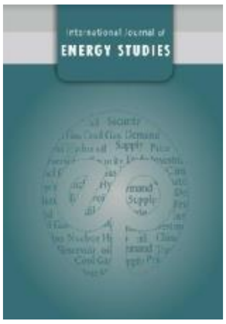
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies, 2021;6(1):37-52

Received: 05 May 2021
Revised: 17 May 2021
Accepted: 19 May 2021

Experimental investigation of the performance of CuO - graphene nanoplatelet / water hybrid nanofluid in concentric tube heat exchanger

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Highlights

- The thermal performance of heat exchangers by using a hybrid nanofluid consisting of CuO & graphene nanoplatelet / distilled water was investigated.
- The overall heat transfer coefficient enhancement for different range of hot fluid flow rates were calculated.
- The total exergy loss was calculated.
- The effect of enhancing thermal performance on fuel and CO2 emissions was calculated

You can cite this article as: Sen, Y., Variyenli, H. I. "Experimental investigation of the performance of CuO - graphene nanoplatelet / water hybrid nanofluid in concentric tube heat exchanger", *International Journal of Energy Studies* 2021;6(1):37-52.

ABSTRACT

In recent years, the need for energy has been increasing, but fossil fuels, which have the largest share in energy production, are gradually decreasing. In order to meet this need, the efficiency of existing systems should be increased. Studies have focused on testing nanofluids in order to increase the efficiency of heat exchangers used in heating and cooling systems applications in many places such as industry, residences, workplaces, etc. In this paper, the effect of hybrid nanofluid consisting of CuO & graphene nanoplatelet / distilled water on the thermal performance of the concentric tube heat exchanger was experimentally investigated. As a result of the experiments it was observed that, if hybrid nanofluid is used instead of water as a hot fluid in the system, an average of 5.5% improvement in overall heat transfer coefficient has been achieved. It was found that the total exergy loss was reduced by an average of 55%. It will be advantageous to use the heat exchanger with increased efficiency, both in terms of cost and in terms of CO2 emission, thanks to less fuel consumption. By increasing the efficiency with nanofluids, it will be possible to design more compact and light heat exchangers in the future.

Keywords: *Hybrid nanofluid, Concentric tube heat exchanger, Heat transfer enhancement, Parallel flow*

1. INTRODUCTION

Consumption increases day by day due to the increasing human population and as humanity develops economically, the amount of energy needed increases also. With the rapid development of technology in recent years, the amount of energy needed has been increasing exponentially. On the other hand, fossil resources, which play an important role in meeting the current energy need, are gradually decreasing. For this reason, it is necessary to prefer alternative energy sources or to reduce the existing energy need by increasing efficiency of processes. Since the production processes have a large share in the energy need, economic development and progress increase in parallel with the energy need [1].

Heat exchangers operating with the heat transfer principle are used extensively in applications that directly affect the existing energy need such as heating and cooling systems. In industrial applications, heat exchangers are preferred for cooling and heat recovery to keep processes at high temperatures at safe temperatures. Heat exchangers can also be preferred in order to transfer high amounts of heat by using low temperature difference and to increase the efficiency of processes with their energy storage properties [2]. For this reason, increasing the efficiency of heat exchangers will directly increase the efficiency of the process and consequently, the targeted process will be achieved by using less fuel. In this way, the gas emission that will pollute the atmosphere and the cost of the process will be reduced with the reduction of fuel.

Studies conducted in recent years to increase the performance of heat exchangers have focused on nanofluids. It is aimed to increase the thermal performance by using nanofluid instead of water, oil, ethylene glycol, etc. which are used as fluids in heat exchangers. It has been observed that the thermo physical properties of the base fluid such as thermal conductivity, viscosity, convective heat transfer coefficient are increased in nanofluids formed by adding nanoparticles to the base fluid. Thanks to the increased thermo-physical properties, the thermal performance of the heat exchanger can be improved and their efficiency can be increased [3].

There is no study in the literature using a hybrid nanofluid consisting of graphene nanoplatelet - CuO / pure water to increase thermal performance. However, there are studies in which CuO and graphene nanoplatelet particles are used alone in different studies to create nanofluids. Alosious S., et al. [4] studied the effect Al_2O_3 and CuO nanofluids on heat transfer enhancement of flat tube radiator. As a result of the experimental and numerical study carried out, it was stated that heat transfer in engines can be increased by using nanofluids with optimum nanoparticle concentration in automobile radiators instead of conventional coolants such as water / ethylene glycol. Abdun N., et al. [5] examined the heat transfer rate for distilled water and nanofluid that consist of CuO/distilled water. Distilled water and nanofluid are used as fluids flowing in cooling coils. As a result of the study, it was stated that CuO nanoparticles increase the thermal conductivity, heat transfer coefficient, heat transfer rate and Nusselt number of pure water which is used as the base liquid. Chavda N.K. [6] investigated the effect of nanofluid consisting of CuO / pure water on heat transfer characteristics of double pipe heat exchanger. As a result of experiments performed in parallel and counter flow, it was observed that when the volume ratio of CuO particles in the nanofluid was increased, the heat transfer coefficient also increased compared to water.

Arshad. A., et al. [7] experimentally studied the preparation, characterization (for stability) and applications of graphene based nanofluids. As a result of the study, it has been observed that the heat transfer rates of nanofluids using graphene as nanoparticles are higher than the nanofluids using metal and metal oxide nanoparticles. Alshikhi O. & Kayfeci M. [8] examined the performance of the hybrid nanofluid, which they created using graphene nanoplatelet and aluminum oxide, in the photovoltaic panel as a coolant. In the data obtained as a result of the experimental study, the data obtained with three different fluids were compared. These fluids are distilled water, nanofluid containing graphene nanopalatelets as nanoparticles and hybrid nanofluid containing aluminum oxide & graphene nanoplatelets as nanoparticles. When the fluids were examined according to energy efficiency, electricity generation and thermal efficency, it was observed that the nanofluid containing only graphene nanoplatelets was more efficient than the hybrid nanofluid and distilled water.

Aytac. I. [9] experimentally investigated the effect of nanofluids on heat transfer performance in heat exchangers with the similar experimental setup and method used in this article. The study investigated the effect of a nanofluid consisting of Al_2O_3 nanoparticles on the heat transfer performance of concentric tube heat exchanger. Experimental work was carried out for parallel and cross flow types. After the measurements, it was found that using nano fluid compared to pure water in both flow types increases the heat transfer performance of concentric tube heat exchanger. After the experimental results were examined, it was seen that parallel flow type provided more enhancement than cross flow type when Al_2O_3 nano fluid was used as a hot fluid. Khanlari. A., et al. [10] investigated the effect of the nanofluid consisting of kaolin / pure water on the thermal performance of the concentric tube heat echanger in their study. Nano fluid containing %2 kaolin nanoparticles by mass was used as a hot fluid in a similar concentric tube experimental setup. As a result of the experiments performed in parallel and counter flow flow types, it was observed that the thermal performance was increased by %37 in parallel flow and %12 in counter flow compared to pure water. Khedkar. R. S, et al. [11] experimentally investigated the effect of nano fluids of different volumetric concentrations of Al_2O_3 nanoparticles on the thermal performance of the concentric tube heat exchanger. As a result of the experiments, it has been determined that the heat transfer coefficient increases with the use of nano fluid. The thermal conductivity coefficient has also been observed to increase with the use of nano fluids. The highest thermal performance in the concentric tube heat exchanger was achieved with a nano fluid containing %3 AL_2O_3 nanoparticles by volume.

In this paper, an experimental study was carried out in parallel flow with a hybrid nanofluid consisting of GNP - CuO / pure water to enhance the thermal performance of the concencticirc tube heat exchanger. The data obtained as a result of the experimental study were compared for two cases where water was used as fluid and hybrid nanofluid formed as fluid was used. By analyzing the comparison results, the effect of the hybrid nanofluid on the enhancement of the thermal performance of the concentric tube heat exchanger has been investigated.

2. THEORETICAL ANALYSIS

2.1. Equations Used

In this experimental study, the thermo-physical properties of the hybrid nanofluid, whose thermal performance was investigated, were calculated using the (φ) function, which represents the volume concentration of nanoparticles. The density, specific heat and thermal conductivity coefficient of the hybrid nanofluid used in the experiments are calculated by equations 1.1, 1.2 and 1.3, respectively.

$$\boldsymbol{\rho}_{nanofluid} = \varphi_{\boldsymbol{\rho}} \times (1-\varphi) \times \boldsymbol{\rho}_{base\ fluid} \tag{1.1}$$

$$c_{p_{nanofluid}} = \varphi_{cp} \times (1-\varphi) \times c_{p_{base\ fluid}} \tag{1.2}$$

$$\mathbf{k}_{nanofluid} = \mathbf{k}_{base\ fluid} \times \left[\frac{\mathbf{k}_{particle}+2\mathbf{k}_{base\ fluid}+2\varphi(\mathbf{k}_{particle}-\mathbf{k}_{base\ fluid})}{\mathbf{k}_{particle}+2\mathbf{k}_{base\ fluid}-2\varphi(\mathbf{k}_{particle}-\mathbf{k}_{base\ fluid})}\right] \tag{1.3}$$

Heat transfer in concentric tube heat exchanger can be defined as heat removed from the hot fluid per unit time ($\dot{Q}_{hot}$) and heat transfer to the heating fluid per unit time ($\dot{Q}_{cold}$). ($\dot{Q}_{hot}$) and ($\dot{Q}_{cold}$) can be calculated as in equation 1.4 and 1.5 respectively.

$$\dot{Q}_{hot} = \dot{m}_{hot} \times c_{p,hot} \times (T_{hot,in} - T_{hot,out}) \quad (1.4)$$

$$\dot{Q}_{cold} = \dot{m}_{cold} \times c_{p,cold} \times (T_{cold,in} - T_{cold,out}) \quad (1.5)$$

When the resistance caused by the wall thickness of the inner pipe is neglected in the experiments performed in the concentric heat exchanger and the errors caused by the measurement device and reading errors are neglected in the experiments, maximum efficiency will be observed in the case where the amount of heat discharged from the hot fluid per unit time is equal to the amount of heat transfer made to the cold fluid per unit time. In other words, when equation 1.6 is satisfied, it is assumed that the maximum efficiency is achieved.

$$\dot{Q}_{hot} = \dot{Q}_{cold} \quad (1.6)$$

The heat transfer between the hybrid nanofluid and the pipe surface along the concentric pipe is calculated by equation 1.7.

$$\dot{Q} = U \times A \times \Delta T_{ln} \quad (1.7)$$

U (W/m^2) in euation 1.7 is the heat transfer coefficient between the fluid and the inner surface of the pipe, A (m^2) the heat transfer area on the inner surface of the pipe, ΔT_{ln} shows the logarithmic mean temperature difference between the hybrid nanofluid and the inner surface of the pipe (eq. 1.8).

$$\Delta T_{ln} = \frac{\Delta T_{in} - \Delta T_{out}}{\ln(\frac{\Delta T_{in}}{\Delta T_{out}})} \quad (1.8)$$

The overall heat transfer coefficient U (W/m^2) was calculated by equation 1.9.

$$U = \frac{\dot{Q}}{A \times \Delta T_{ln}} \quad (1.9)$$

Exergy loss (X) in the system is calculated by equation 1.10.

$$\dot{X} = (T_{environment} \times \dot{m}_{hot} \times c_p \times \ln(\frac{T_{hot,out}}{T_{hot,in}})) + (T_{environment} \times \dot{m}_{cold} \times c_p \times \ln(\frac{T_{cold,out}}{T_{cold,in}})) \quad (1.10)$$

2.2.Uncertainty Analysis

During the experimental study carried out, uncertainty analysis was applied to determine the uncertainties caused by test conditions, device-related errors, calibration, sensor reading errors and connection points. The total uncertainty of the R value and the size of the R value affected by the $x_1, x_2, x_3, \ldots, x_n$ values specified in equation 1.11 is expressed as W_R. Error rates of arguments are assumed as $w_1, w_2, w_3, \ldots, w_n$ [12]. In order to minimize the effect of measurement uncertainties, the data obtained were taken as average values by repeating the experiments three times.

$$W_R = [(\frac{\partial R}{\partial x_1} W_{1)})^2 + \left(\frac{\partial R}{\partial x_2} W_{2)}\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} W_{n)}\right)^2]^{1/2} \quad (1.11)$$

The technical properties and the uncertainty values of measurement equipment were given in Table 1

Table 1. Properties of measurement equipment

Name of equipment	Technical Properties	Uncertainty
Thermocouples and data logger	Type J, measuring range 0°C-350°C Accuracy: ± 0.4 °C	± 0.588 °C

3. MATERIAL AND METHODS

In the experiment, a total of 5 liters of nanofluid was prepared, containing 0.5% CuO, 0.5% graphene nano-plate, 0.05% surfactant by mass. Sodium dodecyl benzene sulphonate, whose chemical formula is $C_{18}H_{29}NaO_3S$ was chosen in order to disperse the nanoparticles in water without precipitation and to increase the stability of the nanofluid. While preparing the nanofluid, the commonly used two-stage method was preferred. The nanoparticles prepared in dry powder form by this method were mixed with pure water and then kept in an ultrasonic bath device for 3 hours in order to increase the stability of the nanofluid and to show high dispersion of the nano particles in the base liquid. After the two-stage method is applied, high surface area and surface activity can occur. This causes the nanoparticles to accumulate. The surfactant has been used to prevent the build-up of nanoparticles and to increase the stability of the nanofluid. A 5 liter nano-fluid consisting of distilled water, CuO, graphene nanoplatelets and surfactant was kept in an ultrasonic bath for 3 hours as shown in Figure 1 to ensure homogeneous distribution of nano powders in water.

Figure 1. Hybrid nanofluid held in an ultrasonic bath

Table 2. Technical properties of ultrasonic bath device

Technical Properties	Value
Voltage (V/Hz)	230/50
Ultrasonic Power (Peek/W)	600/300
Ultrasonic Frequency (kHz)	28

The setup of the experiment performed in the concentric tube heat exchanger is shown in Figure 2. The hot and cold fluids used in the experiments were observed at different mass flow rates and temperatures to measure the heat transfer performance. The installation shown in Figure 2 is placed on a plastic panel made of high quality glass reinforced material to make the test reliable against any external interference. Using the setup shown in Figure 2, overall heat transfer, overall heat transfer coefficient and surface heat transfer coefficient for parallel turbulent flow were calculated. V1, V2, V3 and V4 valves indicated in Figure 2were opened and V5, V6 and V7 valves were closed in order to operate the installation in the case of parallel flow where hot and cold fluids flow in the same direction. There are mainly two loops in the experimental concentric tube heat exchanger setup. The first loop is the hot loop in which hot fluid supplied by an electric resistance water heater is circulated by a pump in the tubes of the heat exchanger. While the experiment set is running, the hot fluid passes through the heat exchanger and reaches the flow meter placed at the

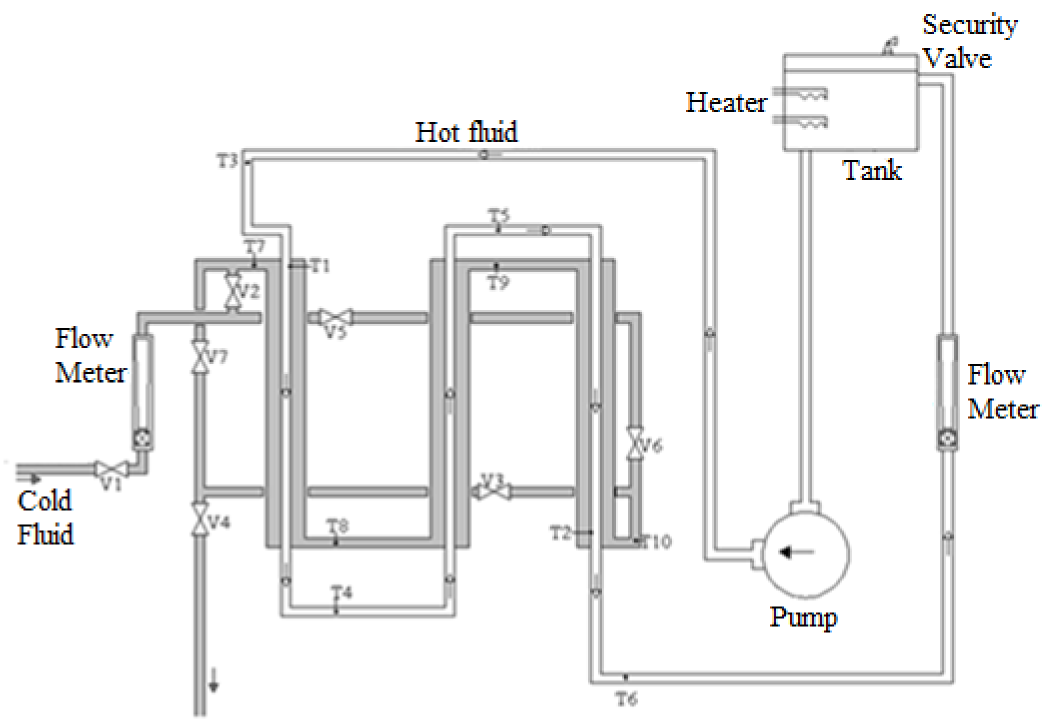

Figure 2. Concentric tube heat exchanger experiment setup [13]

end of the loop. As the hot fluid passes through the heat exchanger, it cools down with the temperature drop and comes to the heating tank for reheating. The second cycle is the cold fluid cycle in which cold water used as cold fluid enters the system through the flow meter. Then the cold water leaves the system by passing through the heat exchanger. Hybrid CuO - graphene nanoplatelet nanofluid used as hot fluid passes through the inner tube, and water used as cold fluid passes through the outer tube. Hot fluid circulation in the inner pipe is provided by a centrifugal pump made of brass and stainless steel. Hot fluid is prepared with 2 electric heaters placed in a container made of stainless steel.

For the safety of the system, there are circuit breakers inside the tank against high temperature, an automatic pressure reduction valve with an external thermostat against uncontrolled pressure rise, and a water level sight glass to control the water level of the system.

A flow meter is installed in the cold fluid and hot fluid circuits to measure the flow rate of the fluids circulating in the system. 10 thermocouples were used to measure the temperatures at different points of the system and a digital temperature indicator was used to read these temperatures. The technical properties of concentric tube heat exchanger used in the experimental setup are given in Table 3.

Table 3. Technical properties of concentric tube heat exchanger

Technical Property	Value
Pumping Capacity (bar)	5
Heater Power (kW / per Unit)	1,5
Cold Fluid Cycle Flow Meter (g/s)	4 - 50
Hot Fluid Cycle Flow Meter (g/s)	3 - 10
Thermocouples (Type)	J
Temperature Display Accuracy (℃)	0,1
Tube Heat Exchanger Inner Tube Inner Diameter (mm)	7,9
Tubular Heat Exchanger Inner Tube Outside Diameter (mm)	9,5
Tube Heat Exchanger Outer Tube Inner Diameter (mm)	11,1
Tubular Heat Exchanger Outer Tube Outside Diameter (mm)	12,7
Length (mm)	3x350 mm
Heating Surface Area (inner tube) Inner Heat Transmission Area (m^2)	0,026
Heating Surface Area (inner tube) Outer Heat Transmission Area (m^2)	0,031
Average Heat Transfer Area (m^2)	0,0288
Flow Area (m^2)	$49x10^{-6}$

4. RESULTS AND DISCUSSION

To study the behavior of the CuO&GNP/distilled water hybrid nanofluid in a concentric tube heat exchanger, CuO at 0.5% volume particle concentration and graphene nanoplatelet nanoparticles at 0.5% volume particle concentration in a 5 liters of total mixture has been tested for 3, 4, 5, 6, 7, 8 and 9 l/min hot fluid flow rates. The flow rate of cold water used as cold fluid during the experiments is 10 g/sec. The experiment was carried out in parallel directional flow with the condition of 72 ° C hot fluid inlet temperature.

For two different situations where water and CuO & GNP / distilled water hybrid nanofluid are used as hot fluid in parallel directional flow, the change of the overall heat transfer coefficient depending on the flow rate of the nanofluid is shown in Figure 3, the change of the heat transfer coefficient of the hot fluid is shown in Figure 4, and the change of cold fluid heat transfer coefficient calculated for cold water used as cold fluid is shown in Figure 5. The total exergy loss according to the hot fluid flow rate is shown in Figure 6.

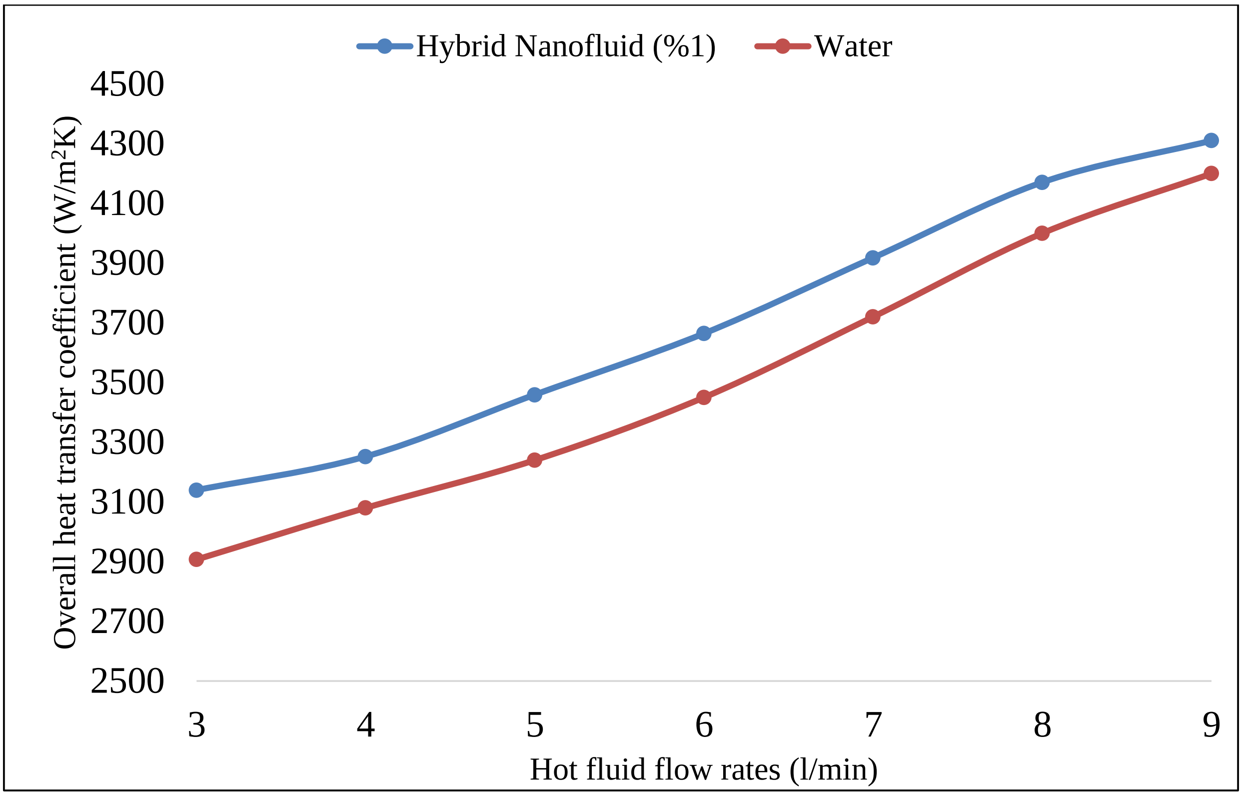

Figure 3. Variation of the overall heat transfer coefficient according to the hot fluid flow in parallel directional flow

The change of the overall heat transfer coefficient according to the hot fluid flow rate is shown in Figure 3. When Figure 3 is examined, it is seen that the hybrid nanofluid enhances the heat transfer coefficient more than water at all hot fluid flow rates. The highest overall heat transfer coefficient enhancement was observed when the hot fluid flow rate was 3 l/min. When the hot fluid flow rate is increased from 4 l/min to 8 l/min, it is seen that the enhancement in the overall heat transfer coefficient increases at a similar rate, but when the hot fluid flow rate is 9 l/min, the enhancement in the overall heat transfer coefficient decreases.

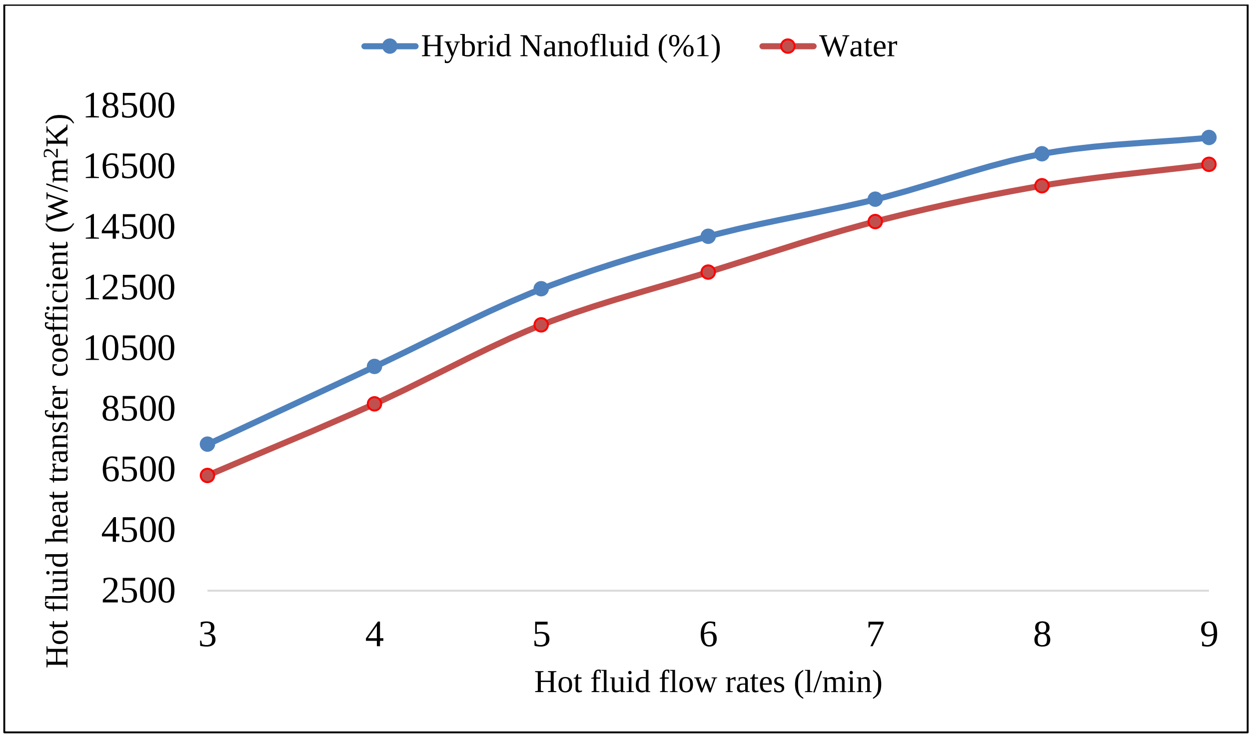

Figure 4. Variation of the hot fluid heat transfer coefficient according to the hot fluid flow in parallel directional flow

In Figure 4, it is seen that with the effect of nano particles in its content, the hybrid nanofluid enhances the hot fluid heat transfer coefficient more in different hot fluid flow rates compared to water. By using hybrid nanofluid, an average enhancement of 9.6% was achieved in hot fluid heat transfer coefficient. Although the flow rate of the hot fluid increases, the enhancement in the heat transfer coefficient of the hot fluid does not change strikingly.

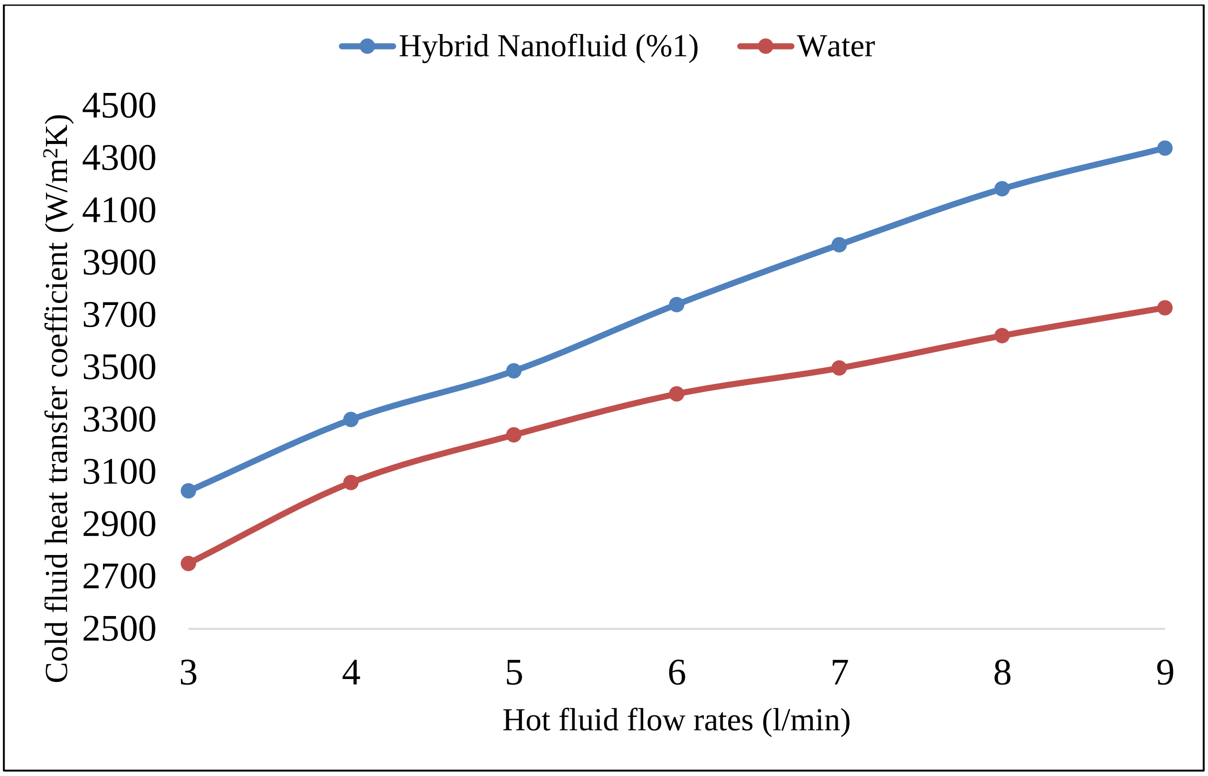

Figure 5. Variation of the cold fluid heat transfer coefficient according to the hot fluid flow in parallel directional flow

The change of the cold fluid heat transfer coefficient according to the flow rate of the hot fluid is shown in Figure 5. While a similar enhancement is observed in the cold fluid heat transfer coefficient when the hot fluid flow rate is 3,4 and 5 l/min, it is observed that the enhancement in the cold fluid heat transfer coefficient increases at 6,7,8 and 9 l/min values by increasing the flow rate of the hot fluid. The highest enhancement in the cold fluid heat transfer coefficient was observed for the case where the hot fluid flow rate was 9 l/min.

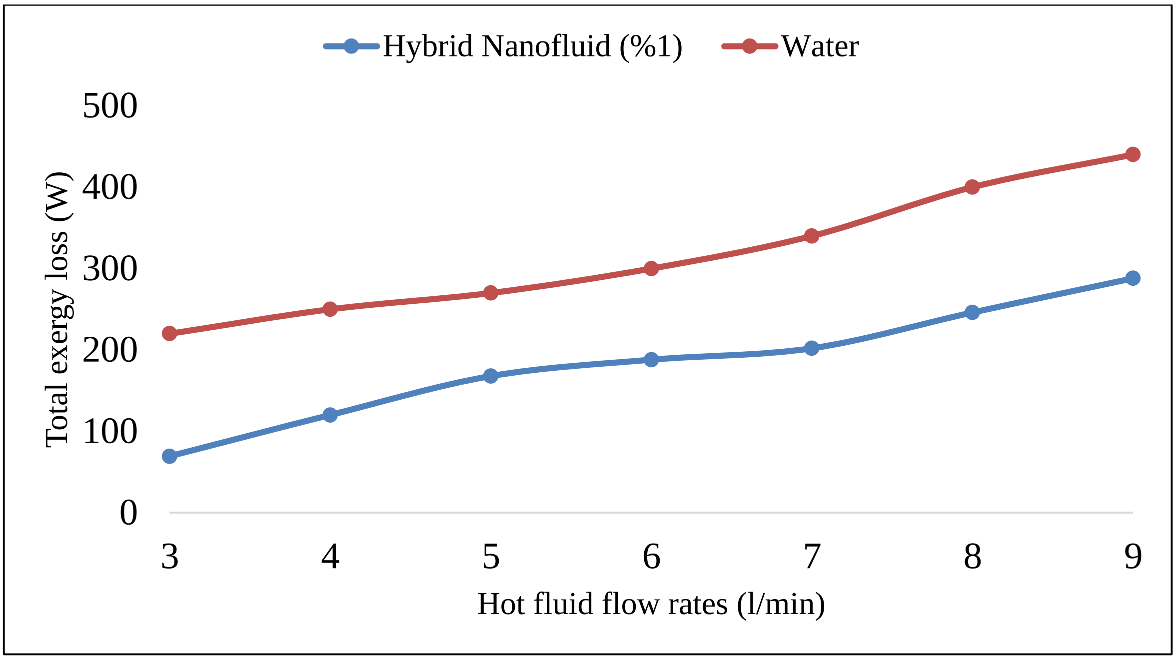

Figure 6. The total exergy loss according to the hot fluid flow rate

In the graph of the total exergy loss seen in Figure 6 according to the hot fluid flow rate, it is seen that the total exergy loss is reduced if hybrid nanofluid is preferred. It is seen that the total exergy loss decreases more with increasing the hot fluid flow rate throughout the graph. The maximum reduction in total exergy loss was observed when the hot fluid flow rate was 8 and 9 l/min.

In the experiments carried out in the concentric tube heat exchanger, it was observed that an average of 5.5% enhancement in the overall heat transfer coefficient was achieved in parallel flow by using a hybrid nanofluid consisting of graphene nanofluid at 0.5% volume concentration and CuO at 0.5% volume concentration. By using hybrid nanofluid, an average enhancement of 9.6% and 11.5% was achieved in hot and cold fluid heat transfer coefficients, respectively. Total exergy loss has been reduced by an average of 55% by using hybrid nanofluid. It is assumed that by improving the overall heat transfer coefficient by 5.5% on average by using the hybrid nanofluid, the electrical power requirement of the heater used for heating the hot fluid in the concentric tube heat exchanger will decrease by 5.5% in a similar manner. Considering that the heater in the Concentric tube heat exchanger has 1.5 kW/unit of electricity consumption, a system consisting of 2 heater units requires 36 kWh of energy per 12 hours of use. With the hybrid fluid, this need will be reduced to approximately 34 kWh, resulting in 0.42 m^3 less natural gas consumption and 0.42 m^3 less CO_2 emission. Thus, environmental pollution can be reduced by increasing the thermal performance of the concentric tube heat exchanger.

As a result of the experimental study carried out, it was concluded that the hybrid nanofluid consisting of GNP + CuO / pure water has a higher heat transfer coefficient compared to conventional working fluids. This result shows that hybrid nanofluid can be used in different heat transfer applications such as in heat exchangers to increase efficiency and thermal performance.

In this way, the need for higher heat transfer can be met with more compact heat exchangers. In addition, by increasing the efficiency of heat exchangers, more profitable systems can be developed by reducing costs in economic terms.

In the next study, to improve the results obtained, the same hybrid nanofluid composition (CuO & graphene nanoplatelet / distilled water) can be tested with different volumetric concentrations to find the optimum concentration value for optimal heat transfer performance.

CONCLUSION

In the present study, a hybrid type nanofluid containing CuO and graphene nanoplatelet has been experimentally tested in a u-tube heat exchanger. In this regard, water based hybrid nanofluid has been prepared and tested at different condition to determine its thermal behavior. The overall results of this study presented successfulness of the utilized nanofluid in the u-tube concentric heat exchanger. Utilizing hybrid nanofluid led to obtain an average enhancement of 9.6% in hot fluid heat transfer coefficient. In further studies, different types of hybrid nanofluids at various particle ratios can be examined to obtain more enhancement.

Declaration of Ethical Standards

The authors of the paper submitted declare/declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

Contribution of the Authors

Yetkin Şen: Methodology, Formal analysis, Investigation, Writing – Original Draft, Visualization. Halil İbrahim Variyenli: Conceptualization, Writing – Original Draft, Supervision, Project administration.

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