



International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013

Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013)

On 12th to 14th December Organized by

Department of Civil Engineering and Mechanical Engineering of Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India

**AN EXPERIMENTAL INVESTIGATION ON THE ENHANCEMENT
OF FORCED ONVECTION HEAT TRANSFER USING TiO₂-
WATER NANOFLUIDS IN TURBULENT REGIME**

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ABSTRACT

Thermal Properties of conventional base fluids in heat transfer equipments are poor. By suspending nanometer sized metallic particles in these base fluids, the thermal properties of base fluids can be increased significantly. By using this nanofluids instead of conventional fluids, the heat transfer rate can be increased. An experimental setup was designed and fabricated for the measurement of convective heat transfer coefficient of nanofluids. Experiments were conducted by varying the flow rates and particle volume concentration in turbulent regime. By analyzing the results it was found that the heat transfer coefficient increases with increase in Reynolds number. As the concentration of nanoparticle increases, the convective heat transfer coefficient first increases and then decreases. This may be due to the settling of nanoparticles at higher concentrations. Dittus-Boelter correlation was modified to suit TiO₂-water nanofluids using the experimental data for a Reynolds number range of 4000 to 10,000.

Keywords: nanofluid, convective heat transfer

NOMENCLATURE

h	Convective heat transfer coefficient
Φ	Particle volume concentration
Nu_{nf}	Nusselt Number for the nanofluid
Re_{nf}	Reynolds Number for the nanofluid
Pr_{nf}	Prandtl number for the nanofluid
m_p	Mass of nanoparticle
m_f	Mass of basefluid
ρ_p	Density of nanoparticle
ρ_f	Density of basefluid

1. INTRODUCTION

Cooling capabilities of heat transfer equipments have been constrained because of the low thermal conductivity of conventional heat transfer fluids. However, it is well known that, metals in solid form have orders-of-magnitude higher thermal conductivities than those of fluids. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. Therefore, the thermal conductivities of fluids that contain suspended solid metallic particles could be expected to be significantly higher than those of conventional heat transfer fluids.

Applying nanotechnology to thermal engineering, the novel concept of “nanofluids”, which was coined by Stev Choi [1] in 1995 has been proposed as a means of meeting these cooling challenges. This new class of heat transfer fluids is engineered by dispersing nanometer-sized solid particles in traditional heat transfer fluids such as water, ethylene glycol or engine oil. The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations by uniform dispersion and stable suspension of nanoparticles (preferably <10 nm) in host fluids.

An experimental investigation on the forced convective heat transfer and flow characteristics of TiO₂-water nanofluids under turbulent flow conditions is reported by Daungthongsuk and Wongwises [2], in 2008. A horizontal double-tube counter flow heat exchanger was used in their study. They observed a slightly higher (6– 11%) heat transfer coefficient for nanofluid compared to pure water. The heat transfer coefficient increases with increasing mass flow rate of the hot water as well as nanofluid. They also claimed that the use of the nanofluid has a little penalty in pressure drop. Hwang et al [3] in 2009 measured the pressure drop and convective heat transfer coefficient of water based Al₂O₃ nanofluids flowing through a uniformly heated circular tube in the fully developed laminar flow regime. The convective heat transfer coefficient increased by up to 8% at 0.3 percentage volume concentration. Based on scale analysis and numerical solutions, they proposed that the fluttering of velocity profile due to particle migration induced by Brownian diffusion and Thermophoresis is a possible mechanism of convective heat transfer enhancement. In 2010, Fotukian and Nasr Elfahany [4] reported considerable enhancement heat transfer coefficient inside a horizontal pipe with CuO-water nanofluid.

2. EXPERIMENTAL ANALYSIS

The aim of this paper is to study nanofluids and their enhancement in the convective heat transfer characteristics over the base fluid experimentally. In this study nanofluid of Titanium dioxide-water nanofluid at various small particle volume fractions are prepared.

3. PREPARATION OF NANOFLUID

Preparation of nanofluid is the first key step in experimental studies with nanofluids. Nanofluids are not simply liquid solid mixtures. They must satisfy some special requirements such as stable and uniform suspension, negligible agglomeration of particles, no chemical change of fluid etc.

A measured volume of TiO₂ nanoparticles is added into the beaker containing measured volume of distilled water.

Mass of nanopowder added, mp

$$\phi = \frac{m_p / \rho_p}{m_p / \rho_p + m_f / \rho_f} \quad (1)$$

The volume fraction is determined as the ratio of the volume of the nanoparticles to the total volume, where the total volume is the sum of the volume of the carrier fluid and the volume of nanoparticles.

The beaker is placed in a controlled chamber where it is agitated for 4-5 hours using ultrasonic agitator. The purposes of the agitation are breakdown or de-agglomerate clustered nanoparticles, facilitate even particle distribution, minimize nanoparticle sediment that may settle after a length of time. The nanoparticles remains suspended for a period of 1-2 hours, after which settling begins to occur. TiO₂-distilled water nanofluid samples of 0.1%, 0.2%, and 0.3% particle volume fractions of nanoparticles was prepared for performing experiments.

Enough precautions are taken while handling nanopowders. Masks and gloves were used to avoid physical contact with nanopowder.

4.EXPERIMENTAL SETUP

Schematic of Experimental setup is shown in Figure 1. Several T type thermocouples are placed along the test section to measure temperature.

The reservoir is filled with required sample fluid. Pump is started and the valves are adjusted to the required flow rate. Heater is switched on and the autotransformer is set to the required voltage. Proper cooling water circulation is maintained at the cooler to get a constant inlet temperature. Temperatures, the rate of flow and power input are noted. Final readings are taken at steady state condition. The procedure is repeated with another flow velocity by adjusting the control valve. Experiments are conducted using water and TiO₂-water nanofluids at various volume Fractions (0.1, 0.2 and 0.3 %).

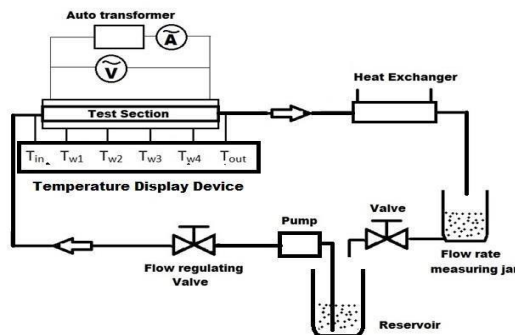


FIGURE 1. SCHEMATIC OF EXPERIMENTAL SETUP



FIGURE 2. PHOTOGRAPH OF EXPERIMENTAL SETUP

The following assumptions are made while doing experiments.

- The Experiment is conducted at fully developed turbulent flow regime. Entrance length is calculated and test section is selected after entrance length.
- The Test section is assumed to be of constant heat flux type. Nichrome wire heating element is uniformly wound over the test section.
- Negligible heat loss is considered in the radial and lateral directions. The heat leak to the surrounding is prevented by providing asbestos insulation over heated test section.
- Measurements were taken after steady state conditions are ensured.

4.1 Validation of Experimental Setup

$$Nu_D = \frac{(f/8)(Re_D - 1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}$$

The experimental setup is validated with distilled water as the working fluid. For this the values of Reynolds number and Nusselt number are calculated from the experimental data. It was seen that the experimental values are having a good agreement with the well-known Gnielinski correlation for turbulent flow of a fluid flowing through a tube.

5.RESULTS AND DISCUSSION

The experiments on the convective heat transfer coefficients are done with distilled water and TiO₂ water nanofluid at different Percentage volume fractions (0.1%, 0.2% and 0.3%). Convective heat transfer coefficients for different samples are calculated using the Experimental readings at different flow velocities. The volume flow rates are maintained to obtain a hydrodynamically fully developed turbulent flow in the test section. The results well establishes an enhancement in the convective heat transfer characteristics of the nanofluid compared to the base fluid. Also there is an enhancement in the heat transfer properties with particle volume fraction up to the 0.3% particle volume fraction.

An empirical relation to relate the non-dimensional Nusselt number with Reynolds Number and Prandtl Number, with in the turbulent region from Reynolds number 4500 to 9000 and for the particle volume fraction up to 0.3 % is suggested. The results are discussed below.

5.1 Convective heat transfer coefficient

Convective heat transfer coefficients are calculated for different volume flow rates and different particle volume fractions. Figure 3 shows variation of convective heat transfer coefficient with Reynolds number for distilled water and different percentage particle volume fractions of the TiO₂-water nanofluid. It is evident that there is an enhancement in the heat transfer coefficient with respect to the flow velocity for all the samples compared to water. As the flow Reynolds number increases the value of convective heat transfer coefficient increases for first two concentrations and decreases for the third concentration. This may be due to the fact that at higher concentrations, nanoparticles start settling down. The increase in convective heat transfer coefficient with increase in Reynolds number is because of the increase in the flow velocity causes an enhancement in the motion of the dispersed nanoparticles and in turn the heat transfer. It is also seen that as the particle volume fraction of the nanofluid increases, there is an enhancement in the convective heat transfer coefficient. This may be due to the more inter-particle collisions and enhanced surface area of heat transfer, with the increased particle volume fractions.

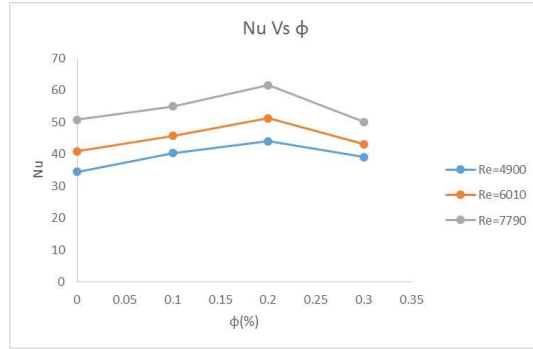


FIGURE 3. NUSSELT NUMBER VS PARTICLE VOLUME CONCENTRATION.

Figure 4 shows the enhancement ratio ie, ratio of the convective heat transfer coefficient of the nanofluid to that of the base fluid at different volume fractions. It is seen that the enhancement ratio increases with increase in the flow velocity or Reynolds number. It is also evident that the Enhancement ratio increase with the increase in particle volume concentration. A maximum of 28% increase in the convective heat transfer coefficient is achieved over the base fluid with a particle volume fraction of 0.2% at a Reynolds number equals to 7790.

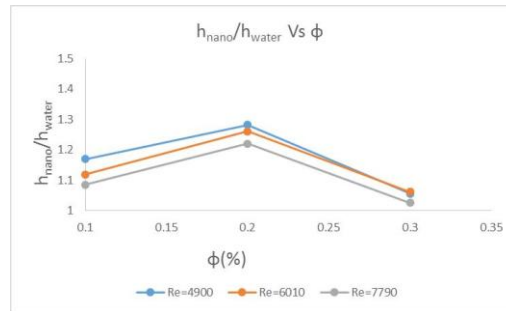


FIGURE 4. RATIO OF CONVECTIVE HEAT TRANSFER COEFFICIENT OF NANOFLUID TO THE BASE FLUID

5.2 Nusselt number

The non-dimensional Nusselt number is calculated from the experimental results and is plotted against the Reynolds numbers. It is seen that as the value of the Nusselt number increases with increase in the Reynolds Number. Figure 6 shows the variation of Nusselt Number for distilled water and nanofluid samples at various Reynolds Numbers.

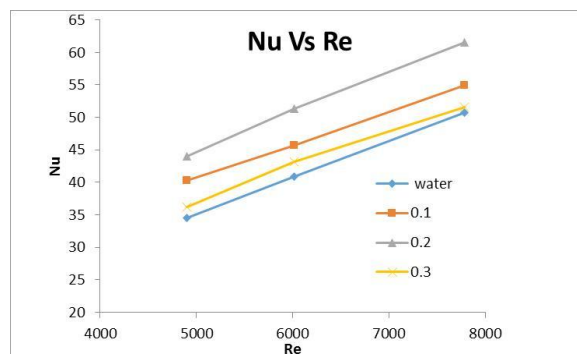


FIGURE 5. NUSSELT NUMBER VS REYNOLDS NUMBER FOR DISTILLED WATER AND NANOFLUIDS.

5.3 Empirical Correlation

The common empirical relations used with the two phase liquids are not suitable to predict the convective heat transfer behaviour of the nanofluids. In the present study an empirical correlation is suggested to relate the Nusselt Number, Reynolds number and Prandtl number for TiO₂-water nanofluid in the range of $4500 < Re < 10000$ at a particle volume fraction up to 0.2 %. The new suggested correlation is,

$$Nu_{nf} = 0.0256 Re_{nf}^{0.8} Pr_{nf}^{0.4} \quad (3)$$

6. CONCLUSION

In the present work experimental studies on the enhancement of the convective heat transfer characteristics of nanofluids are carried out in the beginning of turbulent flow regime. It was found that there is an increase in the convective heat transfer when TiO₂-water nanofluids are used instead of distilled water.

This enhancement increases with increase in the flow velocity and particle volume fraction. But as the concentration of nanoparticle increases beyond a particular limit will have no significant increase in convective heat transfer coefficient due to the settling of nanoparticles. It is found that there is a maximum increase of 28% in the value of convective heat transfer coefficient compared to the base fluid, with TiO₂-water nanofluid of small particle volume fraction of 0.2%. Along with the enhanced effective thermal conductivity and viscosity of the nanofluids, the migration and the random movement of nanoparticles and the resulting disturbance of the boundary layer may be the reasons for such an increase in the heat transfer coefficients of nanofluids. Other possible reasons may be thermal dispersion, Brownian diffusion, particle- particle collisions, thermophoresis and enhanced surface area of heat transfer.

The use of nanofluids seems to be a promising solution toward designing of efficient heat exchanging systems. The high thermal properties of nanofluids translate into higher energy efficiency, better performance, and lower operating costs. They can reduce energy consumption for pumping heat transfer fluids. Miniaturized systems require smaller inventories of fluids where nanofluids can be used. The much larger relative surface areas of nanoparticles compared to micro-particles, provide significantly improved heat transfer capabilities.

The only drawbacks so far for the extensive use of nanofluids are their higher price of nano particles and possible instability of suspension.

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