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Investigation of heat transfer characteristics of Al_2O_3-Water nanofluid in a coiled agitated vessel across varied operating conditions

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ABSTRACT

This study aimed to investigate the heat transfer behavior of an Al_2O_3-water nanofluid within a coil-agitated tank. The experiment utilized Al_2O_3-water nanofluids with varying volume concentrations, namely 0.2 vol%, 0.3 vol%, and 0.4 vol%. Two different cooling water flow rates, specifically 1.8 and 2.2 liters/min, were employed during the investigation. The propeller speed ranged from 2 to 12 (rps), and the temperature spanned from 30 to 80 °C. The findings revealed that the heat transfer coefficient of the nanofluids exceeded that of the base water. Moreover, it increased with higher volume concentrations, reaching its peak at 0.4 vol% with an average rise of approximately ±77.2%. Additionally, the heat transfer coefficient demonstrated an increase of about ±19.8% when the temperature was elevated to 80 °C and approximately ±11.9% when the propeller speed was raised to 12 rps. Comparing the two distinct flow rates, it was observed that the heat transfer coefficient rose with decreasing flow rate to 1.8 liters per minute, exhibiting an average enhancement of approximately ±13.6%.

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1. Introduction

Heat transfer, which involves adding, removing, or transferring heat effectively and efficiently, is a crucial process in the majority of chemical engineering applications [1, 2]. In an industrial setting, improving heating or cooling may result in energy savings, reduced process time, increased thermal efficiency, and longer equipment life. As a result, there is a substantial demand for effective heat transfer in high-heat-flow operations in new technologies [3]. Boilers, heat exchangers, air coolers, evaporators, and agitated vessels are among the often utilized pieces of heat transfer equipment in the chemical industries [4]. Most procedures in the chemical industry include mixing or the interpenetration of one component into another. Agitated vessels are the tools that are used frequently for this purpose and fitted with an agitator. Aerators, mixers, and reactors are frequently utilized in agitated vessels. In addition, it is useful for isothermal reactions with high reaction heat. In order to carry out the reaction at the desired temperature in the reaction system (heated or cooled), the vessel can be jacketed, or a helical coil can be inserted inside the vessel as a heat transfer surface. In some circumstances, both the helical coil and the jacket are employed to enhance the heat transfer. Since helical coils have a higher heat transfer coefficient than jackets, they are often preferable. A significant

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surface area for heat transfer is also provided by the coil in the small reactor volume [2].

Increasing the working fluid's thermal conductivity can also improve the effectiveness of heat transfer [5]. Heat transfer fluids including water, engine oil, and ethylene glycol have thermal conductivities that are relatively low when compared to the thermal conductivity of solid particles. The fluid's thermal conductivity can be increased by adding small solid particles [6]. The ability to create nanometer-sized particles with entirely distinct electrical, optical, mechanical, and thermal properties from the original material was made possible by the invention of novel technologies [3]. Different volume concentrations of Al_2O_3-water nanofluids were used in the experiment to conduct the study. As the volume concentration rises, the heat transfer coefficient of Al_2O_3-water nanofluids increases [3]. Arivazhagan et al. [4], Investigate the convective heat transfer properties of TiO2-water nanofluid experimentally in an agitated vessel with a propeller agitator. They estimated and compared the heat transfer coefficients of water with three different volume concentrations of TiO_2-water nanofluid (0.1vol%, 0.2vol%, and 0.3vol%) in a coiled agitated vessel. It was discovered that the water-nanofluid heat transfer coefficient was greater. As the volume concentrations increase, the heat transfer coefficient also increases. It was discovered that employing nanofluid increased convective heat transfer by about 17.59%. To deliver heat input into the heaters, all previous investigations used wattmeters that ranged in power from 400 to 2200 W [1, 3, 4]. ARIVAZHAGAN et al. experimentally examined by varying the heat input from 400 to 2200 W, they discovered that when the heat input increases, the heat transfer coefficient increases [7]. A steady cooling water flow rate at 1.8 liter/min was used in all previous research. Results were obtained with different enhancements in heat transfer rates by changing the flow rates. Since our paper also uses a coiled-agitated vessel with a propeller, it is evident from the literature review that it is comparable to theirs. This study's objective is to present the heat transfer behavior of an Al_2O_3-water nanofluid at various volume concentrations, cooling water flow rates, and temperatures in a coil-agitated vessel.

2. Materials and experimental procedures

2.1 Experimental Setup

To process the experimental results, a suitable system must be designed. As a result, Fig.1 depicts a schematic diagram of the experimental setup used in the current work. The test vessel (Agitated vessel) was a cylindrical, flat-bottomed vessel made of stainless steel with a height of 0.45 m, and an inner diameter of 0.3. Two digital temperature sensors, a propeller shaft, and the inlet and outlet of the cooling water were all placed in holes at the top of the cover. The vessel's fixed agitator propeller, which is in the center. By dividing the perimeter into four equal pieces, the interior wall of the vessel was welded with four baffles. Utilizing these baffles, vortex development and swirling inside the vessel might be prevented. These baffles are each 0.025 mm in width and 0.42 m in height. Additionally, a single heater was installed at the vessel's side. The agitated vessel contained a helical coil immersed in a pool of agitated liquid media. By completely encircling the test vessel with asbestos with a layer of glass wool, heat leakage into the environment was prevented. The nanofluid was stirred using an agitator propeller with a diameter of 0.1 m, three blades with a thickness of 0.003 m, and a propeller shaft diameter of 0.01 m. The variable speed motor and speed regulator allowed the Propeller Agitator's speed to be adjusted between 2 and 12 (rps). The thermostat on the heater was used to adjust the input temperature, which ranged from 30 to 80 °C.

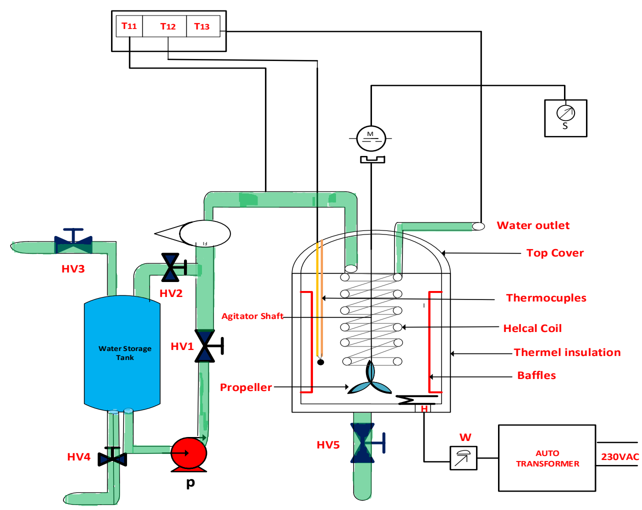


Figure 1. Experimental system; p- centrifugal pump; m-(p.m.d.c) motor; s-speed adjuster; hv1, hv2, hv3, hv4, hv5-hand valves; ti1, ti2, ti3, -temperature indicators; r-rotameter.

A copper tube was used to create a helical coil with 7.5 turns that has an inner diameter of 0.0115 m, an outside diameter of 0.013 m, and a length of 5.7 m. The coil's outside average diameter was 0.25 m, and there was a 0.028 m spacing between each turn. The helical coil was submerged to a depth of 0.3 m within the pool where the working fluid subsequently stirred. Water had been used as a cooling medium and was pumped by a centrifugal pump through the helical coil. A manual valve and a rotameter could be used to calibrate the flow rate. Three digital thermometers with 0.1°C accuracy was used to measure the temperatures of the agitated liquid medium, the cooling water inlet, and the output.

2.2 Nanofluid preparation

To ensure nanofluid stability, the particles must be spread with a low level of aggregation since preparing nanofluids is a crucial step in experimental work [3, 4, 8]. This can be carried out in different methods, but the most popular method is an ultrasonication approach for dispersion, which was used in this work. An 8-hour treatment evenly disperse the nanoparticles throughout the ultrasonication fluid [8]. This led to the Al2O3-water nanofluid developed in this experiment being extremely (China). The nanoparticle has the following characteristics: 99.9% purity, an average particle size (APS) of 12.3–17.5 nm, and a specific surface area of 120 m^2/g.

The following steps are the procedures to produce nanofluids:

a) Using a digital scale, weigh an accurate amount of the nanomaterial. After that, mix the nanomaterial with the distilled water as the base fluid.

b) b) The heated plate is used for mixing Al_2O_3 and water.

c) The solution is ready to put into the ultrasonic bath.

stable for nearly a week [4]. However, the Al_2O_3 nanoparticles used in the preparation of the nanofluid were purchased from Gamma XFNANO Ltd

2.3 Experimental procedure

First, distilled water was used as the working fluid, then three different volume concentrations of nanofluid (Al_2O_3-water) at different temperatures and cooling water flow rates were adjusted. Then the following steps were followed:

a) The working fluid (water, Al_2O_3-water) was placed into the test vessel, and it was agitated to a height of 0.3 m.

b) Start the heater and set the thermostat to a particular setting.

c) The variable speed motor of the propeller (P.M.D.C.) is set and controlled at a specific value.

d) Switch on the centrifugal pump, which helps the cooling water circulate through the helical coil to a flow rate of 1.8 or 2.2 liter/min. However, the heat from the heater into the stirring working fluid and let the experiment run until stable.

e) Records were kept of the temperatures of the working fluid inside the test vessel, as well as the temperatures at the entrance and exit of the cooling water.

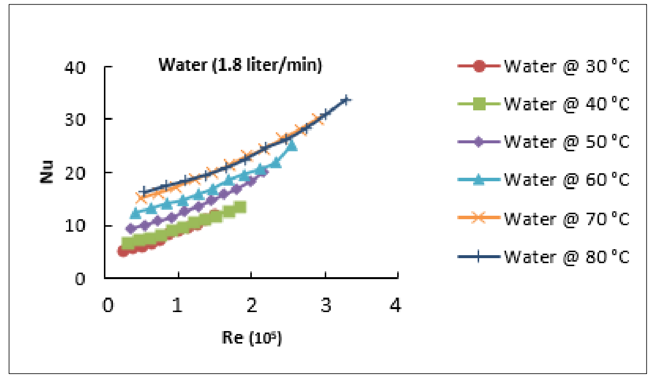
f) After steady state, working fluid information was taken when the propeller speed was adjusted, and the temperature was varied between (30 and 80 °C).

g) After adjusting the heater temperature and agitator rotating speed, temperature readings of the cooling water were taken at the inlet and outlet.

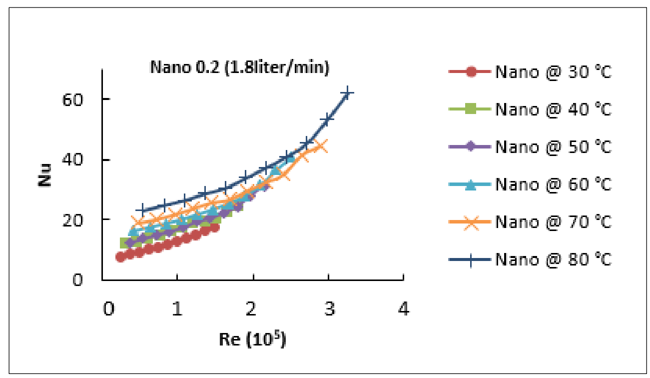
3. Results and discussions

3.1 The influence of Temperature on the Heat Transfer at different volume concentrations

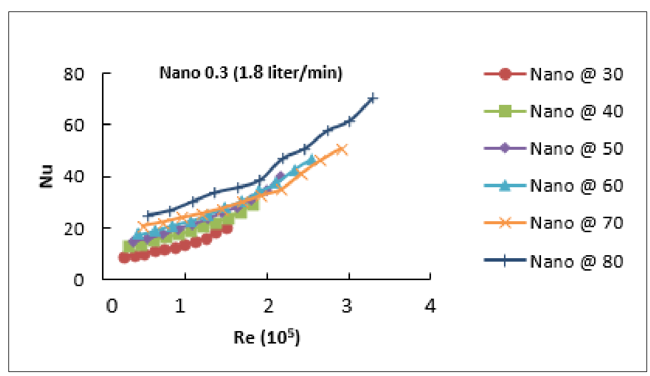
Figure 2 displays the experiment results under various settings, such as inlet heater temperature with constant water flow rates. Figure 2a illustrates the impact of increasing temperatures while using base water as the working fluid at a flow rate of 1.8 liter/min. Figures 2b, c, and d were introduced at the same cooling water flow rate with 0.2 vol%, 0.3 vol%, and 0.4 vol% Al_2O_3 - water nanofluids, respectively. It has been found that adding nanoparticles to the working fluids at various concentrations significantly affects the results. As a consequence, the convective heat transfer coefficient is significantly affected by the presence of these particles [9]. The heat transfer coefficient increases as the volume concentration of Al_2O_3-water suspended fluids increases [9, 10]. The highest results were obtained by 0.4 vol% Al_2O_3 - water nanofluid, which is followed by 0.2 vol% and 0.3 vol% Al2O3 - water nanofluid, all of which have observable effects. This finding results from the dispersed of Al_2O_3 particles in the mixture which lead to increasing its thermal conductivity [2, 11-14].



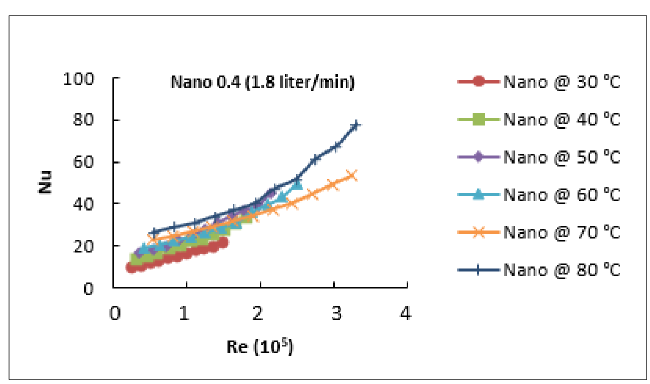
(a) Base water



(b) 0.2 vol% Al_2O_3-water nanofluids

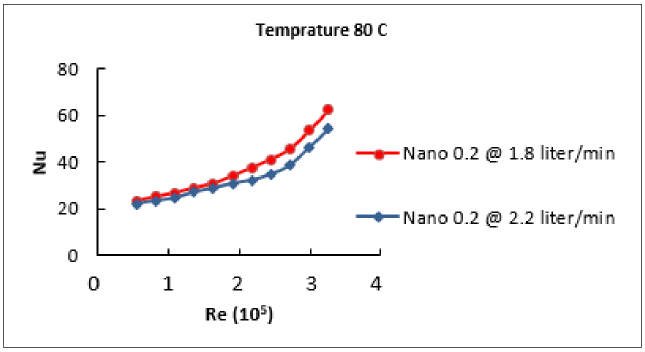


(c) 0.3 vol% Al_2O_3-water nanofluids

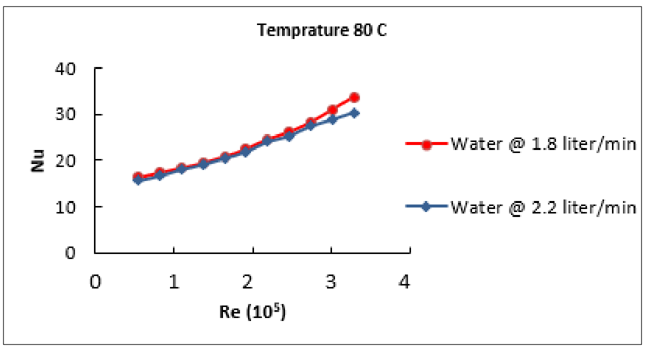


(d) 0.4 vol% Al_2O_3-water nanofluids

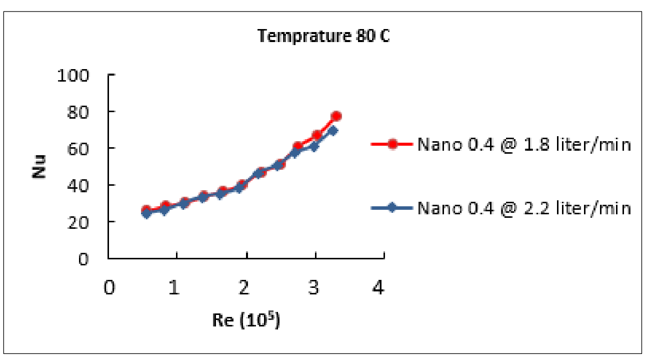
Figure 2. The effect of temperature on the heat transfer behaviour of base water and Al_2O_3 – water nanofluids with a flow rate of 1.8 litter/min.



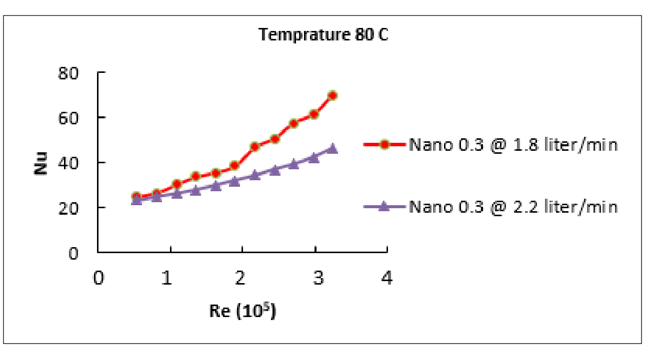
(A) **Base water**



(B) 0.2 vol% Al_2O_3 – water nanofluid at 80°C.



(C) 0.3 vol% Al_2O_3 – water nanofluid at 80°C



(D) 0.4 vol% Al_2O_3 – water nanofluid at 80°C.

Figure 3. Effects of flow rates and nanoparticles volume concentrations on the base water and al2o3–water nanofluids.

Additionally, increased energy exchange is produced by more dispersed suspended particles [1]. For 0.2 vol%, 0.3 vol%, and 0.4% vol Al_2O_3 - water nanofluids, the average enhancement of heat transfer was ±48.1%, ±66.9%, and ±77.2%, respectively. The temperature was set to fall between a range of 30 and 80 °C; as the temperature increased, the Nusselt number increased as well. The reason for this effect is due to an increase in heat input, which increases the temperature of the inlet heater and results in a significant temperature difference in the cooling water [3]. The average improvements in Nusselt number were found to be ±19.8% for temperatures ranging between (30 to 80 °C).

3.2 Effects of Flowrates and nanoparticles concentrations in heat transfer

In Figure 3, basic water and an Al_2O_3-water nanofluid are compared at two distinct flow rates and particle concentrations of 0.2 vol%, 0.3 vol%, and 0.4 vol% while maintaining the temperature constant. At 80°C and 1.8 and 2.2 liters/min of cooling water flow rate, Figs. 3a, b, c, and d illustrate the behavior of the base fluid and Al_2O_3-water nanofluids. However, it can be seen that the Nusselt number and the heat transfer coefficient both increase at 1.8 litter/min and 2.2 litter/min respectively. Thus, it is observed that the Nusselt number increases as the cooling water flow rate decreases [15]**.** The average increase in heat transfer rate was found to be 10.4% at flow rates of 1.8 liter/min. In previous studies, the flow rate was kept constant also at 1.8 liter/min. At the same flow rate, it is seen that better results were achieved in our study when compared to previous investigations, with an average improvement of about 15.6%. Higher volume concentration and 12.3–17.5 nm average nanoparticle sizes used are responsible for this improvement [16, 17].

4. Conclusions

Using distilled water and an Al_2O_3-water nanofluid at temperatures ranging from 30 to 80 °C and two distinct flow rates of 1.8 and 2.2 liter/min, the behavior of heat transfer in a coiled agitator test vessel was experimentally examined. The following findings were attained as a result of the experiment:

(a) It has been shown that improving the heat transfer characteristics occurs at 0.4 vol% Al_2O_3 nanoparticle concentration in the base fluid. Therefore, utilizing Al_2O_3-water nanofluid instead of distilled water as a working fluid result in a considerable increase in heat transfer rate of about ±48.1%, ±66.9%, and ±77.2% for 0.2vol%, 0.3vol%, and 0.4vol% Al_2O_3-water nanofluid, respectively.

(b) The temperature of the input heater has a considerable impact on the rate of heat transfer. With an average percentage of 19.8%, the Nusselt number improved noticeably as the temperature increased gradually up to 80°C.

(c) It has been observed that as the cooling water flow rate is decreased, the heat transfer coefficient increases. The highest improvement is approximately ±13.6% when 1.8 litter/min when compared to 2.2 litter/min.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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