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Experimental Investigation of Heat Transfer Enhancement Using Hybrid Nanofluid with Insert Helical Coil in a Double Pipe Heat Exchanger.

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Abstract

This experiment investigates heat transfer enhancement in a double pipe heat exchanger using a hybrid nanofluid comprising aluminum oxide and copper oxide nanoparticles with and without helical coil inserts. The objective is to examine the heat transfer performance of the hybrid nanofluid and its potential for practical applications in enhancing heat exchanger efficiency. The hybrid nanofluid is prepared by distributing nanoparticles in a base fluid using magnetic stirring. The experimental result demonstrated that higher the concentration of CuO in hybrid nanofluid results considerably high heat transfer coefficient. Specifically, a nanoparticle volume concentration of 30%Al_2O_3 and 70% CuO yields a higher heat transfer rate of 2463.7 W and an overall heat transfer coefficient found about 845.69 W/m^2k. Heat transfer rate is higher for helical coil insert with hybrid nanofluid compared to hybrid nanofluid alone. A comparison with a conventional fluid demonstrates that the hybrid nanofluid with helical coil inserts greatly enhances heat transfer rates due to increased thermal conductivity and fluid mixing. The findings indicate that enhancing energy efficiency and thermal performance in heat exchangers could have practical implications in a variety of industries.

Keywords: Heat exchanger, Hybrid nanofluid, LMTD, Heat transfer rate.

"1. Introduction"

Numerous heat transfer enhancement techniques always grabbed the attention of researchers in the field of energy system. Extensive investigations have been conducted on the development of enhancement devices. Researchers worldwide are seeking optimized devices that can reduce pumping power costs while providing high heat transfer rates their concern about low energy loss with higher performance. Barzegar et al. [1] studied the overall heat transfer in a double-pipe heat exchanger with twisted-tape components and hybrid nanofluid. The results showed that using both twisted tape and nanofluid increased the heat transfer coefficient by roughly 40% compared to not using either. According to the results of the research, 1% hybrid nanofluid with twisted tape has somewhat higher heat transfer than 1% Al_2O_3/CuO nanofluid. Dhar et al. [2] conducted experiments to determine the thermal efficiency of a heat exchanger using Al_2O_3/water, CuO/water, and a mixture of the two as nanofluids. The findings revealed that a heat transfer rate 1250 W and heat transfer coefficient found about 1934 W/m²K. The blended nanofluid's efficiency increased by about 4.3%. Das et al. [3] examined heat transfer in a shell and tube heat exchanger with a TiO_2 nanofluid based on propylene glycol and water. Nanoparticle concentrations of 0.1%, 0.2%, and 0.3% increase the convective heat transfer coefficient by an average of 5.54%, 11.04%, and 14.55%. Bahmani et al. [4] conduct an experiment to analyze turbulent heat transfer using nanofluid. Ther results indicate that raising the Reynolds number or nanoparticle volume percent improves the Nusselt number as well as the convective heat transfer coefficient respectively. Zolfalizadeh et al. [5] experimentally investigated the impact of a graphene/water nanofluid on the heat transfer performance of a shell-and-tube heat exchanger. Their findings showed that the heat exchanger's efficiency increased by 8.88% with the nanofluid for concentration of 0.06 weight percent compared to the base fluid. Jaafar Albadr et al. [6] examined forced convective heat transfer with changing volume concentrations of nanofluid with different flow rate in heat exchanger. Their findings suggest that the nanofluid had a tendency to increase convective heat transfer coefficient than the base liquid at the same flow rate. Hridoy et al. [7] carried out an experiment using perforated twisted tape inserts and two volumes of Al_2O_3/Water (0.1% and 0.2% respectively). The combination of 0.2% volume fraction of Al_2O_3 and perforated twisted tape insert has improved heat transfer rate better than the others. Wei He et al. [8] explored the flow and heat transfer characteristics of CuO-water nanofluid in a tube and shell type heat exchanger with varying solid

concentrations (1-4 vol%) using both single-phase and two-phase (mixed) models. In comparison, a tube with two twisted tapes under the same conditions achieved a performance efficiency coefficient of 2.04Sharma et al. [9] performed an experimental analysis to investigate the heat transfer coefficient and friction factor for flow in a tube with inserts of different twisted tape, specifically using Al_2O_3 nanofluid in the transition flow zone. Karimi et al. [10] performed a numerical analysis of nanofluid flow in a twin-tube heat exchanger with twisted tape inserts. The results revealed that adding alumina nanoparticles into water as a based fluid increased the pressure drop and heat transfer by up to 40% and 30%, respectively.

According to the above study, many researchers have studied both hybrid nanofluid and helical coil inserts individually, and there is a gap of research that no investigations have been done on the simultaneously apply of hybrid nanofluids and helical coil inserts. So, this work aimed to analyze the variation of heat transfer rate using hybrid nanofluids with and without inserts. In this experimental study, it was found that higher concentration of CuO gives high heat transfer rate and insert helical coil also increase the rate, which provides a certain reference to the development of high energy efficiency system.

"2. Experimental facility"

2.1. Nanofluid preparation

The hybrid nanofluid was prepared using the two-step method. At first, the nanoparticle of Al_2O_3 and CuO were weighed according to volume concentration. A ball milling machine was used to further reduction of particle size. The $Al_2O_3$and CuO powder was put inside the machine along with 20 balls. It was then mounted on a 12V DC motor and rotated at high rpm using a DC power supply for 2 hours. This process was repeated several times to prepare the required amount of nanoparticle. Then it was mixed with the base fluid which was water. Sodium lauryl sulphate was used as a surfactant. For the proper mixing, nanoparticles of Al_2O_3 and CuO with water was stirred by magnetic stirrer. This process had been continued for 2 hours with 1500 rpm in a magnetic stirrer. SEM analysis was done for Al_2O_3 nanoparticle. From figure 1 it was found that the nano particles size varied from 29.17 nm to 40.76 nm.

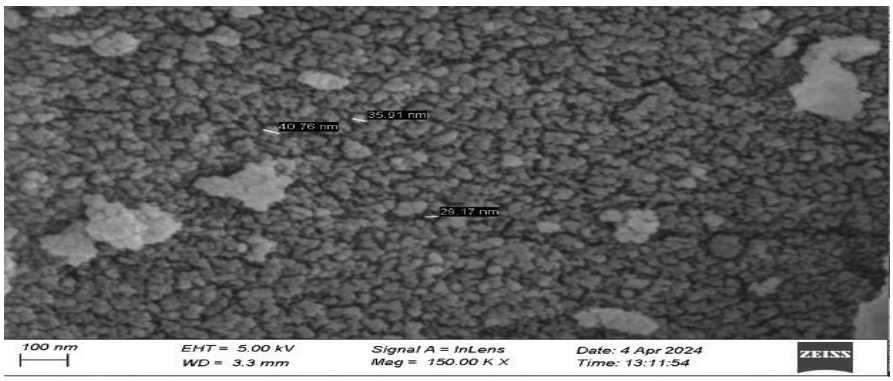


Fig.1. SEM Analysis

2.2. Experimental setup

A double-pipe heat exchanger served as the experimental test section in this study. The test section consisted of a stainless steel tube which length was 1800mm with internal and external diameters of 50 mm and 90 mm, respectively, and a thickness of 1 mm. Four thermometers were utilized to measure the temperature at various locations throughout the setup. Pump was used to move the fluid across the pipe. Flowmeters were used to adjust the flow of water and calculate it's rate. An electric heater was fitted to heat the water delivered to the heat exchanger for hot water flow. The experiment setup included two reservoir tank, a double-pipe heat exchanger, thermometers, a pump, and a flow meter. In this setup, the nanofluid moved through the inner tube, while water passing through the outer tube of the heat exchanger. The hot tank was insulated to prevent heat loss, and two valves were used to regulate the flow. Four thermometers were installed at the inlets and outlets of the heat exchanger. Two thermometers measured the temperature of the nanofluid at the inlet and outlet portion of the tube side, while the other measured the temperature of the water at the inlet and outlet of the external shell. Initially, a plain tube without an insert was used, followed by the insertion of a helical stainless steel coil into the tube. The coil diameter was 42mm and it collect from local workshop. Once all the devices reached steady-state conditions, data were collected by adjusting the flow rate. The schematic diagram and photographic view of test section are shown in Figures 2 and 3 respectively.

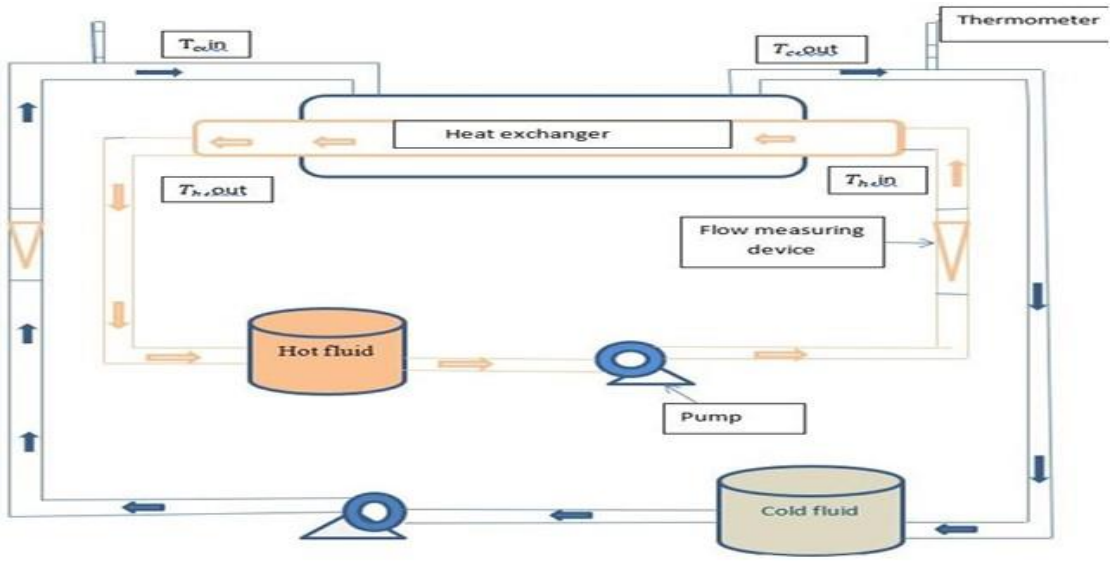


Fig. 2. Schematic diagram of test section



Fig 3. Photographic view of test section

"3. Data reduction"

Several mathematical equations were applied to measure various characteristics of hybrid nanofluid and evaluate the performance. The rate of heat transfer, overall heat transfer coefficient, LMTD, flowrate were calculated using the experimental data and compare them. After analyzing this data, graphical representations were created to visualize the findings.

Density of the Nano-fluid, $\rho_{nf} = (1 - \varphi)\,\rho_{bf} + \varphi\rho_p$ (1)

Density of Hybrid Nano-fluid, $\rho_{hnf} = (1-\varphi_1-\varphi_2)\,\rho_{bf}+\varphi_1\rho_1+\varphi_2\rho_2$ (2)

Specific heat of hybrid nanofluid $\left(C_p\right)_{hnf} = \frac{(1-\varphi)(C_p)_{bf}\,\rho_{bf}+\varphi_1(C_p)_{p1}\,\rho_{p1}+\varphi_2(C_p)_{p2}\,\rho_{p2}}{\rho_{hnf}}$ (3)

Dynamic viscosity of Hybrid nanofluid, $\mu_{hnf} = \frac{\mu_{bf}}{(1-\varphi_1)^{2.5}(1-\varphi_2)^{2.5}}$ (4)

Cross Sectional Area, $A_x = \frac{\pi di\,2}{4}$ (5)

Heat transfer to water was calculated, Q = mCp (To- Ti) (6)

Log mean temperature difference (LMTD), $\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\frac{\Delta T_1}{\Delta T_2}}$ (7)

$$\Delta T_1 = T_{h,in} - T_{c,out}$$
$$\Delta T_2 = T_{h,out} - T_{c,in}$$

Here,

$T_{h,in}$ = Hot water inlet temperature, $T_{h,out}$ = Hot water outlet temperature.

$T_{c,in}$ = Cold water inlet temperature, $T_{c,out}$ =Cold water outlet temperature.

Overall heat transfer coefficient, $U = \frac{Q}{AF\Delta T_m}$ (8)

Here, U = Overall heat transfer coefficient, W/m^2K, F = Correction factor

"4. Results and discussion"

For a 0.1% volume fraction of Al_2O_3, CuO, and different hybrid combinations (30% Al_2O_3 & 70% CuO, 50% Al_2O_3 & 50% CuO, 70% Al_2O_3 & 30% CuO), Figure 4 shows that the 30% Al_2O_3 and 70% CuO nanofluid exhibits superior thermal performance compared to the other nanofluids at a fixed flow rate of 4 L/min. Adding a helical coil to a double-pipe heat exchanger will indeed change the cross-sectional area available for fluid flow, impacting flow characteristics and heat transfer performance. The helical coil creates secondary flow patterns (vortices) due to its curvature, which can increase the heat transfer rate. Figure 5 represent the comparable heat transfer rate with and without insert of helical coil.

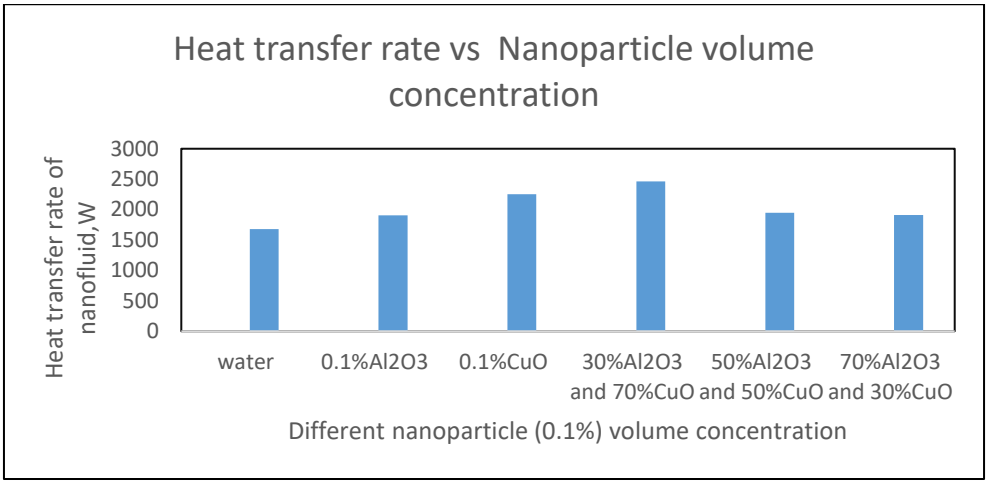


Fig.4. Influence of different volume concentrations on the heat transfer rate

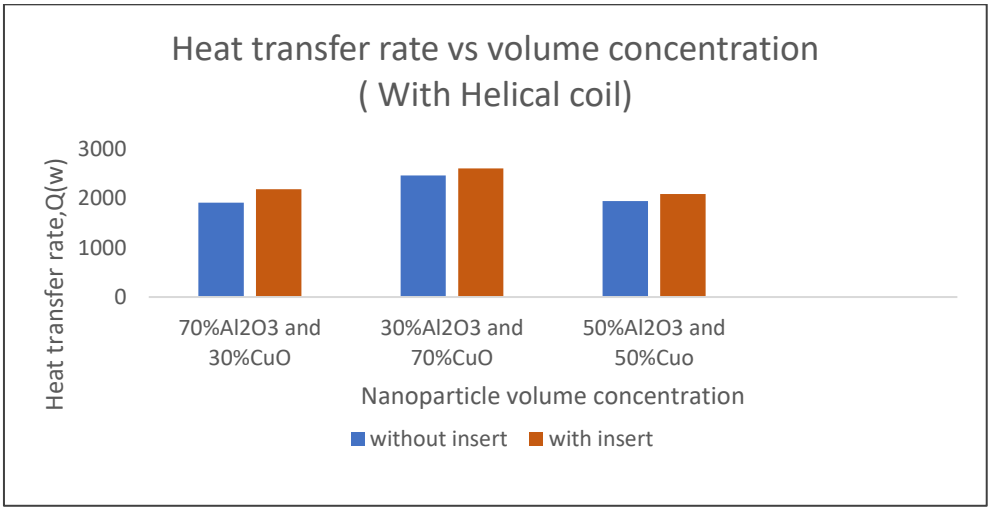


Fig.5. Change in the heat transfer rate as a function of volume concentration with and without insert

Figure 6 shows the relation between overall heat transfer co-efficient and Reynolds number. The overall heat transfer coefficient (U) is a measure of how easily heat passes through a material. Heat transfer co-efficient increase with the change of Reynolds number. At high Reynolds number mixing of fluid occurs and more heat is taken away from tube. Figure 7 shows the relation of overall heat transfer co-efficient and LMTD. The overall heat transfer coefficient tends to increase with a larger Logarithmic Mean Temperature Difference (LMTD) because a higher LMTD indicates a greater temperature difference between the hot and cold fluids in the heat exchanger. This larger temperature gradient drives more heat to transfer across the heat exchanger surfaces. As the heat transfer rate increases, the overall heat transfer coefficient rises because it depends on both the heat

transfer rate and the temperature difference. The more efficiently heat is transferred, the higher the coefficient becomes, reflecting the system's improved thermal performance.

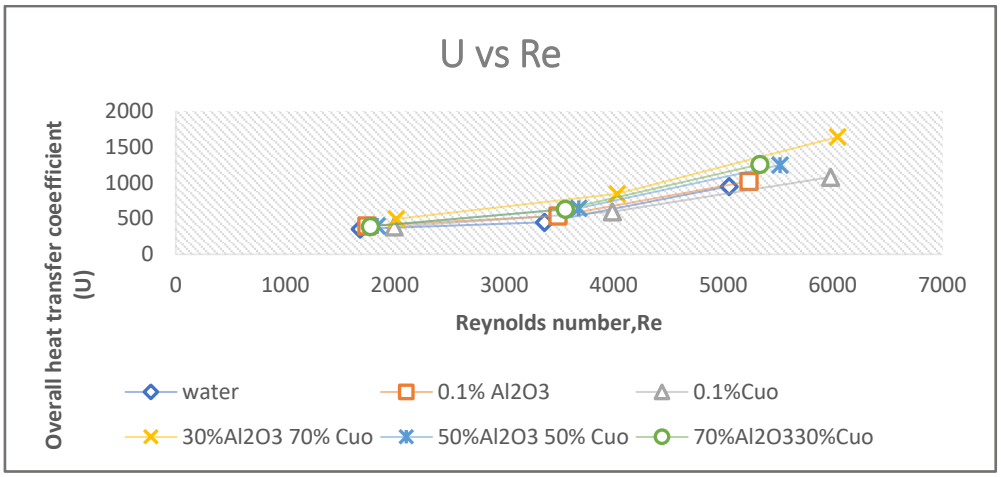


Fig.6. Overall heat transfer co-efficient change with Reynolds number

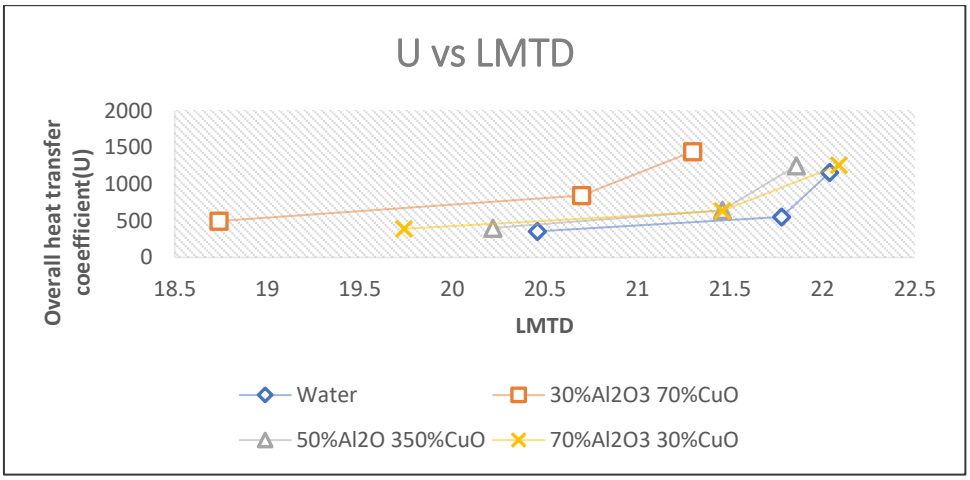


Fig.7. Overall heat transfer co-efficient change with LMTD

Figure 8 shows the relation of heat transfer rate vs flow rate. The heat transfer rate increases with the flow rate. Higher flow rates increase the heat transfer coefficient, resulting in more efficient heat transfer from surface to fluid.

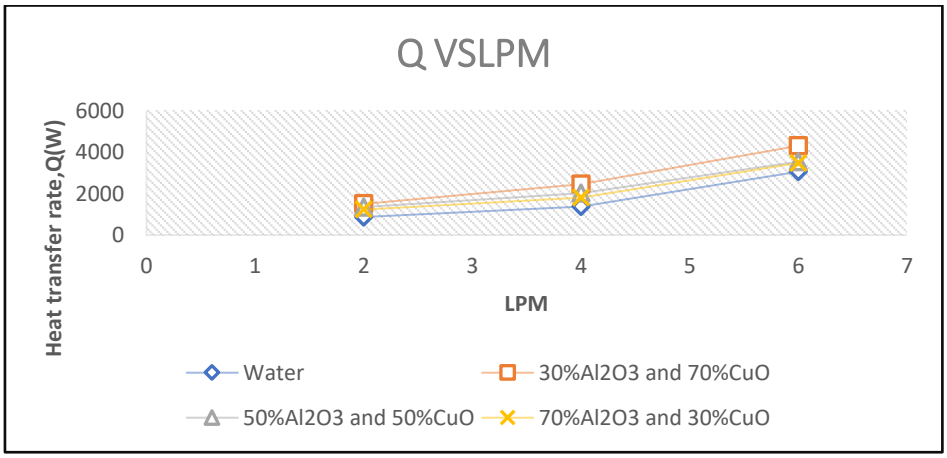


Fig.8. Heat transfer rate increase with LPM

"5. Conclusion"

The application of nanotechnology in the heat transfer process holds the potential to revolutionize the field by enhancing the efficiency of heat transfer devices. As nanotechnology continues to expand into various branches of engineering, its integration into these devices can significantly boost performance and longevity. Enhanced heat transfer systems can have a transformative impact in industries such as steam and thermal power plants, HVAC, and chemical processing, where even minor efficiency increases can lead to significant economic and environmental benefits. Improved heat transfer in cooling systems can result in higher fuel efficiency and better performance in automobile engines, aeronautical equipment, and solar thermal plants. Undoubtedly, this study will provide valuable insights into the properties of nanoparticles and demonstrate their effectiveness in enhancing heat transfer. The findings of the study can be concluded as follows:

- CuO nanofluid has greater thermal conductivity than Al_2O_3 nanofluid. CuO gives higher heat transfer coefficient than Al_2O_3 and pure water.
- Higher the concentration of CuO in hybrid nanofluid results considerably high heat transfer coefficient. Water, 30% $Al_2O_3$70%CuO Nanofluid, 30% $Al_2O_3$70%CuO Nanofluid, 30% $Al_2O_3$70%CuO Nanofluid among them 30% $Al_2O_3$70%CuO volume concentration gives higher heat transfer coefficient.
- Using the same volume fraction of nanofluid and hybrid nanofluid, both the heat transfer rate and the overall heat transfer coefficient increase with increase of logarithmic mean temperature difference (LMTD).
- Heat transfer rate is higher for helical coil insert with hybrid nanofluid compared to hybrid nanofluid alone.

"6. Acknowledgement"

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