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# Heat transfer intensification in a shell and helical coil heat exchanger using water-based nanofluids

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ABSTRACT

Nanofluids have been reported to be capable of heat transfer intensification. Performance of an agitated shell and helical coil heat exchanger has been experimentally investigated using three water based nanofluids ($Al_2O_3$, CuO and $TiO_2$). The studies were carried out at different concentrations of nanofluid, nanofluid temperatures, stirrer speeds and coil-side fluid flow rates. Nanofluids of three concentrations 0.3, 0.6, 1, 1.5 and 2% by weight have been prepared for this purpose. Cetyltrimethyl ammonium bromide (CTAB) was used as stabilizer. Nanofluid was used as heating medium (shell-side) and water was used as coil-side fluid. It was found that heat transfer rate increases with increase in nanofluid concentration. Higher values of nanofluid concentration, stirrer speed and shell-side fluid temperature resulted in greater effectiveness of heat exchanger. A maximum increase of 30.37%, 32.7% and 26.8% in effectiveness of heat exchanger was observed for $Al_2O_3$, CuO and $TiO_2$/water nanofluids respectively, when compared to water, indicating intensification of heat transfer.

## 1. Introduction

Heat transfer intensification in heat exchangers can be achieved by active, passive and compound heat transfer techniques. The active techniques require external forces, e.g., electric field, surface vibration, etc. The passive techniques require fluid additives (e.g., nanoparticles) or special surface geometries (e.g., helical coil). The widely used conventional intensification techniques in process industries are internal and external tube fins, twisted-tape inserts, coiled-wire inserts, helical baffles and fluid additives. Helical coiled tubes are used in many engineering applications, such as heating, refrigeration and HVAC systems [1–3]. Helical coiled tubes are also used in steam generators, nuclear reactors and condensers in power plant due to their large surface area per unit volume. Many researchers have experimentally investigated the heat transfer in the helical coil heat exchanger [4–9]. They reported that the heat transfer coefficients obtained from the coiled tube were higher than those obtained from a straight tube.

Wongwises and Polsongkram [10] have experimentally investigated the heat transfer coefficient and pressure drop of refrigerant HFC-134a during evaporation inside a smooth helically coiled concentric tube-in-tube heat exchanger. They reported that the average heat transfer coefficient of HFC-134a during evaporation increased with increasing average quality, mass flux, heat flux and saturation temperature. Naphon [11] experimentally investigated the thermal performance of helical coil heat exchanger, which consisted of thirteen turns of concentric helically coiled tubes with and without helically crimped fins. He reported that the cold water outlet temperature, heat exchanger effectiveness and average heat transfer rate increased with increase in hot water mass flow rate. Mixed convection heat transfer in helical coiled tube heat exchanger was investigated experimentally by Ghorbani et al [12]. They found that the convection heat transfer coefficient of shell-side increased when the coil pitch was increased, and the overall heat transfer coefficient of heat exchanger increased with increase in heat transfer rate.

Chen et al. [13] have studied the heat transfer coefficients and wall temperature distribution in a helically coiled tube under low mass flux and low pressure conditions. It was found that the wall temperatures in descending segments of coiled tube were higher than those of climbing ones and the heat transfer coefficient increased with increasing mass flux, vapor quality and heat flux. Moawed [14] has studied forced convection from outside surfaces of helical coiled tubes with a constant wall heat flux. It was observed that the average Nusselt number increased with increase in diameter ratio and pitch ratio.

It has been found from the literature that there is a significant increase in heat transfer rate using nanofluids due to their higher thermal conductivity compared to base fluid [15,16]. Many researchers have experimentally investigated heat transfer

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**Nomenclature**

| | |
|---|---|
| $C_p$ | Specific heat (kJ/kg °C) |
| $d$ | Diameter of the coil tube (m) |
| $De$ | Dean number |
| $m$ | Mass flowrate (kg/s) |
| $Q$ | Heat transfer rate (W) |
| $R_c$ | Curvature radius of the coil |
| $Re$ | Reynolds number |
| $T$ | Temperature (K) |
| $v$ | Velocity of the fluid through the coil (m/s) |
| wt | Weight |

Greek symbols

| | |
|---|---|
| $\varepsilon$ | Effectiveness of heat exchanger |
| $\mu$ | Viscosity (kg/ms) |
| $\rho$ | Density (kg/m$^3$) |

Subscript

| | |
|---|---|
| BF | Basefluid |
| ci | Coil-side fluid inlet |
| co | Coil-side fluid outlet |
| i | Inner |
| max | Maximum |
| NF | Nanofluid |
| o | Outer |
| s | Shell-side fluid |

intensification due to different types of nanoparticles such as metallic particles (Ag, Au, Cu, and Fe) [17–20]. non-metallic particles ($Al_2O_3$, CuO, $Fe_3O_4$, $SiO_2$, $TiO_2$ and $ZrO_2$) [21–27]. Kannadasan et al. [28] experimentally investigated the effect of CuO/water nanofluid in a helically coiled tube heat exchanger with horizontal and vertical positions under turbulent condition. The experimental results showed that the heat transfer intensification was more in vertical position than in horizontal. They also reported that the friction factor of nanofluid increased while increasing particle volume concentration in turbulent flow conditions.

Jamal-Abad et al. [29] have experimentally investigated the performance of a spiral coil heat exchanger using Cu/water and Al/water nanofluids. It was found that the maximum thermal performance factor was 4.27 for 2.23% vol. of Cu/water nanofluid. The thermal performance factor is the ratio of the Nusselt number ratio ($Nu_{NF}/Nu_{BF}$) to the friction factor ratio ($f_{NF}/f_{BF}$) at the same pumping power. Jamshidi et al. [30] have experimentally investigated the performance of shell and helical tube heat exchangers by changing the coil diameter and pitch. Their experimental results indicated that heat transfer rate increased with increase in coil diameter, coil pitch and mass flow rate. Kahani et al. [31] have experimentally investigated the heat transfer behavior between metal oxide nanofluid ($Al_2O_3$/water and $TiO_2$/water) flows through helical coiled tube with uniform heat flux boundary condition. They reported that the maximum thermal performance factor was found to be 3.82 for 1.0% vol. concentration of $Al_2O_3$/water nanofluid through helical coiled tube heat exchanger. Khairul et al. [32] have investigated the performance of a helically coiled heat exchanger using different types of nanofluids (CuO/water, $Al_2O_3$/water and ZnO/water). Their experimental results showed that the maximum enhancement heat transfer coefficient was 7.14% for 4% vol. of CuO/water.

There have not been many studies in literature involving nanofluids on shell-side in shell and helical coil heat exchanger. In the literature cited above, researchers [12,30] have used continuous flow of nanofluid on the shell-side. In the present study, there was no continuous flow of shell-side fluid (water and subsequently nanofluid). Further, stirrer was used to promote heat transfer to coil-side fluid. Heat transfer intensification was determined in terms of enhancement in heat transfer rate and effectiveness of heat exchanger involving nanofluids. $Al_2O_3$, CuO and $TiO_2$/water nanofluids were used on shell-side and water on the coil-side. The effect of Dean number and shell-side temperature (40, 45 and 50 °C) at stirrer speeds (500, 1000 and 1500 rpm) on the forced convection heat transfer from the shell-side fluid to coil-side fluid was investigated.

## 2. Materials and methods

### 2.1. Nanofluid preparation

Preparation of nanoparticle suspension in water is the first step in applying nanofluid for heat transfer enhancement. In this study, $Al_2O_3$, CuO and $TiO_2$/water nanofluids were prepared separately by dispersing nanoparticles into the base liquid, water. Details of $Al_2O_3$, CuO and $TiO_2$ nanoparticles are listed in Table 1. Stability of nanofluid was increased by adding surfactant (Cetyltrimethyl ammonium bromide (CTAB) 1% wt. of nanoparticle). Addition of surfactant did not affect the properties of nanofluid. A similar observation was made by Aguiar et al. [33]. In order to break down the large agglomerates, ultrasonic processer (Hielscher, UP200H) was used at 200 W and 24 kHz for 3 h to mix a preset amount of nanoparticles with water to give required nanoparticle concentration. Nanofluids with five different nanoparticle concentrations (0.3%, 0.6%, 1%, 1.5% and 2% wt.) were prepared to measure the thermal conductivity of nanofluids. The thermal conductivity of $Al_2O_3$, CuO and $TiO_2$/water nanofluids was measured with KD2 Pro thermal property analyzer.

### 2.2. Experimental set-up

Fig. 1 shows the schematic diagram of the experimental set-up used in the present work [34]. Dimensions of helical coil tube and shell are given in Table 2. The shell is insulated with glass wool and shell-side fluid temperature was maintained constant using a temperature controller. Two 5 kW electrical heaters were used to heat the shell-side fluid, and temperature measurements were made using PT-100 type RTD sensors. An axial turbine type stirrer (Make: Remi Laboratory Instruments, model: RQ-121/D) was used to (i) promote heat transfer from the shell-side fluid to the coil-side fluid (water) by forced convection and (ii) maintain uniform temperature in the shell. Flow rate of the water through the coil was measured using rotameter (0.5–5 lpm). The set-up is provided with a data acquisition system to record all temperatures. As water flows through the coil, heat is transferred from the shell-side fluid to water in the coil.

### 2.3. Experimental studies

Studies were carried out with water (base fluid) and subsequently nanofluid on the shell-side. The effect of coil-side flow rate (0.5–5 lpm), nanofluid concentration (0.3%, 0.6%, 1%, 1.5%

**Table 1**
Details of nanoparticles.

| S.No. | Nanoparticle | Manufacturer | Size (nm) |
|---|---|---|---|
| 1 | $Al_2O_3$ | Sisco Research Laboratories Pvt., Ltd., India | 20–30 |
| 2 | CuO | Sisco Research Laboratories Pvt., Ltd., India | 40 |
| 3 | $TiO_2$ | MKnano, USA | 10 |