer rate [19] and system performance [20].

Several studies have been conducted on the performance of ethylene glycol/water (EG/water) mixtures. Manik et al. [21] conducted EG/water research with a volume ratio of 50: 50 as a cold fluid and water as a hot fluid in a cooling system using a radiator, as shown in Figure 1. The research was carried out using a radiator by varying the hot fluid discharge flow rate of 0.000000067 to 0.00027 m^3/second.

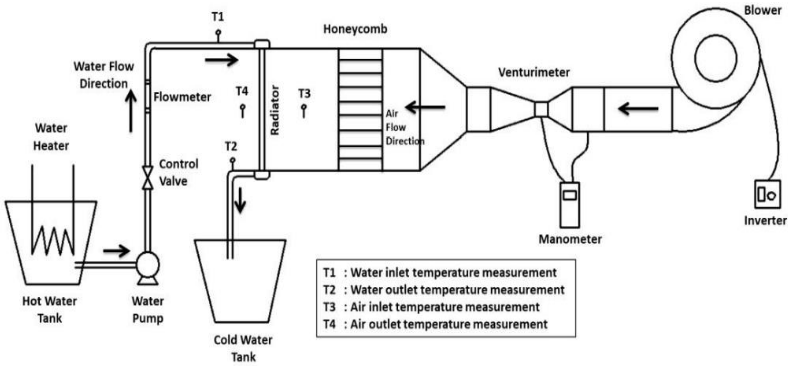

Figure 1. The experimental set-up of EG/water by 50/50 volume ratio was provided by [21]

Further research was conducted by [22] using a ratio of EG/ graphene (EG/Grn) nanofluid with a volume concentration variation of 0.1% to 1.5%. Heat transfer coefficient testing used a shell and tube heat exchanger (STHE) with EG and EG/Grn as hot and cold fluids, respectively. Data analysis was compared with the base fluid EG. Azari et al. [2] esearched heat transfer coefficient and overall heat transfer coefficients using a 50:50 EG/water ratio. The experimental method was chosen by using a compact heat exchanger test section. The results of empirical data analysis compare the value of the heat transfer coefficient and overall heat transfer coefficient to the performance of water fluid as the base fluid. Go et al. [23] conducted further research using a numerical approach. The heat transfer phenomenon was carried out using a coarse-grained molecular dynamics (CGMD) method. The simulation uses a nanopore that has a length of 800 Å. "800 Å" refers to a length measurement of 800 angstroms, a unit commonly used in atomic and molecular scales

In cooling and heating systems, fluid development is necessary to reduce the evaporation rate while transferring heat. As a result, in addition to water and ethylene glycol (EG), other materials are required to raise the evaporation point of the working fluid. Therefore, additional materials are needed to raise the evaporation point of the working fluid through the combination of water and ethylene glycol (EG). Using ethylene glycol/water base fluid will be more efficient and reduce the freezing point of the liquid and the evaporation point, which will help increase the efficiency of fluid used in the heating or cooling process.

The theme of research on heat transfer coefficient and friction factor using EG/water fluid in single pipe systems has not been widely done. This research discusses the heat transfer coefficient and friction factor for an EG/water volume ratio of 40:60. This research uses an experimental approach with fluid flow rate variation. The test section used copper pipes with an inner diameter of 19 mm and an outer diameter of 13 mm. The fluid flow rate varied in the 4-18 LPM range.

2. METHODOLOGY

2.1. Experimental Set up

Experimental methods are used under treatment conditions to determine the nature of the relationship between independent variables (such as treatment or care programmed) and dependent variables. These conditions are carefully managed (such as events that will take place). A control group is useful when conducting experimental research for various reasons, including ensuring that variables are managed appropriately. The laboratory is the most frequently used place when practicing this research methodology. The experimental setup used for the further testing conducted is illustrated in Figure 2.

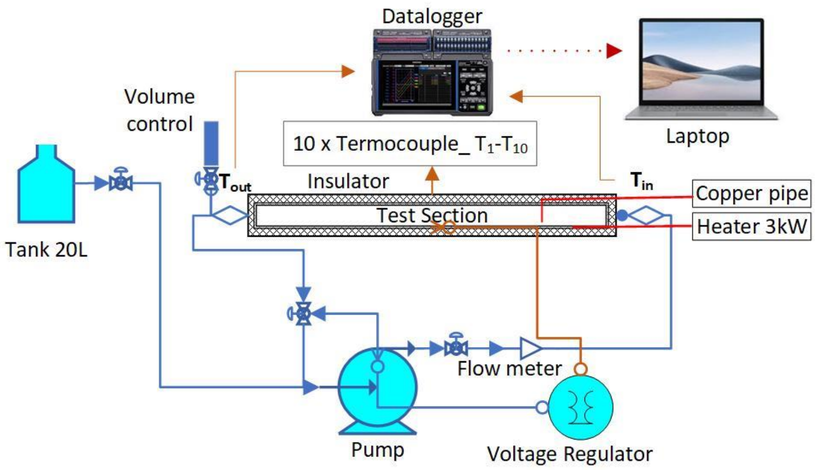

Figure 2. Test section and experimental set-up

The test section uses pure copper with an inner diameter of 18 mm and a thickness of 1.5 mm. Thermocouples of type k, T_1-T_{10}, were installed along the test section. K-type thermocouples T_i and T_o were installed at the inlet and outlet of the test section. Pressure sensors P_1 and P_2 are installed to detect the pressure difference at the inlet and outlet of the test section. A voltage regulator is used to adjust the input power to the heater. AC Voltage Regulator reduces or increases AC voltage from 0-volt to 250 volts. Voltage regulators have input specifications: 220VAC, 50/60Hz and Output Voltage: 0-250VAC. The voltage regulator used is presented in Figure 3.2. The tubular heater is used to heat the test suction, a copper pipe. This study uses the 2-unit tubular heater with a power capacity of 1000 W each. A centrifugal pump is installed to transfer the EG/tater into the test section. The data logger has temperature and pressure accuracy of 0.25°C and 0.1 psi (6894.76 Pa), respectively.

The stages of taking experiments begin with calibrating all the measuring instruments used. EG/water fluid with a ratio of 40:60 is put into a tank with a capacity of 20L, which is then inserted into the testing system until the pipeline and hose are filled. Recording on the data logger was set at 1-second intervals. The heater was turned on, and simultaneously, the process of recording data on temperature, temperature and fluid flow rate was carried out at a temperature of 50°C.

2.2. Physical Properties of Ethylene Glycol and Water

Ethylene glycol is an organic compound used as a raw material in producing polyester fibres, industrial plants, and *polyethene terephthalate* (PET) used in plastic bottles. Its IUPAC name, 1,2-

ethanediol, knows *Ethylene Glycol* (EG). Ethylene glycol is a colourless, odourless liquid that is miscible with water and a variety of organic compounds. The thermophysical properties data of the EG/Water mixture at 40/60 volume percentage are shown in Table 1 [24].

2.3. Heat Transfer Coefficient, *h*

The heat transfer coefficient is used in calculating heat transfer, usually by convection or phase transition between liquids and solids. The heat transfer coefficient has SI units in watts per square metre-Kelvin. The heat transfer coefficient is calculated using Equation 1 [25].

$$h = \frac{Q"}{Ts - Tm} \tag{1}$$

where T_s, is the average temperature in Kelvin (K) of the suction test surface, whose value is calculated using Equation 2. [25].

$$T_s = \frac{(\sum_{i=1}^{8} T)}{10} \tag{2}$$

where T_m the average temperature in Kelvin (K) of the suction test surface, and the average temperature value is calculated using Equation 2. At the same time, Tm is the bulk temperature of the fluid whose value is calculated using Equation 3

$$T_m = \frac{T_{in} - T_{out}}{2} \tag{3}$$

Table 1. Thermophysical of EG/water at volume ratio of 40/60.

Temperature (K)	Density (kg/m^3)	Heat Specific (kJ/kg. K)	Thermal conductivity (W/m. K)	Viscosity (mPa/s)
303	1041.26	3.674	0.441	2.19
308	1039.08	3.688	0.445	1.88
313	1036.78	3.702	0.450	1.63
318	1034.36	3.716	0.453	1.43
323	1031.81	3.730	0.457	1.26
328	1029.15	3.745	0.460	1.13
333	1026.36	3.759	0.463	1.01
338	1023.45	3.773	0.466	0.92
343	1020.42	3.787	0.469	0.83
348	1017.27	3.801	0.471	0.76
353	1014.00	3.816	0.473	0.70
358	1010.60	3.830	0.474	0.65
363	1007.09	3.844	0.476	0.60
368	1003.45	3.858	0.477	0.56

The calculation of the heat transfer rate in watt (W) in this study was calculated using Equation 4 [25].

$$Q = \frac{Q_1 + Q_2}{2} \tag{4}$$

where Q_1 donated for the heat transfer rate of the power source used and it calculated by using Equation 3. At the same time Q_2 is the heat transfer rate of the fluid performance used and is calculated using Equation 4 [26].

$$Q_1 = VI \tag{5}$$

$$Q_2 = \dot{m} C_p (T_o - T_i) \tag{6}$$

Where V donate the voltage in volts (V), I donated for current in Ampere (A), $\dot{m}$ donate for mass flow rate (kg. s^{-1}) and C_p donate forspecific heat capacity (J/kg.K). The rate at which heat energy is transferred through a surface is referred to as heat flux. Heat rate is measured in joules per second or watts (W) , and heat flux is expressed as watts per square meter. A common method for calculating heat flux using equation 7 is to measure the temperature difference in a material whose heat conductivity value has already been determined [25].

$$q'' = \frac{Q}{\pi DL} \quad (7)$$

Where, *D* donate for inner diameter (m), and *L* donate for length of the pipe (m).

2.4. Determination of Reynold Number *(Re)*

The Reynolds number summarizes the relationship between two forces for a given flow condition—the Reynolds number, calculated using Equation (8). The Reynolds numbers are used to identify different types of flow, such as laminar, turbulent, and transitional flow [27] [3].

$$Re = \frac{\rho v D}{\mu} \quad (8)$$

Where *Re* denotes the dimensionless Reynolds number, v denotes fluid velocity (m/sec), D denotes pipe inner diameter in meters (m), μ denotes absolute viscosity, and ρ is fluid density (kg/m3).
[25].

$$q = A_c v \quad (9)$$

where *q* is donated for the flow rate directly measured through the peristaltic pump in L/min and converted to m3/sec. Furthermore $A_c = \frac{\pi D^2}{4}$, s the cross-sectional area of the copper tube in meter square (m^2).

2.5 Determination of Nusselt number (Nu)

The Nusselt number (Nu) measures convection heat transfer at the surface, expressing the non-dimensional temperature gradient. The Nusset number in this experiment was calculated using equation 10 [28].

$$Nu = \frac{hD}{k} \quad (10)$$

The Nusselt number in this experiment was calculated using equation 10. Nusselt numbers in this experiment were compared using Bottler's Disstut equation calculated using Equation 11 and Notter & Rouse's Equation 12 [29].

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad (11)$$

$$Nu = 5 + 0.015 Re^{0.856} Pr^{0.347} \quad (12)$$

2.6. Determination Pressure Drop (ΔP) and Friction Factor *(f)*

The pressure drop provided in Pascal (P) was calculated by calculating the pressure difference at the inlet *Pin* with the outlet *Pout*. The pressure drop result is used fully to calculate the friction factor *(f)* amount using EG/H2O fluid—pressure drop (ΔP) calculation using Equation 13.

$$\Delta P = P_{in} - P_{out} \quad (13)$$

The friction factor is the loss of fluid pressure in the pipe due to the interaction between the fluid and the pipe. The Darcy friction factor is a dimensionless quantity used in the Darcy-Weisbach equation to describe frictional losses in pipes or ducts and for open channel flows. The experimental friction factor is calculated using Equation 14 [30].

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\rho_f \frac{v^2}{2}\right)} \quad (14)$$

The friction factor is also calculated using the Petukhov formula and Blasius equation shown in equations 15 and 16 [31].

$$f = (0.79 \ln Re - 1.64)^{-2} \quad (15)$$

$$f = \frac{0.3164}{Re^{0.25}} \quad (16)$$

3. RESULT AND DISCUSSION

3.1. Analysis of Heat Transfer Coefficient, *h*

The heat transfer coefficient of experimental data was calculated using Equation 1. The heat transfer coefficient has SI units in watts per square metre-Kelvin.The calculation data is averaged and analysed to see the effect of EG/H2O fluid flow rate on the heat transfer coefficient—the effect of fluid flow rate on the heat transfer coefficient is shown in Figure *3*.

Figure 3 shows that the heat transfer coefficient increases as the EG/H2O fluid flow rate increases. The lowest heat transfer coefficient (h) was obtained in this study at a fluid flow rate of 4 L/min with a heat transfer coefficient value of 717 W/m^{2}K, and the highest heat transfer coefficient (h) was obtained at a fluid flow rate of 18 L/min with a heat transfer coefficient value of 3993 W/m^{2}K. When the fluid flow rate increases, the heat transfer coefficient increases exponentially. The increase in heat transfer coefficient can be predicted using the equation $y = 684.28e^{0.2158x}$, where y is the predicted heat transfer coefficient, and x is the fluid flow rate. The phenomenon of the increase in heat transfer coefficient along with the increase in flow rate follows the previous theory, where the heat transfer coefficient is directly proportional to the Nusselt number and Reynolds number [32]. Reynolds number is directly proportional to the fluid flow rate [33].

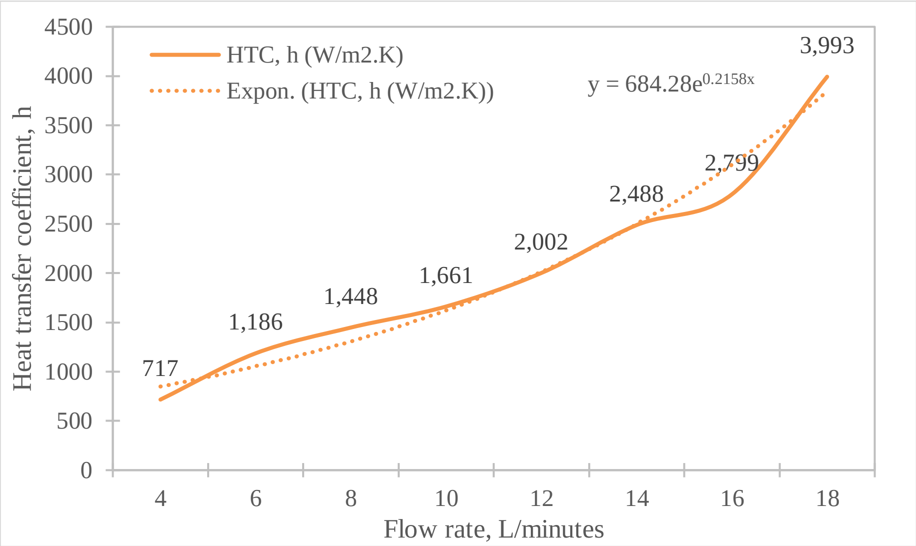

Figure 3. The influence of the EG/H2O fluid flow rate on the Nusselt number.

3.2. The Effect of Flow Rate on Nusselt Number *(Nu)*

Calculation of Nusselt number (Nu) Experimental data was carried out using equation 2.13. This data is compared with the Nusselt number (Nu) calculation according to Disstut-Bottler and Notter & Rouse calculated using equations 11 and 12. The calculated data were averaged and analyzed to see the effect of EG/H2O fluid flow rate on the Nusselt number. The effect of fluid flow rate on Nusselt number (Nu) is shown in Figure *4*.

Figure 4 shows that the value of the Nusselt number (Nu) increases as the EG/H2O fluid flow rate increases. This study obtained the lowest Nusselt number (Nu) at a fluid flow rate of 4 L/min, while the highest Nusselt number (Nu) was obtained at 18 L/min. The experimental Nusselt number (Nu) data is lower by about 2-27% compared to the Nusselt number (Nu) calculation using the Dittus-Boelter equation [34]. Meanwhile, compared to the Notter & Rouse equation [34], the experimental data is lower by about 4-29%. The experimental Nusselt number (Nu) data is closer to calculating the Nusselt number (Nu) using the Dittus-Boelter equation.

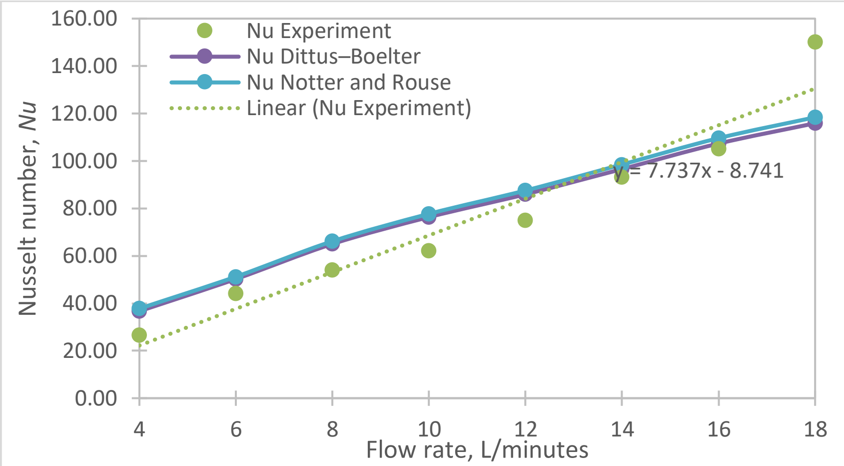

Figure 4. The influence of the EG/H2O fluid flow rate on the Friction Factor

3.3. The Effect of Flow Rate on Friction Factor, *f*

Furthermore, the calculation of pressure drop (*ΔP*) is averaged and analysed to see the phenomenon of friction factor (*f*) against changes in Reynold number (Re) in EG/H2O fluid flow. Experimental friction factor calculations are compared with friction factor (f) calculations using the Petukhov formula approach and the Blasius equation. The calculation using the experimental friction factor (f) approach was carried out using equation 2.17, while the calculation using the Petukhov and Blasius formula approach was carried out using equations 15 and 16. The effect of changing Reynold number (Re) on friction factor (f) is shown in Figure 5.

The value of the friction factor (f) decreases as the Reynold number (Re) of the EG/H2O fluid increases, as shown in Figure 5. The highest friction factor (f) obtained in this study was 0.373 at Reynold number 3478, while the lowest friction factor (f) obtained was 0.026 at Reynold number 13269. This data shows that changes in pressure drop do not significantly affect the friction factor value because turbulent fluid flow characteristics influence it. The friction factor approaches the Blasius equation when Re is between 7000 and 13000 [35]. The results of the friction factor analysis indicate a decrease as the Re number increases; this condition is based on previous studies conducted by [36][10].

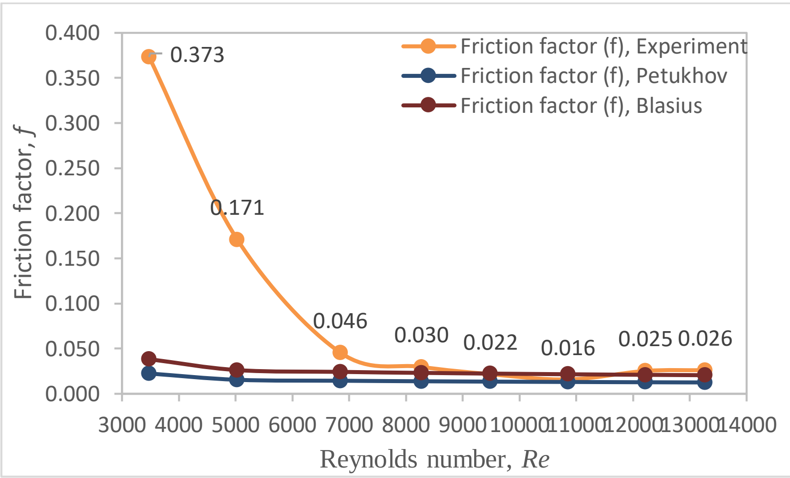

Figure 5. Effect of Reynold number (Re) on friction factor (f) in EG/H2O

4. CONCLUSION

The heat transfer coefficient of the EG/H2O fluid in the copper pipe increases exponentially upon increasing the fluid flow rate caused by the increase in Reynolds number. The Reynolds number increases as the flow rate of the turbulent fluid increases. The heat transfer coefficient of the EG/H2O fluid in the copper pipe increases exponentially with an increase in Reynolds number. Pressure drop on the EG/H2O fluid in the copper pipe fluctuates at a fluid flow rate of 4-18 L/min. Pressure drop on the EG/H2O fluid increases slightly at an increase in fluid flow rate of 4-6 L/min, drops significantly at 6-8 L/min, tends to be constant at 8-14 L/min, and rises significantly at 14-18 L/min. Despite the fluctuating pressure drop, in the case of the friction factor, there is a decrease in the friction factor of the EG/H2O fluid in the copper pipe, along with an increase in the fluid flow rate. A significant decrease in friction factor occurs at fluid flow rates of 4-8 L/min. The Reynolds and Prandtl numbers of the copper pipe's EG/H2O fluid flow are directly proportional to the fluid flow rate. The Reynolds number of the EG/H2O fluid increases as the fluid flow rate increases.

AUTHOR'S DECLARATION

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

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