Investigation On Heat Transfer Properties Of Water Based TiO2-ZnO Nanofluids

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Abstract: Nanofluids in heat transfer applications exhibit effective performance over conventional heat transfer fluids. High thermal loads due to miniaturization in a wide variety of applications offers technological challenges in designing efficient thermal management systems. Traditional heat transfer fluids such as air, water, engine oil, and ethylene glycol (EG) have very low thermal conductivities of 0.03, 0.613, 0.145 and 0.253 W/ mK respectively. The poor thermal conductivity of these fluids is an obstacle in improving heat transfer and compactness of the heat exchangers. Determination of properties of nanofluids and its performance in water based base fluids has been studied by many researchers. However the heat transfer performance of mixed nanofluids ie., hybrid nanofluids is yet to be explored. TiO₂ and ZnO nanofluids were prepared at 0.5%, 1.5% and 2.0% volume concentration. Thermal conductivity estimated for temperature range of 30-70°C. Significant enhancement of both heat transfer rate and effectiveness of heat exchanger was noticed with TiO₂ nanofluids at 2.0% volume concentration and with 1.5% volume concentration of TiO₂-ZnO hybrid nanofluids.

Keywords: Heat transfer, thermal conductivity, effectiveness, double pipe heat exchanger, nanofluid

1. Introduction

Nanofluids are nano scale colloidal suspensions containing solid nanoparticles. Research with nanofluid for heat transfer applications has increased significantly in the past decade. Still, it is in its adolescence stage, number of issues is yet to be investigated. Water is widely used and most cost effective conventional fluid that has high heat transfer efficiencies. But, at a temperature above 100°C it starts to boil and cannot be controlled easily. Nano-sized particle dispersed in base fluids (nanofluids) is an emerging and efficient thermal management concept. It has potential applications in many areas such as micro-electronics, transportation, power generation, aerospace, chemical
engineering and manufacturing. Further composite (a mixture of two or more nanoparticles) nanofluids have the advantage of tuning thermal conductivity with a proper choice of nano particles and concentration which will not be the case with single component or conventional nanofluids.

Nanofluids are called as a two-phase system as solid nanoparticles are dispersed in a liquid medium. Stability of nanofluids for longer duration plays an important role in the heat transfer properties of the nanofluids. Many articles published the progress in achieving the stability of nanofluids, experimental and theoretical studies of the thermo physical properties, and convective heat transfer properties of single component nanofluids. Experimental investigations to estimate the heat transfer coefficients of either composite or hybrid nanofluids are scarce in literature. [1-11]

2. THERMAL PROPERTIES OF NANOFLUIDS:

Thermo physical properties such as viscosity, thermal conductivity, thermal diffusivity and convective heat transfer coefficient of nanofluids are higher compared to those of conventional fluids like water and oil etc. Nanofluids have potential applications in many fields, but still there are some important issues to be investigated. Preparation methods, stability and performance of nanofluids are main challenges to the researchers. Number of studies was carried out by various researchers to investigate the transport properties of nanofluids. A few of them focused on the methods of synthesis for the preparation of nanofluids in desired concentrations.

2.1 Thermal Conductivity and viscosity:

Studies conducted by researchers found that the thermal conductivity of nanofluids increase with particle concentration. It also depends on the particle size. Experiments undertaken with Al2O3, Cu, CuO, TiO2, SiO2 and other nanofluids observed the enhanced thermal conductivity at different volume concentrations of nanoparticles. Chandrasekhar et al. [12] concluded that the effective thermal conductivity and viscosity of Al2O3-water based nanofluids increased with that of nanoparticle volume concentration. Suresh et al. [13] conducted experiments using Al2O3-Cu water based nanofluids and found 12.11% enhancement of thermal conductivity for a volume concentration of 2%. Usri et al [14] experimented with TiO2/Water-EG based nanofluids and measured the thermal conductivity values at 1.0 and 1.5% volume concentrations for automotive applications and found the enhanced thermal conductivity values. Bhosale et al. [15] reviewed stable homogeneous graphene nano platelet (GNP), SiO2, CeO2, Al2O3, TiO2; nanofluids and concluded that they have great potential in augmentation of heat transfer. Al2O3, TiO2 and SiO2/water based nanofluids were modeled using CFD by Adnan et al. [16] and found thermal conductivity and viscosity to increase with concentration. Hamid et. al [17] used TiO2 nanoparticles in water-ethylene glycol mixture at 0.5 and 1.5% volume concentrations and found significant improvement in the thermal properties of nanofluids. Ding et al.[18] and Bhattacharya et al.[19], measured the rheological properties of nanofluids. It was observed that in both EG-water based suspensions, the viscosity decreased with increase in the average size of the particle. However a marginal increase in relative viscosity observed by Timofeeva et al., compared to water based suspensions having smaller nanoparticles.

2.2 Pressure drop and Friction Factor:

Heat transfer and pressure drop properties were investigated by Suresh et al.[20] and Chandrasekar et al. [21] using Al2O3-Cu water based nanofluids at 0.1% volume concentration. Experiments were conducted using hybrid nanofluids under fully developed laminar flow conditions and found a maximum enhancement of 13.56% in Nusselt number. Similar work conducted by Sahin et al [22] using CuO-Water nanofluids at different volume fractions of 0.5%, 1%, 2% and 4%. Experiments were carried out under study state, constant heat flux and turbulent flow conditions. Heat transfer
coefficient of highest value is achieved at Re=16,000. Fotukian et al [23] observed 25% increase in heat transfer coefficient using CuO-Water nanofluid with significant 20% penalty in pressure drop. Azmi et al [24-25] in their experiment with SiO$_2$ nanofluid found that friction factor of nanofluid decreased with increase in Reynolds number at any concentration. Also Hussein et al found that the nanofluid friction factor with twist ratio of 5, for Reynolds number 23,558 was greater than twice the value for flow of water in a tube. [26]

2.3 Heat Transfer Enhancement:

Numerical studies of various nanofluids at different volume concentrations were conducted by many researchers. The investigations were conducted at steady-state turbulent convection with water and water-EG based nanofluids of Al$_2$O$_3$, SiO$_2$, TiO$_2$, ZnO, etc. Overall results show that heat transfer enhanced with particle volume concentration and Reynolds number. Experimental investigations were also conducted by researchers at different nanofluid volume concentrations and found significant enhancement in both thermal conductivity and heat transfer coefficient. Hwang et al [27] investigated the pressure drop and convective heat transfer coefficient of water based Al$_2$O$_3$ nanofluids in a uniformly heated circular tube under fully developed laminar flow regime. They concluded that the convective heat transfer coefficient of the nanofluids enhanced by 8% at a volume concentration of 0.3% compared to pure water. Certain researchers investigated the effect of particle size on nanofluid heat transfer enhancement. Heris et al [28] found that increase in thermal conductivity of nanofluids may not be the only reason for enhanced heat transfer coefficients, but can also be attributed to factors such as dispersion and chaotic movement of nanoparticles, Brownian motion and particle migration. Similar results of enhanced heat transfer properties observed with TiO$_2$, SiO$_2$, CuO, Cu, and ZnO nanofluids by other researchers [29-34] can be found in the literature.

3. METHODOLOGY:

3.1 Preparation of nanofluid:

Titanium oxide i.e., TiO$_2$ and Zinc Oxide i.e., ZnO and their composites are used to prepare nanofluids. Nanoparticles are procured from Sigma Aldrich and nanofluids prepared for volume concentrations of 0.5%, 1.5% and 2.0 % using distilled water as the base fluid. The nanofluid thus prepared is mixed thoroughly using mechanical stirrer for half an hour and then sonicated using ultra-sonic bath for two hours to ensure homogeneous solution and proper stability of nanofluids.

3.2 Experimental set up to estimate the heat transfer properties of nanofluids:

A double pipe heat exchanger was used to conduct experiments and to estimate the heat transfer performance of nanofluids. Heater of 1.0 kW rating with regulator is provided. Pipes are insulated with ceramic fiber insulators. Thermo couples are placed at inlet and outlet and at four intermediate points to estimate the surface temperatures. Constant heat flux was maintained by voltage regulator. Chiller is provided to cool the working fluid coming from the outlet of the test section. Adjustable flow meter is provided to regulate and measure the flow rates in LPM. Schematic diagram of the experimental set up and the photograph of the experimental setup are shown in the figure 1 and 2. Two Pumps of 0.5 hp each are provided to circulate both nanofluid and hot water from the collecting tank through the test setup. Data collection is taken manually and required calculations are made to estimate the heat transfer performance of nanofluids.
4. **BASIC EQUATIONS:**
The following basic equations are used to estimate the heat transfer properties of the nanofluids

(a) **Heat Transfer Rate, \( Q \)**

\[
Q = \frac{Q_H + Q_C}{2} \quad \text{Watts}
\]

Where,

\[Q_H = \text{heat transfer rate from hot water and is given by}
= m_h \times C_{PH} \times (T_{hi} - T_{he})
\]

\[m_h = \text{mass flow rate of hot water in kg/sec}
\]

(b) **Overall Heat Transfer Rate**

\[
Q = U \times A \times \Delta T_m
\]

\[U = \frac{Q}{A \times \Delta T_m} \quad \text{Where,}
\]

\[Q = \text{Heat transfer rate, W}
\]

\[A = \text{contact area of surface in m}^2; \quad A = \pi \times D_o \times L
\]

(c) **Convective Heat Transfer Co-Efficient**

\[Q = h \times A \times (t_i - t_f)\]
5. RESULTS AND DISCUSSION:

Heat transfer rate, thermal conductivity, heat transfer coefficient, capacity rate ratio and effectiveness of double pipe heat exchanger using water, coolant and also using TiO$_2$, ZnO nanofluids at volume fractions of 0.5%, 1.5% and 2.0% are estimated and correlated. The above parameters using TiO$_2$-ZnO hybrid nanofluids also estimated and the comparative values are shown in Table 1. As seen from the table, the effectiveness of heat exchanger using water, 1.5% TiO$_2$, 2% ZnO, and 2% TiO$_2$ are 0.787, 0.802, 0.792, and 0.831 respectively. Better and highest effectiveness of heat exchanger i.e., 0.893 was shown using 1.5% TiO$_2$+ZnO composite nanofluid. Variation of thermal conductivity, effectiveness of heat exchanger and heat transfer coefficient verses volume concentration was shown in figure 3, 4 and 5 respectively. It is observed that both TiO$_2$ and ZnO nanofluids with 2.0% volume concentration and TiO$_2$-ZnO nanocomposite at 1.5% volume concentration give better enhancement in heat transfer coefficient and effectiveness of heat exchanger compared to water.
6. CONCLUSION:

TiO₂ and ZnO nanofluids were prepared and experimented in double pipe heat exchanger to obtain heat transfer properties. Thermal conductivity of TiO₂ nanofluid has shown a marginal enhancement of 14.8%, at 1.5% volume concentration but at 2.0% volume concentrations the enhancement is significant and is 27.9% compared to water as working fluid. Thermal conductivity of ZnO nanofluid has shown an enhancement of 11.5% and 18.1% at 1.5% and 2.0% volume concentrations respectively compared to water as working fluid. Other parameters such as heat transfer rate and effectiveness of heat exchanger also exhibited significant enhancement at these volume concentrations. Thermal conductivity and effectiveness of heat exchanger enhanced to 40.9% and 13.5% respectively at 1.5% volume concentrations of TiO₂ and ZnO hybrid nanofluid.

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