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Experimental Studies on Helical Coiled Heat Exchanger with Al_2O_3/Water Nanofluid

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Abstract

The nanomaterials dispersion in fluid is effective to improve the thermal/physical properties of fluids. Secondary flows created by helical coils may improve the mass and heat transfer. Usage of nanofluids in heat transfer may improve the heat transfer coefficient. Present study focused on the heat transfers of a shell and helical coil tube heat exchanger using water as base fluid with aluminum oxide (Al_2O_3) nanoparticles at 0.01, 0.02 and 0.05 volume % concentration and different flow rate were tested at constant wall temperature as boundary condition. Water as shell side fluid and Al_2O_3/water nanofluid as in coil side were studied with different dean number. Change in heat transfer due to use of Al_2O_3/water nanofluid has been observed in terms of heat transfer rate.

Keywords

Nanofluids, Helical coil, Aluminum oxide, Heat transfer, Secondary flow

Introduction

Transfer of heat is vital area of study and research in thermal engineering. When designing heat exchangers, choosing the right heat transfer fluid (HTF) for heat dissipation is an important factor to take into account and one of the most important parameters since it impacts the size and price of heat exchanger systems. The potential for heat transfer in conventional HTFs is limited. It is urgent to create a new class of HTFs in order to save costs and satisfy industrial demand today. Fortunately, improvements in nanotechnology have made it possible to increase the heat transfer operations' efficiency and reduce costs. Nanoparticles are chosen to be a new class of materials with potential uses in the field of heat transfer [1].

Despite of recent progress in the process of heat transfer enhancement, some constrained in improving cooling capacity of conventional fluids because of low thermal conductivities. Solid metals thermal conductivity is higher than fluids at ambient temperature, consider the copper metal, thermal conductivity is 600 times higher than the water and 2000 times higher than the lubricant oil at room temperature. Similarly metallic liquids thermal conductivity is higher than non-metallic liquids. Therefore, the thermal conductivity of fluids with solid metal suspension is expected to be higher than that of conventional HTFs [2].

The studies of Maxwell [3] on effective thermal conductivity of dispersions with micrometer size solid particles shown that an increase in thermal conductivity. This increase also observed with volume fraction of solid particles. Choi [2] described that increasing in thermal conductivity of suspensions with the ratio of the surface area to volume of nanoparticles. A nanofluid is a solid-fluid suspension. This solid metal is having a nanometer-size particle (≤ 100 nm) which are dispersed in conventional HTFs which is emerging as a new HTF. As these nanofluids are having possible and possible applications in the area of heat transfer, it has been a attracted many researchers [4].

Choi and Eastman [2] from Argonne National Laboratory explained that suspension containing nanometer size metallic particles as a nanofluids with higher thermal conductivity as compared to conventional HTFs like water, engine oil and ethylene glycol. These nanofluids also used in different applications such as to improve the solar thermal devices performance. Tyagi et al.'s [5] investigation on the thermal performance improvement by the use of nanofluids in solar collectors revealed that the presence of nanoparticles causes incident radiation absorption to rise by more than 9 times compared to pure water. Additionally, certain military applications use of nanofluids as high heat flux cooling fluids to effectively remove a significant quantity of heat from mechanical and electrical military equipment, such as submarines and high-power lasers [6].

Helical coil heat exchangers widely used in various chemical and biological industrial applications, because of large heat transfer areas, compact in nature and helical coil promotes secondary flow of fluids, increase in heat transfer coefficients, and also equipment construction and maintenance are easy [7].

Pawar and Sunnapwar [8] explained that these secondary flows increase the heat and mass transfer in curved pipes in comparison to straight pipes and they explain that the ratio of heat transfer coefficients from the coil to the flowing fluid by heat transfer coefficients from the straight pipe to the flowing fluid is more than one. The studies of Tancer et al. [9] aimed to study the effect of addition of CuO in TiO_2/water nanofluid with finned heat transfer equipment. Studies of Shin et al. [10] revealed that total heat transfer rate increased with number of turns of helical coil or number of coils present in the helix using natural convection.

Methodology

Experimental apparatus

The experimental schematic diagram is shown in figure 1. The experimental apparatus which comprising the test section, refrigeration loop, cold water bath, hot water bath, the test section is the vertical helical coil, which is immersed in hot water storage tank, the close loop of nanofluids consists of pump, hot water bath, hot water bath heated with steam with controlled pressure and temperature. The nanofluid entering the vertical coiled tube is cooled by cold water system where cold water is chilled by the refrigeration system. The hot water and nanofluids temperatures are adjusted to desired level with the help temperature controllers and temperature is measured by thermocouples. The flow rate of the nanofluid measured by flow meter.

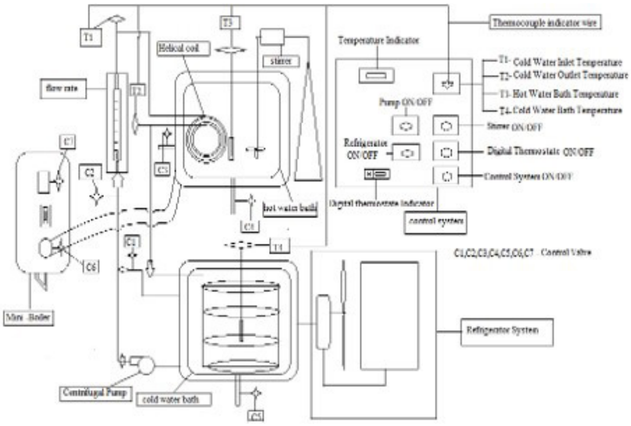

Figure 1: Schematic of experimental set up.

Nanofluids preparation

Al_2O_3 nanoparticles with particle size 40 nm (purchased from Nano Research lab), ultrapure water (Millipore) was used in this study. Al_2O_3/water nanofluid of desired concentration was prepared by the dispersing of the nanopowder in ultrapure water. The nanofluid subjected to ultrasonic pulses using ultra sonicator for 3 h to obtain the uniform dispersion and stable suspension [11]. The nanofluid with Al_2O_3 nanoparticles of concentration 0.01%, 0.02%, 0.03%, 0.04%, and 0.05% by volume without using surfactants were used in this study.

Test section

The test section was made using copper tube with inner diameter (ID) of 10 mm and outer diameter (OD) of 14 mm, respectively. Tube dimensions were mentioned in table 1. The temperature of inlet and outlet nanofluids were measured, hot water bath temperature with different position from the tube wall measured.

Table 1: Physical dimensions of helical coil tube.

Parameters	Dimensions
OD of helical coil tube, mm	14
ID of helical coil tube, mm	10
Length of tube, mm	6100
Helix dimeter, mm	190
Number of coil turn	5

Experimental process

1. The hot water bath is filled with ultrapure water.
2. Boiler is switched on for steam and condensing steam of 1 kg/cm^2 to hot water bath.
3. Fill the cold-water bath with desired concentration of nanofluid (0.01 to 0.05 vol.%).
4. The nanofluid flow rate was set with the help of centrifugal pump at 2 lpm using rotameter.
5. Hot water bath temperature maintained at constant and also cold-water bath using temperature controller and experiment is allowed to run with constant flow rate. The inlet and outlet temperature from the coil is noted.
6. Flow rate of nanofluid through coil was increased to 2.5 lpm and step 5 repeated.
7. The same procedure was repeated further till 4 lpm in the increment of 0.5 lpm.
8. Now steps 3 to 7 repeat with different concentration of nanofluids.

Experimental procedure

The effect of flow rate from 2 lpm to 4 lpm with increment of 0.5 lpm and Al_2O_3/water nanofluid concentration of 0.01, 0.02 and 0.05 vol.% has been studied.

Physical properties calculation

Thermal conductivity [3], viscosity [12], density [13], specific heat [14] of nanofluid was calculated using the below equations.

$$\frac{k_{nf}}{k_w} = \left[\frac{k_p + 2k_w - 2\Phi\left(k_w - k_p\right)}{k_p + 2k_w - \Phi\left(k_w - k_p\right)}\right] \tag{1}$$

Where k thermal conductivity, nf is nano fluid, w is nanoparticles, p is base, and k_{nf}, k_w, k_p, ϕ are the thermal conductivities of nanofluids, nanoparticles, the base fluid's thermal conductivity, the volume concentration of the nanoparticles, respectively.

$$\mu_{nf} = \left(1 + 2.5\phi\right)\mu_w \tag{2}$$

Where μ_w and μ_{nf} are the viscosity of the base fluids and nanofluid respectively and ϕ is volume concentration of nanoparticle.

$$\rho_{nf} = \phi\rho_p + \left(1-\phi\right)\rho_w \tag{3}$$

Where ρ_{nf}, ρ_p, ρ_w and ϕ are density of nanofluids, density of nanoparticles, density of base fluid and the volume fraction of the nanoparticles, respectively.

$$\left(\rho C_p\right)_{nf} = \phi\left(\rho C_p\right)_p + \left(1-\phi\right)\left(\rho C_p\right)_w \tag{4}$$

Where $(\rho C_p)_{nf}$ heat capacity of nanofluids, $(\rho C_p)_w$ heat capacity of base fluid, $(\rho C_p)_p$ heat capacity of nanoparticles and ϕ is volume concentration of nanoparticle.

Data handling for helical coil

The heat absorbed by the nanofluids is calcualted by.

$$Q_{nf} = m_{nf} C_{nf}\left(T_{in} - T_{out}\right)_{nf} \tag{5}$$

Where Q_{nf}, m_{nf}, $T_{out.nf}$ and $T_{in.nf}$ are heat absorbed by nanofluids, mass flow rate, the outlet and inlet temperatures.

The heat transfer coefficient of nanofluids (inside) is calculated from equation 6.

$$h = \frac{Q_{nf}}{A_s\left(\Delta T_{LMTD}\right)} \tag{6}$$

Where h is the average inside heat transfer coefficient, A_s is the inside area of heat transfer and ΔT_{LMTD} is the logarithm mean temperature difference as follows.

$$\Delta T_{LMTD} = \frac{\left(T_h - T_{in.nf}\right) - \left(T_h - T_{out.nf}\right)}{\ln\left(\frac{\left(T_h - T_{in.nf}\right)}{\left(T_h - T_{in.nf}\right)}\right)} \tag{7}$$

Where T_h is the hot water bath temperature in the tank.

The Nusselt number is calcualted using equaiton 8.

$$N_u = \frac{hD}{k_{nf}} \tag{8}$$

Where h is the average inside heat transfer coefficient, D is the tube diameter of pipe and k_{nf} is nanofluids thermal conductivity.

Results and Discussion

The experiments were conducted with water in hot water bath and Al_2O_3/water nanofluid concentrations (0.01, 0.02, and 0.05 vol.%) in coil side. In the present work transfer of heat from hot water present in reservoir/bath to Al_2O_3 nanofluid flowing in tube side. Heat transfer rate (Q) calculated form equation 5. Heat transfer rate of three various concentration of Al_2O_3/water nanofluids with various flow rates were calculated and shown in figure 2. Use of nanofluid as a coolant in coil side flow result higher rate of heat transfer as compared to water and increasing the concentration of nanofluid increase in heat transfer rate. From the graph the heat transfer rate is increasing with flow rate of nanofluid. It can be observed that increase in rate of heat transfer while using nanofluid than that of plain or raw water. It can be observed that the rate of heat transfer increases with increase in concentration of nanofluids. The maximum enhancement shown in 0.05 vol.% nanofluid. This can be attributed to the outlet nanofluid temperature tends to decrease as nanofluids flow rate increases. Figure 3 shows the variation of heat transfer coefficient with nanofluid flow rate. It can be observed from the figure 3 that heat transfer coefficient increases with increasing flow rate of nanofluid flow rate for different concentrations of nano particles in base fluid. The similar trend observed by Naphon [15].

As shown in figure 4 increase in Nusselt number as increase in flow rate and nanofluid concentration, because of Nusselt number is directly proportional to the heat transfer coefficient as increase in the heat transfer coefficient increase in the Nusselt number, and influence of thermal conductivity of nanofluid shown in Nusselt number enhancement. As the enhancement of heat transfer coefficient in 0.05 vol.% is more as compared to enhancement of Nusselt number of same concentration.

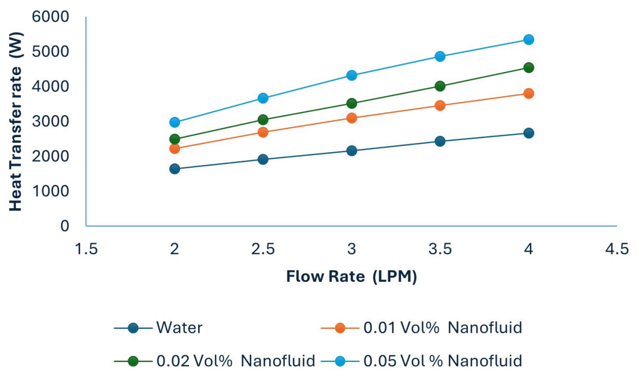

Figure 2: Variation of heat transfer rate with flow rate for different concentration of nanofluid.

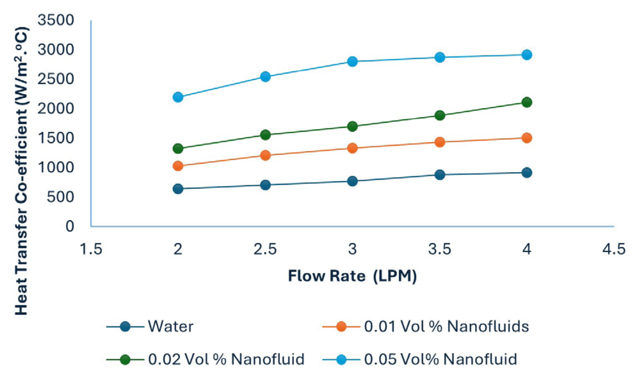

Figure 3: Variation of heat transfer coefficient with flow rate for different concentration of nanofluid.

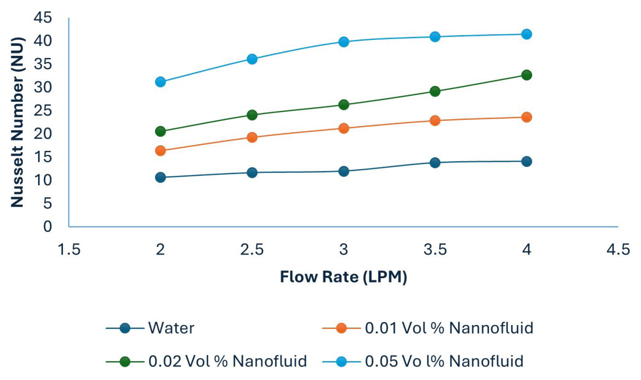

Figure 4: Variation of Nusselt number with flow rate for different concentration of nanofluid.

Conclusion

The result of rate of heat transfer, heat transfer coefficient and Nusselt number flows through the coil is presented and compared with the deionized water. Enhancement in the rate of heat transfer, heat transfer coefficient and Nusselt number shown for Al_2O_3/water nanofluid. Increasing the nanofluid concentration increase in the rate of heat transfer and heat transfer coefficient and Nusselt number. Maximum rate of heat transfer was obtained for 0.05 vol.% Al_2O_3/water nanofluid.

Acknowledgments

None.

Conflict of Interest

None.

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