Laminar Convective Heat Transfer of Al_2O_3 /Thermic Oil Nanofluid in a Plain Tube

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ABSTRACT

An experimental investigation on convective heat transfer and friction factor characteristics of Al_2O_3/therminol 55 nanofluid in the plain tube under laminar flow with constant heat flux is presented. The nanofluids of 0.1%, 0.2% volume fractions are prepared for the property studies like thermal conductivity and viscosity. The thermal conductivity and viscosity are measured by using KD2 thermal property analyzer and Brooke field viscometer respectively. From the measurements, it is found that the viscosity increase is substantially higher than the increase in the thermal conductivity. Convective heat transfer experimentation in the laminar flow regime under constant heat flux boundary condition is also done using thermic fluid based nanofluids as working fluids. From the results it is found that the Nusselt number increases with Reynolds number for both pure thermic fluid and nanoparticle enhanced thermic fluids. The average increase in Nusselt number for thermic fluid based nanofluid in comparison with pure thermic fluid is 11.12% and 19.69% for 0.1% and 0.2% volume fractions respectively.

Keywords: Nanofluid, Heat transfer enhancement, Therminol 55, Thermal conductivity, Nusselt number.

1 INTRODUCTION

Heat Transfer studies have always been a subject of interest and intrigue to the scientific world. The thrust is always into finding methods to enhance heat transfer properties like thermal conductivity, heat transfer rates, etc. This branch of study has become more important with issues like energy wastage, "waste heat" losses which tend to reduce the efficiency of a process in the industry or in research facilities. In cases of heat transfer coupled with fluid flow like a heat exchanger, there is a good chunk of heat energy lost and in the worst case unutilized. This eventually creates problems in energy generation where more money and resources (natural and man-made) need to be pumped in.

Thermal oils or heat transfer fluids are widely used to carry thermal energy in process heating, metal working and machine cooling applications. They are mainly used in high temperature process applications where the optimum bulk fluid operating temperatures of between 150°C and 400°C are safer and more efficient than steam, electrical, or direct fire heating methods. Amongst the high temperature heat transfer fluids, the molecular structures of aromatic synthetic oils (Therminol 55) provide higher stability at elevated temperatures than hot oils (paraffinic hydrocarbons) or silicone oils. The decision to use thermal oil as a heat transfer medium can be based on many reasons but one of the major incentives is the use on a non-pressurized system. Steam systems operate under pressure and are subject to statutory and regulatory requirements due to the inherent risk from pressure and the increased cost of installation and routine insurance inspection requirements. The introduction of nano-sized particles to heat transfer fluids (nanofluids)[1] is an emerging thermal management concept with implications in many disciplines including power generation, transportation, micro-electronics, chemical engineering, aerospace and manufacturing nanofluids in organic and mineral oils for heat transfer applications. Many research works have been carried out to investigate the thermo physical properties of nanofluids [2-4]. The convective heat transfer enhancements using different nanofluids in laminar and turbulent flow regimes have also been studied [5-11]. The heat transfer correlations for nanofluids have been developed [12]. In this work, the thermo hydraulic performance of Al_2O_3/Therminol 55 nanofluid of volume concentrations 0.1% and 0.2% have been investigated experimentally under constant heat flux condition in the hydrodynamically developed flow regime.

2 EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is shown in Fig.1. It consists of a calming section, test section, pump, cooling unit and a fluid reservoir. The test fluid is directed from the reservoir to the calming section and then to the test section by using a pump. The fluid after passing through the heated test section flows through riser section and then through the cooling unit and finally it is collected in the reservoir. The test section is heated uniformly by the electrical heating wire, attached to an autotransformer, by which heat flux can be varied by varying the voltage. Calibrated RTD sensors of $0.1^{\circ}C$ accuracy are placed in the thermowells mounted on the test section to measure the outside wall and fluid temperatures. The pressure drop across the test section is measured using a differential pressure transducer mounted across the test section which can able to read up to 1 cm of water column. A differential U-tube manometer is also fitted across the test section to validate the pressure drop shown by the pressure transducer.

A plastic container of 5 liter capacity is used as the fluid reservoir.

The experimental study on passive heat transfer and friction factor characteristics of Al_2O_3/Therminol 55 nanofluids is carried on in a straight circular tube of copper with constant heat flux.

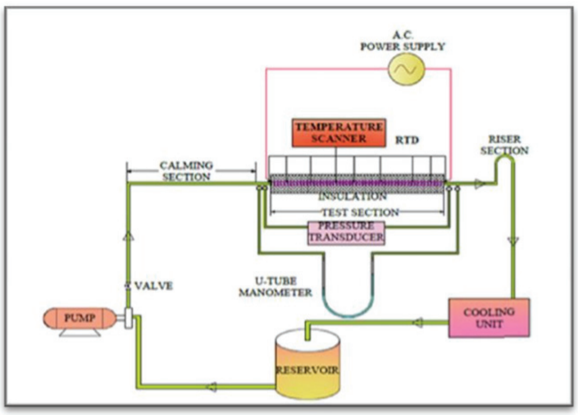

Fig.1 Schematic diagram of experimental setup

3 RESULTS AND DISCUSSIONS

3.1 Validation of the Experimental Setup

3.1.1 Heat Transfer Study

To validate the experimental setup, experiments are conducted with pure therminol 55 in plain tube in the Reynolds number range of 350 to 650. The experimental data in heat transfer study is compared with Shah's equation. The experimental results are found in good agreement with the theoretical values given by Shah's equation within a deviation of 13% as evident from Fig.2.

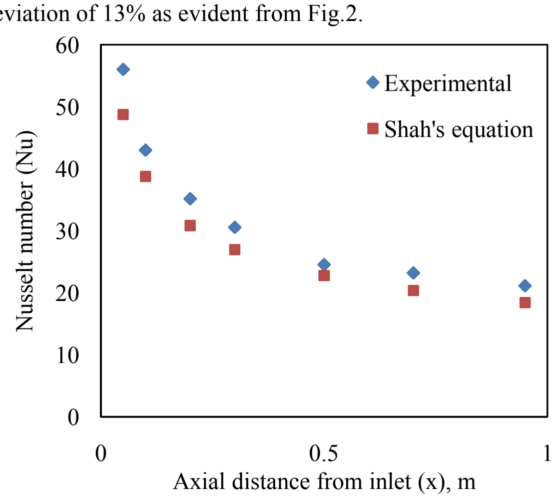

Fig.2 Comparison of experimental Nusselt number with Shah's equation

3.1.2 Pressure Drop Study

For pressure drop study, the experiments are conducted in isothermal conditions. The experimental data are compared with the theoretical values obtained using Hagen-Poiseuille equation. Fig.3 shows the comparison of the experimental results in pressure drop study with theoretical values. The deviations of the experimental data from the respective theoretical values are within ±8%. The deviation may be due to the uncertainties in the experimental measurements.

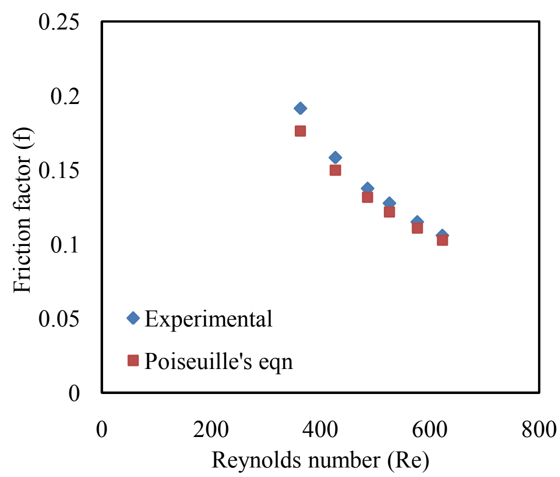

Fig.3 Comparison of experimental friction factor with Hagen-Poiseuille equation

3.2 Heat Transfer Study Using Al_2O_3/Therminol 55 Nanofluid

The experimental results clearly show that the nanoparticles suspended in TH55 increases the Nusselt number even for a very low volume concentration of 0.1% and 0.2%. The Nusselt number is increased respectively by 11.12% and 19.69% in the Reynolds number range of 350 to 650 as shown in Fig. 4. It was also observed from the experimental study that the enhancement increases with increase in particle volume concentration and Reynolds number. Fig. 5 shows that the enhancement of heat transfer for 0.2% is more compared with 0.1% volume concentration for all Reynolds numbers.

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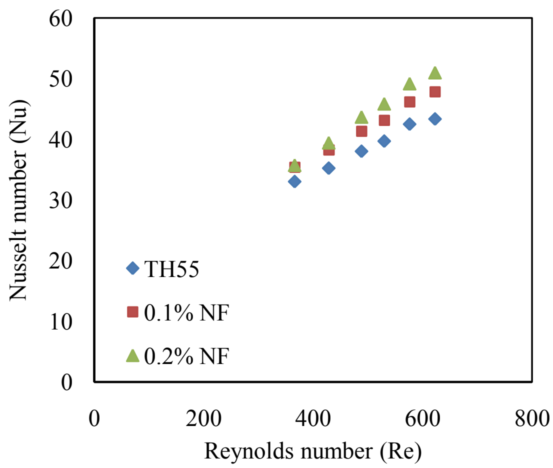

Fig.4 Variation of Nusselt number with Reynolds number

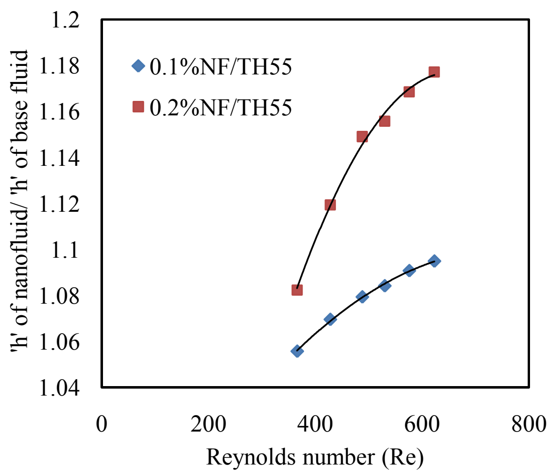

Fig.5 Variation of ratio of heat transfer coefficient of nanofluid to heat transfer coefficient of base fluid with Reynolds number

3.3 Pressure Drop Study Using Al_2O_3/Therminol 55 Nanofluid

The pressure drop of Al_2O_3/TH55 nanofluids flowing through a circular tube is experimentally measured using a U-tube manometer to investigate flow characteristics of the nanofluids. Here, the pressure drop is measured for laminar flow under isothermal conditions. The pressure drop (Δp) measured across the test section is used to calculate the friction factor. Fig. 6 shows that the friction factors of the Al_2O_3/TH55 nanofluid are almost equal to those of TH55 for the same Reynolds number and thus the pumping power does not increase. Compared with TH55, no significant augmentation in pressure drop for the nanofluid is found under the present experimental condition. Fig.7 shows that thermal resistance of nanofluids is less compared to pure therminol 55.

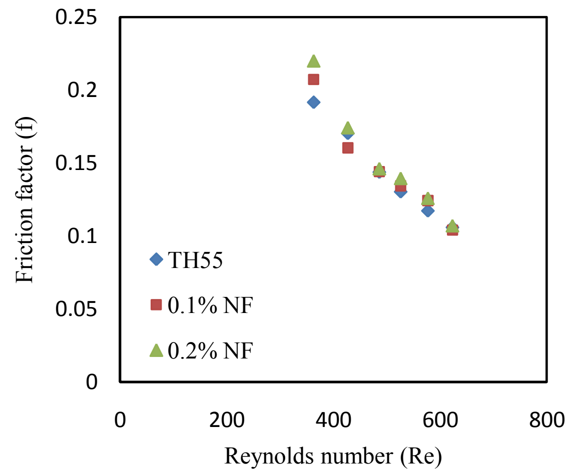

Fig.6 Variation of friction factor with Reynolds number

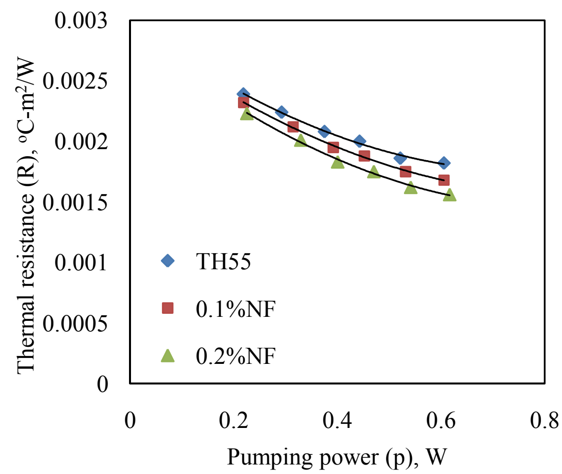

Fig.7 Variation of thermal resistance with pumping power

The experimental results of heat transfer study and pressure drop study are used to derive the following correlations of Nusselt number and friction factor using least square method of regression analysis. The correlations are valid for laminar flow (Re < 650) of 0.1% and 0.2 % volume concentration of Al_2O_3/therminol 55 nanofluids.

$$Nu = 0.99(Re)^{0.86}(Pr)^{-0.32}(1+\Phi)^{82.88} \quad (1)$$

$$f = 1.0088(Re)^{-0.345}(1+\Phi)^{25.469} \quad (2)$$

where, Φ is the volume concentration of nanofluid.

The Nusselt number and friction factor values predicted by the above correlations show reasonable agreement with the experimental results with maximum percentage deviation of ±7% and ±9% respectively.

4 CONCLUSIONS

Experimental investigation on the convective heat transfer and friction factor characteristics of Al_2O_3/TH55 nanofluids in the plain tube under laminar flow with constant heat flux is carried out. The results show that the thermal conductivity of nanofluids increases linearly with increasing particle volume concentration. At higher volume concentrations, the increase in relative viscosity is high and shows a nonlinear relationship with volume concentration. The increase in the Nusselt number of Al_2O_3/TH55 nanofluids is higher compared to pure TH55. The enhancement in heat transfer coefficient of 0.2% Al_2O_3/TH55 nanofluid is much higher than the 0.1% Al_2O_3/TH55 nanofluid. The Nusselt number increases with increasing Reynolds number and volume fraction of the nanofluid. There is no significant increase in pressure drop or friction factor in comparison to pure therminol 55. The use of nanofluids will not cause extra penalty in pumping power.

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