Heat transfer enhancement of Al2O3 based nanofluid in a shell and helical coil heat exchanger

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**Abstract**

Active and passive techniques are generally used by the researchers for the heat transfer augmentation of fluids. Conventional fluids like water, ethylene glycol, and oils have not enough heat transfer capabilities to fullfill current requirements of high heat transfer rates of heat exchangers. Nanofluids are the new generation fluids that have better heat transfer capabilities over traditional heat transfer fluids. The current study examines heat transfer analysis in a shell and helical tube heat exchanger using Al2O3 nanoparticles in aqueous solution. The analysis was carried out to determine the enhanced heat transfer rate as compared to the base fluid (water) in a vertical shell and helical coil geometry. Four different nanoparticles concentrations 1% to 4% by volume along with four different mass flow rates varies from 0.03 to 0.113 kg/s were used to simulate the results. Results showed that the heat transfer rate of nanofluids was enhanced at higher mass flow rates, concentrations and coil side inlet temperature

***Keywords*:** *heat transfer, nanofluids, helical coil*

**1. Introduction**

Enhancement in the thermal conductivity of heat transfer fluids through the addition of solid particles has attracted the interest of researchers in this diverse field. These fluids are known as nanofluids, have been considered to have a prominent potential in energy and heat transfer applications for the development of sustainable energy devices and system1.

Helical coils are widely used in many industrial applications, like food and dairy processes, nuclear reactors, chemical and refrigeration and air-conditioning appliances. In the last ten years the area of research on curved tubes is quite demanding because of their compact structure and high heat transfer coefficients. Earlier helical coiled tubes were studied by Dean2,3 and found that symmetrical circular zones were formed over the cross section of coils due to the induced centrifugal force. Pourhedayat et al.4 developed a correlation for exergy losses of Newtonian fluids for a helical tube. They investigated exergy extracted by hot fluid, exergy taken by cold fluid, total exergy loss, NTU and non-dimensional exergy loss. Finally a correlation was developed for total non-dimensional exergy loss with respect to Number of Thermal Units (NTU).

From literature it is concluded that the heat transfer analyses of nanofluids in a shell and helical coil only few investigations were found in the past. The objective of present simulated work is to investigate the effect of nanofluids in a shell and helical coil geometry on the thermal aspects.

1. Numerical Model
   1. Geometry

The design module consists of two sections, shell and helical coil as shown in figure 1 (a). View of computation fluid domain shown in figure 1(b) and 1(c). Water was used as the hot fluid in the coil side and Al2O3 nanofluid was used in the shell side as working fluid with four different concentrations 1%, 2%, 3% and 4% by volume. Mass flow rates for both sides shell and coil side were 0.03, 0.05, 0.09 and 0.113 Kg/s. The specifications of physical model are given in Table 1.

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| --- | --- |
|  | C:\Users\hp\Desktop\shell20.png |
| (b) |
| file spiral |
| (a) | (c) |
| Figure 1. Schematic diagram of computational fluid domain(a), CAD model of shell (b) and helical coils (c). | |

Table 1. Physical specifications of computational fluid domain.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **No.** | **DS,o(mm)** | **DS,i(mm)** | **Dc(mm)** | **N** | **H** | **t (mm)** |
| 1 | 160 | 90 | 125 | 22.5 | 360 | 0.86 |

* 1. Validation

Validation of the numerical results compare to the experimental measurements was given in a similar study reported in5. The results measure for heat transfer coefficient of shell side with heat flux per unit area as shown in figure 2. The validation was done for water at both the sides shell and helical coil.

* 1. Thermophysical properties of nanofluids

The density of nanofluid was find out by using the general formula for the mixture:

(1)

The specific heat of the nanofluid was evaluated from:

(2)

These above equations have been gives significant results for nanofluids on comparing with experimental results by Pak and Cho6 and Xuan and Roetzel7.

The Maxwell model8 was used to find out the thermal conductivity:

(3)

Einstein equation was used to find out the effective viscosity of nanofluids for the concentrations less than 5% by volume ­9:

(4)

* 1. Governing Equations

The basic governing equations, which are used for heat transfer and flow analysis are given below:

(5)

(6)

(7)

Average heat flux and convective heat transfer coefficient were calculated as follows

(8)

and

(9)

Overall heat transfer coefficient

(10)

Where Aois the surface area of coil ∆TLMTD is the log mean temperature differences. ∆TLMTD can be calculated as per following equation.

(11)

Where TH and TC are the temperature of hot and cold fluids at inlet and outlet sections.

1. Result and discussion

In the present work, laminar heat transfer and fluid flow for Al2O3 based nanofluids in a three-dimensional fluid domain through a shell and helical coil heat exchanger is numerically investigated for counter flow. The simulations were done for four different values of particle concentrations in the range 1%<̲ ϕ<̲ 4% and four different mass flow rates 0.03, 0.05, 0.09 and 0.113 Kg/s. Al2O3 nanofluids used in the shell side region with a constant inlet temperature of 293 K and pure water used in the coil side with different inlet temperature from 323 K to 353 K.

The temperature contours of fluid domain for pure water at both the sides (shell and coil) for counter flow as shown in figure 3. From the temperature contours it is found that the coil temperature goes down from inlet to outlet and shell temperature rises from inlet to outlet. The whole phenomenon satisfied the general heat balance equation.

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|  |  | x-y plane | x-z plane |
| Figure 2. Validation of present study with Ghorbani et al.[8]. | Figure 3. Temperature contours of fluid domain in x-y and x-z plane for pure water at inlet coil temperature of 353 K. | | |

* 1. Heat transfer analysis

The effects on heat transfer coefficient of shell side with the aluminium oxide particle concentration variation from 1% to 4% by volume for different inlet temperature of coil side from 500C to 800C as shown in figure 4. From the figure it is found that on increasing particle concentration the heat transfer coefficient increases with the increase in coil inlet temperature. The region of this enhancement is addition of nanoparticles changes the thermophysical properties of base fluid like density, specific heat, thermal conductivity and viscosity. The maximum heat transfer coefficient was found 723 W/m2 at 4% of particle concentration for 353 K inlet temperature of coil. Moreover overall heat transfer coefficient at a particular mass flow rate increases with the increase in nano particle concentration as shown in figure 5. This is due to the increase in the average surface area of metallic particles in the base fluid, which is responsible for better heat transfer rate. Another reason for enhanced heat transfer rate is Brownian motion of particles. Brownian motion is taking place due to random movement of nanoparticles caused by the impact of fluid molecules in the surrounding. Thus, as the concentration of nano sized metallic particles increases more augmentation of heat transfer occurs. The maximum overall heat transfer coefficient were found 460 W/m2K for Al2O3/water nanofluids.. The above discussion suggests that the random movement of aluminium oxide nanoparticles improves the thermal dispersion.

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| Figure 4. Variation in heat transfer coefficient with particle concentration at different inlet temperatures of coil section. | Figure 5. Variation in overall heat transfer coefficient with mass flow rates at different particle concentration. |

1. Conclusions

The present study covers numerical investigation of convective flow heat transfer in a three dimensional shell and helical coil heat exchanger. Al2O3 nanoparticle is used with four different particle concentrations with water as a working fluid. From the above study following conclusion are summarized:

1. The results concluded that the heat transfer rate is enhanced by the use of nanoﬂuids. It is also concluded that on increasing the mass flow rate and inlet temperature of coil side leads to increase in the value of heat transfer coefficient.
2. The Al2O3 nanofluids with 4% particle concentration gives 176% better heat transfer coefficient with respect to pure water. While the overall heat transfer coefficient found 380 % better at a mass flow rate of 0.113 kg/s with 4% particle concentration as compare to pure water.
3. The implementation of helical coils over circular concentric type accompanied in enhanced heat transfer rate because of aggrandizes mixing of fluids and covers more surface area for convection.

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