Heat transport and pressure drop characteristics of ethylene Glycol-based Nano fluid containing silver nanoparticles

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Abstract. In the current work, the heat transport characteristics of ethylene glycol with different volume fractions of silver nanoparticles dispersed to form a nanofluid that flows through an inner tube of the annular heat exchanger were investigated experimentally. The mass flow rate of nanofluid varied from 5 g/s to 25 g/s at 50°C inlet temperature of nanofluid on the heat transfer co-efficient were carried out under laminar flow conditions. The nanofluid was prepared with 0.05% and 0.1% volume percent of silver nanoparticles. The thermo-physical characteristics of pure ethylene glycol and silver/ethylene glycol nanofluid were measured experimentally. The heat transfer co-efficient was significantly increased with respect to Reynolds number and volume percent of silver nanoparticles. The experimental results show that the of convective heat transfer coefficient of the nanofluids increases up to 38% at a volume percent of 0.1% with those compared with basefluid at same Reynolds number. The enhanced thermal conductivity of nanofluid and the clustering of nanoparticles could be the probable reasons for the increment of heat transfer co-efficient. The pressure drop of the nanofluid increases as a function of Reynolds number and volume percent of nanoparticles. The increment in pressure drop is more predominant with respect to Reynolds number as compared to volume percent of nanoparticles.

1. Introduction

Forced convective heat transfer is the current developing sector which finds a wide variety of applications starting from micro level to the macro level. Heat transfer can be achieved by means of conduction, convection and radiation. In the context of bulk heat transfer, convection plays a major role in which heat transfer fluids are quite significant. Most of the researchers involved in developing the heat transfer medium which transports the energy effectively and efficiently. The development of this effective medium involves the synthesis, thermo-physical characteristics, heat transport characteristics and flexibility of its applications under various areas. Variety of conventional mediums such as water, ethylene glycol, aqueous ethylene glycol, oil and air are being used to transfer the heat depending upon the application. However these mediums are posing a poor thermal transport characteristics which is the major problem concerned.
Several researchers after huge attempts solved the above problem by introducing a new class of heat transfer mediums called as nanofluids which involves the addition of solid nano-sized particles into the conventional mediums. These nano-sized particles provide an excellent thermal transport properties as well as excellent stability based on the existing nature of nanoparticles as compared to micro-sized particles. Several published literature show that the convective heat transfer coefficient (CHTC) increases substantially for nanofluid with those compared to the respective base mediums. There are many nanoparticles that are considered for such nanofluids. Various metal and non-metallic spherical nanoparticles such as aluminum (Al), aluminum oxide (Al₂O₃), copper (Cu), copper oxide (CuO), gold (Au), iron (Fe), silver (Ag), titanium dioxide (TiO₂) and zinc oxide (ZnO) were considered since late 1995 for the nanofluid preparation [1-7]. Several published literature show that the CHTC enhances substantially when conventional heat transfer mediums are seeded with suitable nanoparticles [2-7]. It is also reveals that the heat transfer enhances with increase in volume fraction posing disadvantages of simultaneous increase in viscosity. This is due to the higher density of nanoparticles which in turn increases the pumping power. However experimental studies are needed to understand the exact behaviour of nanofluids in thermal systems.

Godson et al. [8] experimentally studied the heat transport characteristics of Ag/H₂O nanofluid in a tube-in-tube heat exchanger test section for higher temperature application. It was reported that the CHTC increases effectively by addition of Ag nanoparticles in the base medium. The improvement in CHTC was reported to be ~69% at 0.9 vol% of Ag. Selvam et al. [9] performed the experiment on the CHTC of Ag/H₂O-EG nanofluid and reported that the CHTC enhances upto 42% at 0.45 vol% of Ag. Several experimental studies have been performed using ethylene glycol (EG) based nanofluids on its heat transfer performance with various nanoparticles by different authors [10-15]. Few authors were carried out the experiments on the heat transfer performance of metallic and metallic oxide nanofluids with different base mediums [16-22]. Published literature reveals that there is no effective improvement was found with addition of metallic oxide nanoparticles in the base medium at lower volume percent of nanoparticles while the addition of higher volume percent increases the viscosity and pumping power significantly. To overcome this issue, the metallic nanoparticles at lower volume percent in the base mediums can be used for various heat transfer applications.

The aim of the study is experimental analysis on the heat transport and pressure drop of ethylene glycol seeded with silver nanoparticles (metallic particles) under low volume fraction. Ag nanoparticle was considered due to its higher thermal conductivity as compared to the other metal based nanoparticles. In the current work, the forced convective heat transport and pressure drop characteristics were studied in an annular counter current heat exchanger test section as a function of mass flow rates and volume percent of nanoparticles.

2. Experimentation

2.1 Synthesis of Ag/EG nanofluid

In this study, the metal based nanostructure namely silver nanoparticle (Ag) was used to make high thermal conductive stable nanofluids. The ethylene glycol was used as the basefluid. The volume percent (vol%) of Ag considered was 0.05% and 0.1%. Ag nanoparticles were mixed with the basefluid under ultrasonic vibration for 2 hrs with 0.25 vol% Sodium dodecyl sulfate surfactant (SDS). The produced nanofluids were stable up to one month.

2.2. Thermo-physical characteristics

The thermo-physical characteristics such as thermal conductivity (kₙf), viscosity (µₙf), specific heat capacity (Cₙf) and density (ρₙf), of nanofluids were performed using hot wire transient method, cannon fenske viscometer, differential scanning calorimeter and electronic weighing balance respectively for the temperature ranging from 30-50°C.

2.3. Experimental set up and procedure
The experimental analyses on the heat transport and pressure drop behaviour were performed in an annular current heat exchanger test facility as shown in Figure 1. It has two flow loops that carry the hot fluid (Ag/EG nanofluid) and cold fluid (water). There is a flow meter and pump in each loop. The hot fluid flows through the inner tube while the cold fluid flows through the annulus. The inner diameters of the inside and annular tube were 4.3 mm and 10.5 mm respectively. A differential pressure transmitter was fixed across the inlet and outlet of the inner tube. The detailed information about the experimental facility was reported in our previous investigation [14]. The mass flow rate of nanofluids (hot fluid) was varied from 5 to 25 g/s with an interval of 5 g/s while that of water (cold fluid) was maintained at 15 g/s. The inlet temperature of hot fluid and cold fluid were 50°C and 25°C respectively. After attaining the steady state condition, the temperatures along the test section were logged into a data-logger and the pressure drop ($\Delta P_{nf}$) in the Ag/EG nanofluid was noted.

![Figure 1. Annular counter current heat exchanger test facility [14]](image)

### 3. Data reduction

The heat transfer rate ($Q_{nf}$) of EG based Ag/EG nanofluid was determined using the following Eq. (1).

$$Q_{nf} = \dot{m}_{nf} C_p_{nf} (T_{N_{i}} - T_{N_{o}})_{nf}$$

The CHTC ($h_{nf}$) of EG based silver nanofluid was determined as given in Eq. (2)

$$h_{nf} = \frac{Q_{nf}}{A(T_{N_{i}} - T_{W}^{\prime})}$$

where, $T_{N_{i}}$ and $T_{W}$ are mean temperature of EG based silver nanofluid and wall temperature of tube respectively and ‘$A$’ is the inner surface area of the tube.

Reynolds number ($Re_{nf}$) and Nusselt number ($Nu_{nf}$) of EG based silver nanofluids were found out using the following Eqs. (3-4).
\[ \text{Re}_{nf} = \left[ \frac{\rho V d_i}{\mu} \right]_{nf} \]  \tag{3}  
\[ \text{Nu}_{nf} = \left[ \frac{h d_i}{k} \right]_{nf} \] \tag{4}  

where, \( V \) and \( d_i \) are correspond to the velocity of nanofluid and diameter of inner tube respectively. \( \rho, \mu, k \) are correspond the density, viscosity and thermal conductivity respectively.

4. Uncertainty study

The uncertainty investigation was performed as per the method proposed by Moffat [23] in order to corroborate the experimental results. The highest uncertainty in the experiment was observed at the higher mass flow rate conditions. The uncertainty in heat flux and CHTC were found out as reported in our previous investigations [9, 14]. The accuracies of the measuring instruments used in the experiments and estimated uncertainties of heat flux and CHTC are given in table 1.

| Measuring instruments/ Parameter | Accuracy/uncertainty range |
|----------------------------------|---------------------------|
| Temperature sensor (PT100 RTD)   | ±0.15°C                   |
| Differential pressure transducer | ±0.075%                   |
| Coriolis type mass flow meter    | ±0.1%                     |
| Heat flux (q) and CHTC (h)       | 1-5%                      |

5. Results and discussions

The experimental work on the convective heat transport and pressure drop behaviour of Ag/EG nanofluids were performed under laminar flow regions at two volume percent of nanoparticles (0.05 and 0.1 vol%). Initially the thermo-physical characteristics were measured as a function of volume percent of nanoparticles and temperature. The CHTC was determined using the measured temperature from the experiment along with thermo-physical characteristics. The results of thermo-physical characteristics and CHTC along with pressure drop were discussed in this section.

5.1 Thermo-physical characteristics

Initially the thermo-physical characteristics of pure EG were experimentally measured and compared with ASHRAE standard [24] data. It is found that the experimental values are in excellent agreement with ASHRAE standard data within ±5% variation. Figure 2 (a-d) illustrated the variation in thermo-physical characteristics of Ag/EG nanofluid for various temperatures and volume percent of Ag. The thermal conductivity of Ag/EG nanofluid enhances as a function of volume percent and temperature. The highest improvement in thermal conductivity is found to be ~20% at 0.1 vol% as compared to EG. The particle clustering and dispersion of high thermal conductive Ag particle could be the reasons for the significant enhancement even at lower volume percent of nanoparticles. The viscosity of Ag/EG nanofluid increases as a function of volume percent while it decreases with temperature. The highest increment in viscosity is found to be ~11% at 0.1 vol% as compared to EG. The increment in viscosity can be attributed to the higher density of the Ag nanoparticles. The specific heat capacity of Ag/EG nanofluid decreases as a function of volume percent while it increases with temperature. The decrement in specific heat capacity of Ag/EG nanofluid can be attributed to the lower specific heat capacity of the Ag nanoparticles. The highest reduction in specific heat capacity is found to be ~1% at
0.1 vol% as compared to EG. The variation in density of Ag/EG nanofluid is similar to viscosity of nanofluid. The maximum improvement in density is found to be ~1% at 0.1 vol% as compared to EG.

![Thermo-physical characteristics of Ag/EG nanofluid. (a) Thermal conductivity (b) Viscosity (c) Specific heat capacity (d) Density](image)

**Figure 2.** Thermo-physical characteristics of Ag/EG nanofluid. (a) Thermal conductivity (b) Viscosity (c) Specific heat capacity (d) Density

5.2 Convective heat transfer coefficient

Figure 3 illustrates the variation in CHTC of Ag/EG nanofluid for various Reynolds number and volume percent of Ag. It is found that increasing the volume percent of nanoparticles reduces Reynolds number and hence even for the same mass flow rate of nanofluid the Reynolds number takes lesser value as volume percent increases. This is because of the increase in viscosity as volume percent of particles increases. The higher mass flow rate of nanofluids enhances the heat transfer due to more convection and thinner boundary layer. At fixed mass flow rate the CHTC increases even though the Reynolds number decreases as a function of volume percent of nanoparticles. Thus the CHTC of Ag/EG nanofluid increases with respect to volume percent of particle as well as Reynolds number.
The average improvement in CHTC is observed in the range of 1 to 25% for every increase in 0.05 vol% of Ag for the considered Reynolds number range. The enhancement is limited beyond 5 g/s mass flow rate due to decrease in specific heat capacity at corresponding mean temperature. The highest improvement in CHTC is found to be ~38% at 0.1 vol% for Re= ~600 (25 g/s) as compared to pure EG. The improvement in thermal conductivity, reduction in boundary layer thickness [25] and participation of Ag nanoparticles during the energy transfer between two fluids [26] are the main reasons for the improvement in CHTC.

5.3 Pressure drop

The variation in pressure drop ($\Delta P_{nf}$) of Ag/EG nanofluid for various Reynolds number and volume percent of Ag is illustrated in figure 4. It is observed that the pressure drop of Ag/EG nanofluid increases as Reynolds number and volume percent of Ag increases. The increment in pressure drop is found in the range of 1.4 to 2.5 kPa for every increase in 5 g/s mass flow rate. The increment is predominant as a function of Re as compared to volume percent of Ag. The increment of pressure drop is varying in the range of 0.2 to 1.5 kPa for every increase in 0.05 vol%. The pressure drop increases in the range of 0.8 to 2.6 kPa when the volume percent of the Ag increases from 0% to 0.1%. The highest pressure drop value is found for highest mass flow rate and volume percent of Ag (25 g/s and 0.1 vol%). In this work, the observed pressure drop is not too high at lower volume percent of Ag which can be beneficial for practical heat transfer process in thermal systems.
6. Conclusions

The experiments on forced convective heat transport and pressure drop behaviour were performed under laminar flow conditions at two volume percent of Ag nanoparticles (0.05 vol% and 0.1 vol%). The thermal conduction and CHTC were significantly increased even at lower volume percent of Ag nanoparticles. The improvement in CHTC and thermal conduction were found to be 38% and 20% respectively. The Ag/EG nanofluid can be used as an alternate heat transfer fluid for compact thermal systems. Further experimental works to be performed under higher flow rate conditions with higher volume percent of Ag nanoparticles in order to predict the exact characteristics of the Ag/EG nanofluid for effective thermal systems.

7. References

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