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Enhancement of heat transfer in helical coil heat exchangers using nano-fluids

Malik Parveez[1*], Mohammad Hanief[2]

[1]National Institute of Technology, Chemical Engineering Department, Srinagar, Jammu and Kashmir, 190006, India

[2]National Institute of Technology, Mechanical Engineering Department, Srinagar, Jammu and Kashmir, 190006, India

Investigation for heat transfer behaviour of Al_2O_3 and CuO nano-fluid in helical coil heat exchangers was carried out in this study. The thermo-physical properties of the fluids have temperature dependent nature. The main emphasis was to depict the influence of nano-particle concentration by volume on the characteristics of temperature, rate of heat transfer and heat transfer coefficients (convective). In order to enhance efficiency, density and thermal conductivity are considered to be the most important variables. In comparison to water and for equal flow rate, the rate of heat transfer of nano-fluid increases conspicuously. Efficiency of the helical coil heat exchanger increased by 38.80%.

Keywords: nano-fluids, heat transfer, Nusselt number, Prandtl number, volume fraction

1. INTRODUCTION

Helical coil heat exchangers are used in nuclear plants for electricity generation, heating ventilation, air conditioning and chemical reactors, as they possess low volume to surface ratio. The increase in thermal conductivity of the working fluid enhances heat transfer efficiency. As water, ethylene glycol, and engine oil have comparatively low thermal conductivities, nano-fluids offer a solution to this problem. First it was pioneered by Choi and Eastman (1995). A numerical study to cover heat transfer characteristics and pressure drop of Al_2O_3/water nano-fluid in double coil in helical pattern heat exchanger was carried out by Aly (2014).

The main observation was that the overall heat transfer coefficient increases by increasing the coil dimension i.e. diameter and concentration of nano-particle (by volume) and the transfer of heat augmentation in shell and helical coil heat exchanger was experimentally investigated by Jamshidi et al. (2013). It was perceived that with the increase in pitch of the coil, diameter of coil and flow rate in shell and tube can augment the heat transfer. Experimental investigation for the transfer of heat and pressure drop pattern of CuO/water

* Corresponding author, e-mail: pkash123@yahoo.com

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nano-fluids in a shell and helical tube heat exchanger was carried out by Kannadasan et al. (2012) for both the vertical and horizontal orientations. The heat transfer (convective) characteristics in horizontal shell and helical coil heat exchanger were experimentally investigated by Salem et al. (2014).

For the helical coil heat exchanger, there are numerous parameters that have effect on the momentum and transfer of heat. Here, endeavour has been made to evaluate the optimal design for enhancing heat transfer using nano fluids of different volume concentrations, using helical coils.

2. RESULTS AND DISCUSSION

The experimentation involved testing 5 samples, each of Al_2O_3/water nano-fluid and CuO/water Nano fluid subjected to different surfactants, 3 hours of magnetic stirring and 2–2.5 hours of ultrasonication. The samples were compared on the basis of the settling time. The particle size (average) of the Al_2O_3 and CuO nano-particles used in the experimental analysis was 80 nm each. The flow loop for the nano-fluids comprised nano-fluid reservoir tank, centrifugal pump, rotameter, shell of the HCHE (helical coil heat exchanger), cooling section, and thermocouples. Two heaters of 2 kW each were installed in the hot water reservoir to be flown in the coil of the heat exchanger. The outer walls of the HCHE were insulated to prevent any heat loss. Total pressure drop between the coil inlet and outlet was measured using manometer. RTD PT 100 type thermometers with a precision of 0.1 °C were installed. The coil side flow rates were varied ranging from 1.0 L/min to 3.0 L/min. The shell side flow rate was fixed to 600 ml/min and the observations were recorded. In order to envisage the viscosity and thermal conductivity and other parameters of nano-fluids, empirical models were used as proposed by Khairul et al. (2013), similar to Eq. (1) and (2) used to determine specific heat capacity and viscosity.

$$C_{p,nf} = \frac{\O_s \rho_{bf} C_{p,s} + (1-\O)\rho_{bf} C_{p,bf}}{\rho_{nf}} \tag{1}$$

$$\mu_{\text{eff}} = \mu_{bf} (1-\O)^{-2.5} \tag{2}$$

Increasing the volume fraction of the nano-particles depicts a decreasing trend for the specific heat capacity, Fig. 1 Specific heat capacities when compared at the same temperature show a decrease of about 0.085% for Al_2O_3/water system when compared with water as base fluid and for CuO/water system it shows a decrease of 0.088%. Further as the volume fraction increases, the thermal conductivity increases and as such specific heat decreases. The heat will be transferred faster and in greater proportion through such a substance. This is typically the case with good conductors of heat like the metals because: $\alpha = \dfrac{k}{\rho C_p}$, α represents thermal diffusivity, conversely, lower the thermal conductivity and higher the specific heat, heat will transfer in small proportions. These variations were recorded for nano-particle concentration of 1g/L. It was observed that maximum decrease in the specific heat capacity can be seen for CuO/water system of about 0.144% whereas that for Al_2O_3/water system was 0.140% which shows that at any volume fraction CuO/water nano-fluid has lower specific heat capacity than that Al_2O_3/water nano-fluid. In Fig. 1 it was observed that with the increase in the fraction (by vol.) of the nano-particle in the base fluid, the density increases. There was augmentation in the density of Al_2O_3/water nano-fluid by 0.075% and for CuO/water nano-fluid it was about 0.085% when compared to water as base fluid at the same temperature. The minimal change can be attributed to the small change in the nano-particle volume fraction. The increase in the volume fraction of the nano-particles in the base fluid results in increase in the thermal conductivity of the nano fluid, when compared at the same temperature, CuO/water system shows increase in thermal conductivity of about 56.50. Nano fluids with higher volume fraction may be a good choice as a working fluid because of their entropy generation rate is lower than that of Al_2O_3 nano fluids. Maximum 26.47% decrease in entropy generation is found for CuO/water as highlighted in Fig. 2. Nusselt number (N_{Re}) increases with increase in coil side, Reynolds number as well as volume concentration of Al_2O_3 and CuO nano-particles, as depicted in Fig. 3.

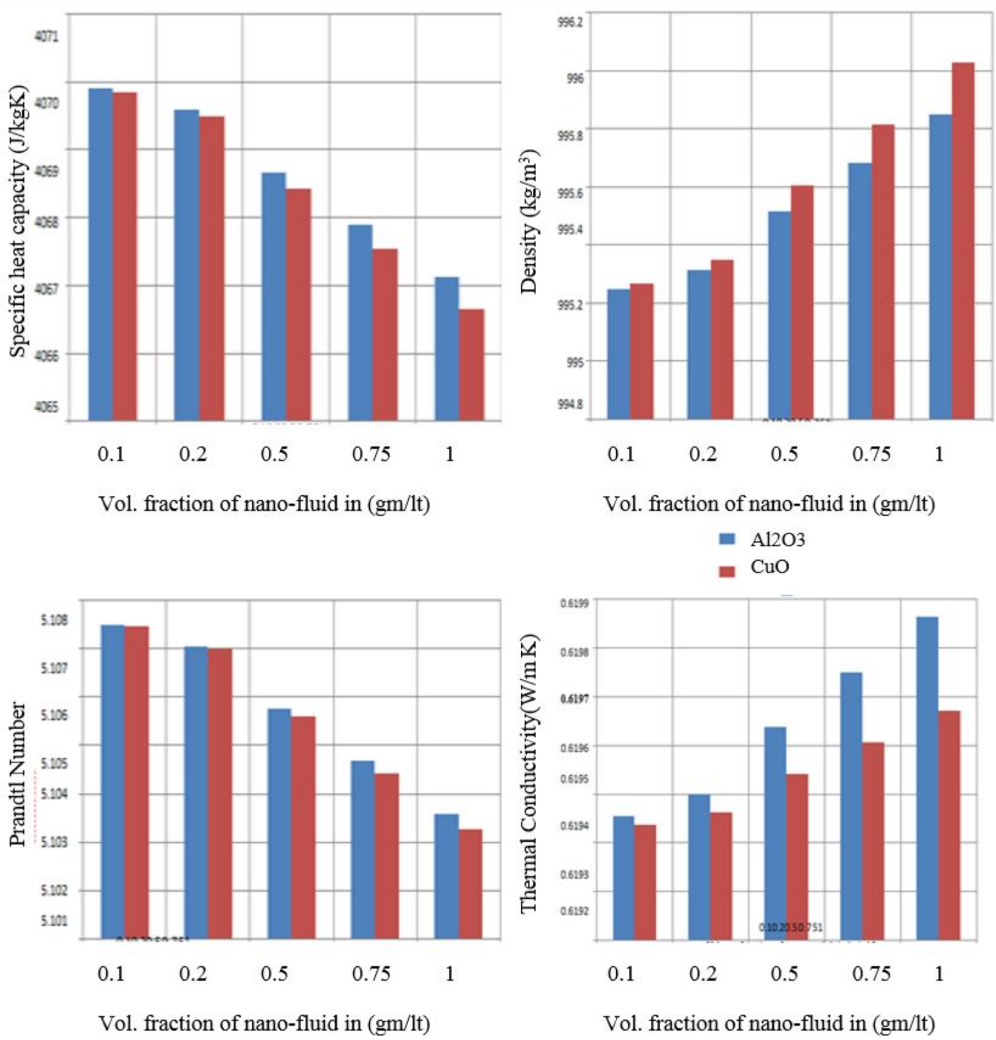

Fig. 1. Variation of specific heat, density, Prandtl number and thermal conductivity with change in the volume fraction of nano-particle in g in 1 L

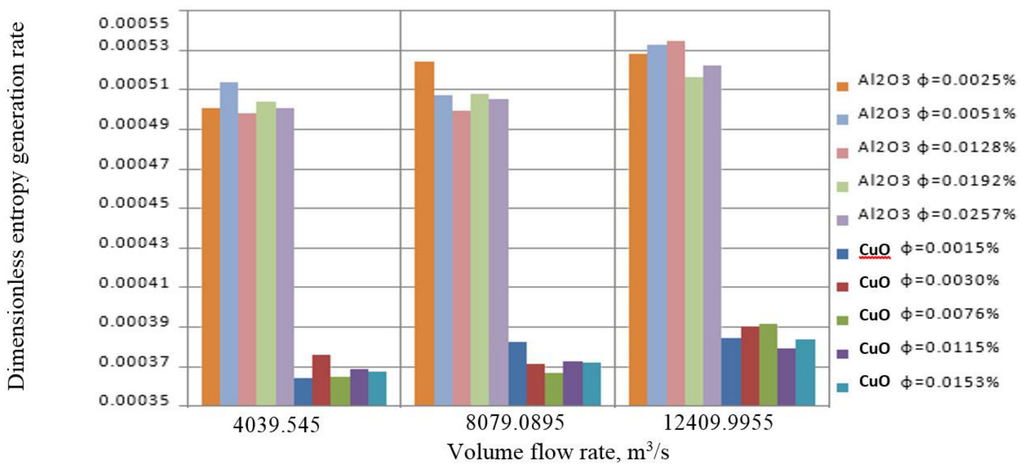

Fig. 2. Effect of volumetric flow rate and volume fraction on entropy generation (i.e. the ratio of entropy generation rate per unit length to product of thermal conductivity of nano fluid and dimensionless heat flux)

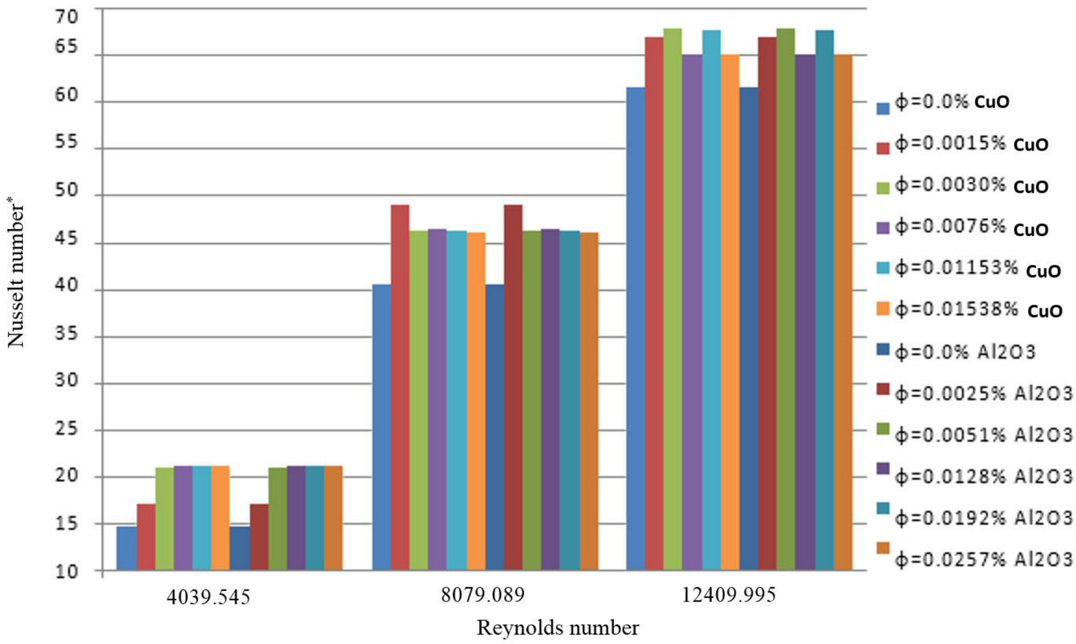

Fig. 3. Variation of coil side Nusselt number* vs. Reynolds number. *Calculated by correlation for vertical helically coiled heat exchanger proposed by Kannadasan et al. (2012)

3. CONCLUSION

The present experimental work of using nano fluids instead of conventional base fluids for heat transfer application has shown promising effects with the overall increase in parameters, such as overall heat transfer coefficient, Nusselt number for both shell and coil side, effectiveness, heat transfer rate and entropy generation rate with the increase of nano-particle volume fraction. For improvement in efficiency, density and thermal conductivity, the most important parameters are considered. For the identical flow rate, the rate of heat transfer of nano-fluid enhances conspicuously in comparison to water. Efficiency of the helical coil heat exchanger increased by 38.80%.

SYMBOLS

N_{Re} Reynolds number
C_p specific heat, J/(kg·K)

Greek symbols

ρ density of fluid, kg/m^3
k conductivity of thermal fluid, W/(m·K)
Ø volume fraction of nano-particle, –

Subscripts

nf nano fluid
bf base fluid
S sample
eff effective

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