Effect of copper oxide nano fluids as coolant on thermal performance of spiral heat exchanger

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Abstract: Over the past couple of years, the use of nano fluids to enhance the heat transfer has been reported by several researchers. The experimental investigation was done on the forced convection heat transfer of spiral heat exchangers using copper oxide (CuO) nano fluids (of fixed volumetric concentration) as a coolant. The various heat transfer parameters considered for the study which are Nusselt number, heat transfer coefficient, heat transfer rate and Reynolds Number. Studies revealed that, the heat transfer enhancement does occur in the heat exchanger (HE) using nanofluids but at the cost of pumping power.

Keywords: Nano fluids; Heat flux; Turbulent flow; Spiral heat exchanger; Reynolds number

1. Introduction

Spiral heat exchanger (SHE) is a compact-type heat exchanger. Its flow path can be set to counter current analogous to counter flow exchanger to obtain maximum rate of heat transfer (HT). A high coefficient of convection heat transfer (CHT) is obtained in this heat exchanger (HE) due to the presence of spiral channels. It also incorporates significant less amount of space due to spiralling which helps in installation and shipping. Another interesting characteristic of SHE’s is that, the presence of low fouling which occurs due to the presence of particular geometry of the SHE which causing a continual change in flow path direction and producing higher turbulence and smaller stagnant zones. Many such factors make this HE a superb HE [1]. The concept of SHE may be said to be introduced in the late nineteenth century, and in 1930s, this device was modified and reinvented in Sweden [2]. After that, more research was carried out on SHE’s. For example, Bahiraei and Ahmadi [3] numerically investigated the thermal-hydraulic efficacy of a SHE filled with H2O-Al2O3 nanofluid under turbulent flow conditions. They noticed that, as an increase in the volume fraction of nanofluids and Reynolds number (Re), the average heat flux increases while it decreases with channel spacing. In addition, the coefficient of CHT and overall heat transfer coefficient (U) increases with volume fraction of nanofluids and Re. By increasing either volume fraction of nanofluids or Re and decreasing the spacing, the pumping power increases. In a similar study, Bahiraei et al. [4] used graphene
nanofluid in the SHE and numerically evaluated the thermal-hydraulic efficacy of a SHE. They found that the effectiveness, Number of Transfer Units (NTU), performance index and pressure loss increases with increase in Re and nanoparticles concentration (φ). Rajavel [5] analysed mathematically and quantitatively, the thermal performance features of a SHE. The effect of geometrical and process parameters on the HT characteristics of the HE was investigated. In addition, they validated the computer model at various flow rates. A correlation for estimating the Nusselt number (Nu) was also extracted from the results. Rostami et al. [6] numerically investigated the influence of channel spacing on the thermal performance of SHE filled with hybrid nano fluids. They found that the outlet temperature and thermal efficacy can be improved either by reducing the channel spacing or increasing the nanoparticle φ, at constant flow velocity. Also, the pressure loss increases with decrease in spacing. Khorshidi and Heidari [7] quantitatively investigated the effectiveness of a SHE by building a framework for this HE. The analysis indicates that Nu increases by increasing the mass flow rate. They were able to get an increment of nearly 100 % in the mean Nu which showed a remarkable improvement. Nguyen and San [8] proposed a new method of developing a SHE using the 3d scanning method. Using this method, they were able to improve the effectiveness of the HE by selecting a proper material. This material reduced the wall thermal resistance and improved the performance of the SHE. Sterger et al. [9] showed that double spiral is better than other types of heat exchangers in terms of reducing the heat loss to environment. Wu [10] presented the calculation process and derived formulas to construct the shape of a SHE. Picon-Nunez et al. [11-12] done a numerical and analytical study and provided a method to estimate the size of spiral heat exchangers in single-phase flow conditions. Targett et al. [13] showed the distribution of temperature in the fluid domain of a double-spiral heat exchanger. Naphon and Wongwises [14] calculated average in-tube heat transfer coefficients (HTC) in a SHE under dehumidifying conditions. They also considered the effect of inlet conditions of both the fluids. Ho et al. [15] and Wijeyundera et al. [16] analysed heat transfer performance of a compact spiral-coil heat exchanger. They found an increment in heat transfer rate of the heat exchanger using nanofluids. Wilhelmsson [17] showed various applications of spiral heat exchangers. Segundo et al. [18] conducted optimization studies on SHE by means of wind-driven optimization and a new version of this approach by adding a statistical distribution to adjust the evolution parameters to themselves. The parameters adopted for optimisation were the HE’s length, width and thickness as well as the channel space between the two fluids. The main objective was to minimize the price and maximize the overall heat transfer coefficient (U). Using this technique, they were able to achieve a cost reduction of nearly 23 percent and a rise of almost 16.4 percent in U. Turgut and Coban [19] optimized SHE’s and heat pipes for thermal design using a optimization algorithm called global best algorithm. Both single variable and multivariable objective optimisation were carried out. The technique showed good results as compared to other studies in terms of consistency and performance. They found that the operating expenses were extremely dependent on hot and cold side pressure drops. Bidabadi et al. [20] carried single objective and multi-objective optimization (using genetic algorithm) to investigate the optimum performance of SHE. Various geometrical parameters (with logical constraints) were used for optimization. With single objective optimization, they were able to achieve a reduction in pressure loss (by about 50 %) and increment in overall heat transfer coefficient (by about 13 %). Using multi objective optimization which was carried out to obtain a trade-off between these two parameters, they were able to achieve an improvement in heat transfer coefficient (by about 60 %) with a reduction in pressure loss by about 20 %. From the literature it is clear that many researchers have conducted analysis study on SHE due to its high performance. But most of the studies were done using water as a coolant. Nanofluids with high thermal conductivity can be used further to improve its performance. Only few studies have used nanofluids for investigating the performance of SHE. To the author’s best knowledge, the study was not carried out using CuO nano fluids of various concentrations. So in this paper an experimental study was carried out to analyze the thermal performance parameters of the spiral heat exchanger. The study was carried for steady forced flow conditions using copper nanofluids of various concentrations (0.2 % to
0.6%) as the coolant. The flow rate on one side of the heat exchanger (hot water) was kept constant during the study.

2. Methodology

![Experimental setup](image1a.png)

![Schematic diagram of 2D geometry of SHE](image1b.png)

The schematic diagram of experimental set-up is shown in Figure 1.a and the 2D geometry of SHE is shown in Figure 1.b. The set-up is a well instrumented single-phase heat exchanging system which has a hot water stream flowing inside the tube-side is cooled with a cold water stream flowing in the shell-side. The main parts of the cycle are SHE, centrifugal pump, storage tank, and heater. The heat exchangers include a copper coiled tube and an insulated shell. The water in storage tank is heated using an electric heater, reaching to a prescribed temperature, pump is started to circulate the hot water in the cycle. A ball valve is used to control the flow rate of coolant water and hot water respectively. To measure the flow rate of the cold stream/hot stream, a rotameter is installed upstream of the heat exchanger. The inlet and outlet temperatures of hot and cold water were recorded manually using four glass alcohol thermometers inserted in the small holes made in the inlet and outlet tubes of each heat exchanger and sealed to prevent any leakage. Also, all the pipes and connections between the temperature measuring stations and heat exchanger were duly insulated.

3. Results and Discussion

Figure 2 depicts the effect of Re on Nu. It should be known that the flow rate on one side of the heat exchanger (hot water side) is kept constant, so that the increase in Re is applicable to the other side (nano fluid side). It can be observed that, as expected and very much clear from the figure that as Re increases, Nu also increases. Because at higher Re, the boundary layer gets thinner and the rate of convection of fluids amplifies. The convective coefficient therefore rises. Hence, the heat transfer rate increases. But, it can be seen that the rate of increase of Nu with Re decreases as Re increases. So, it can be addressed that there is a limit beyond which the Nu cannot be increased just by incrementing Re. It can also be seen that the value of Nu is more when CuO nano fluids are used instead of water and it increases with increase in volume concentration of nanofluids. Hence the hot water, which has a constant mass flow rate, experiences a higher temperature decline in the counter flow configuration and demonstrates a higher heat transfer rate in the heat exchanger.
The effectiveness of HT’s is a significant criterion in the analysis that compares the actual transfer rate of heat with probable highest heat transfer rate. In the present SHE being studied, lowest possible heat capacity rate for all situations are linked to hot water and therefore the effectiveness is given by as follows [4]:

\[
\epsilon = \frac{C_{c}(T_{co}-T_{ci})}{C_{h}(T_{hi}-T_{ci})} \tag{1}
\]

Figure 3 shows the effect of flow rate on effectiveness (\(\epsilon\)) of the HT for both the cases (cold water and nanofluids). It can be noted that as flow rate increases, the \(\epsilon\) amplifies. Flow rate increases due to Leftovers invariant i.e. Ch(Thi-Tci), while the numerator rises because of the increase in heat transfer rate at higher flow rate. Hence \(\epsilon\) increases with flow rate. Also, it can be seen that, as predicted and very much evident from Figure 3 that \(\epsilon\) was found to be more for the HT using nano fluids as compared to water for the same flow rate and also, it increases with volume concentration of nanofluids. Because higher volume concentration nanofluids have higher thermal conductivity which increases the heat transfer rate. Hence the numerator part of equation 1 increases and increases the \(\epsilon\).

NTU is among the main heat transfer features that determine the size of the heat transfer area and heat exchanger efficiency. Figure 4 shows the effect of Re on NTU. It can be seen that, as Re increases, NTU decreases indicating the smaller size requirement for the fluids at high Re. Also NTU was more for the SHE using nano fluids as compared to water, indicating more space requirements for these heat exchangers. The NTU value increased with concentration of the nanofluids. Hence nano fluids of higher concentration require a bigger size of HE to transfer the same amount of heat transfer.
Figure 4 shows the graph of NTU vs Re. It can be seen that, as the Re value increases, the temperature difference between the cold flow and the hot flow decreases. It can also be seen that NTU value is low for nano fluids as compared to water for a given Re indicating a smaller size heat exchanger requirement when nano fluids are used. Figure 5 shows the consequence of Re on Heat transfer rate of the SHE. It can be seen that, as Re increases, heat transfer rate also increases as expected. It can also be noted that this increase in the heat transfer rate decreases as Re further increases. So it can be easily concluded that there is upper limiting value of Re beyond which the increase in heat transfer rate is negligible. Also, the heat transfer rate was higher for nanofluids as compared to water, as expected. This is because of the high thermal conductivity of the nano fluids as compared to water. It can also be seen that heat transfer rate was more for nano fluids of high concentration due to high thermal conductivity.
Apart from the thermal features, hydraulic features like the friction factor or the pumping power must also be taken into account for the HE’s, since they indicate the power usage rate for the heat exchanger process. When nano particles were added, exaggerate the friction factor (pressure drop) as well as raise the heat transfer rate. The drop in pressure upsurge is an unwanted problem for HE’s as they increases the energy usage. Figure 7 depicts the effect of Re on friction factor for both the cases (nano fluids and cold water) maintaining hot water flow rate at one side as constant. It is evident and abundantly clear from Figure 7 that the friction factor amplifies by rising Re. This is because with rise in Re, the gradients of the velocity rise and hence the friction factor and pressure drop rises. In fact, greater Re means higher speed (turbulence) and thus greater flow rate. Hence, pumping capacity is more at higher Re. Also, it can be seen that the friction is more for nanofluids as compared to water for the same Re due to high viscosity of the nano fluids.

4. Conclusions
An experimental investigation was carried out and evaluated the thermal performance parameters of SHE using both cold water and nano fluids (of different concentrations). The flow rate of hot water, at the other side, was kept constant. The experiment was carried under steady forced flow conditions. It was observed that, the following conclusions were drawn from the analysis as follows:

1. Nu and HTC increases with Re. The increase was higher for nano fluids especially for higher volume concentration (0.6 %) as compared to water,
2. The effectiveness of the heat exchanger increases as Re increases and it was higher for nano fluids of higher volume concentration,
3. As Reynolds number increases, NTU decreases which indicating a small size heat exchanger requirement at high Reynolds number. Also, the NTU was higher for nano fluids of higher concentration indicating a large size HE requirement if nano fluids are used as a coolant as compared to water,
4. As NTU value increases, the temperature difference between the cold flow and the hot flow decreases and
5. As Re increases, friction factor (pressure drop and pumping power) increases. The friction factor was more for nano fluids as compared to water due to the high viscosity of nano fluids which indicating that the heat transfer enhancement does occur in nano fluids but at the cost of pumping power.

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