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Characteristics Assessment of Titania/Water Nanofluid in Circular Channel

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Abstract: Different properties of titania/water nanofluid namely as density, viscousity and pressure in a cicular channel have been investigated in this paper. The assessments were carried out for both laminar and turbulent flows at different tempratures viz. 10, 20, 30 and 40°C. Different weight percentages of nano TiO_2 with particle size of 20±5 as 0, 0.5, 1 and 1.5 wt% were also used to prepare the nanofluid. The results obtained in this study showed that TiO_2 /water nanofluid density and viscousity decrease by temperature rise, however the pressure drop increases by temperature rise. The proportional increase in pressure drop for turbulent flow is lower than that for laminar flow.

Key words: Density · Viscousity · TiO_2 nanofluid · Pressure drop

INTRODUCTION

Along with decreasing of electronic components dimensions and increasing of heat generation by these devices, the problem of removing heat from them and achieving a successful design for maximum cooling has become drastically important. Then, in order to overcome the challenge of keeping electronic equipment at their best performance, finding new ways of thermal load managing and performing optimization processes is inevitable. Incapability of conventional fluids such as water in critical heat flux situations was compensated with the creation of ‘‘Nanofluid’’ conception. The inno-vative idea of adding metallic and non-metallic nanopowders to a base fluid was proposed first by Choi [1], showing a number of potential advantages, such as increase in heat transfer and reduction of heat transfer system size. Khanafer *et al*. [2] investigated the heat transfer improvement in a 2D enclosure utilizing nanofluids for a range of volume fractions and Grashof numbers. It was found that the heat transfer across the enclosure increases with enhancement of the volumetric fraction of the copper nanoparticles in water for all given Grashof numbers. Later, Kim *et al*. [3] assessed the pool boiling characteristics of dilute dispersions of Al_2O_3, ZrO_2 and SiO_2 nanoparticles in water. Their study showed that a significant improvement in critical heat flux can be achieved even in the lowest nano-particle concentration. Ho *et al*. [4] studied the effects of uncertainties due to adopting different formulas for the effective thermal conductivity and dynamic viscosity of alumina/water nanofluid on the heat transfer characteristics and found that heat transfer efficacy of nanofluid can strongly be dependent on how the dynamic viscosity is estimated. More recently, investigation of heat transfer enhancement with use of TiO_2 -water nanofluid filled in a rectangular enclosure heated from below was carried out by Wen and Ding [5]. Research conducted by Vasu *et al*. [6, 7] resulted in a series of thermophysical correlations to calculate thermal conductivity, viscosity and Nusselt number in both turbulent and laminar flows of different nanofluids (Al_2O_3 + H_2O, Cu + H_2O, etc.) and it was concluded that these fluids possess higher thermal properties relative to their pure base fluids. Mohammed *et al*. [8, 9] investigated the effect of using a wide range of different nanofluids on heat transfer and laminar fluid flow characteristics in microchannel heat sinks with various shapes using FVM. They demonstrated that an increase in volume fraction does not necessarily increase the heat transfer coefficient. Gunnasegaran *et al*. [10] presented a comprehensive

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analysis of roughness effect and regions that the high and low temperatures occur in a microchannel heat sink. Numerous other theoretical and experimental studies were conducted by different researches [11-14] using nanofluids and they have shown that these new class of coolants can be considered as a promising replacement for conventional coolants.

All analytical and numerical studies pursue a much more important goal than just to report a single analysis of fluid flow and heat transfer characteristics: optimization. In order to design an efficient heat sink which is the objective of multiple studies, simulation of heat and fluid flow in the device is required. Knight *et al*. [15, 16] tried to optimize heat sink in both laminar and turbulent flow regimes. It was shown that in small pressure drops, laminar flow will be the main flow regime leading to lowest thermal resistance. On the other hand, when the pressure drop is high, the optimal resistance is found in the turbulent region. Some other works concerning optimization of heat sinks can be found in literature [17-23].

MATERIALS AND METHODS

Preparation of Nanofluid: The TiO_2/water nanofluid produced from a direct synthesis method was used as an experimental sample and mechanical agitations were used for dispersing the nanoparticles into three weight fractions (0.5, 1.0, 1.5 wt%). The solid volume was determined by calculating the equivalent weight of the solid based on its true density (approximately 3840 kg/m^3). The nanoparticles, purchased from Yong-Zhen Technomaterial Co. Ltd. generally form loose agglomerates as shown in Fig. 1.

Fig. 2, the TEM photograph of TiO_2 nanoparticles with nominal particle sizes of 20±5 nm, shows that the shapes of nanoparticles are mainly rectangular and the particle size closely meets the nominal particle size of the supplier.

Fig. 3 shows the XRD pattern of TiO_2 nanoparticles, confirming the main component to be anatase. The nanoparticles can be successfully dispersed in deionized water using a homogenizer with electromagnetic agitation and ultrasonic vibration, to form a TiO_2 /water nanofluid without addition of any dispersant or surfactant.

Experimental Method: Fig. 4 shows this experiment used a thermostatic bath (Firsteck B403L) to stabilize the temperature of the sample until it reached the expected temperature of ±0.5°C. A density meter and a rheometer

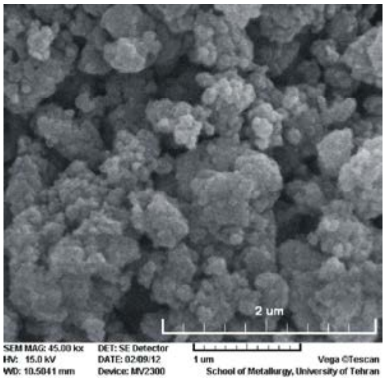

Fig. 1: SEM image of TiO2 nanoparticles.

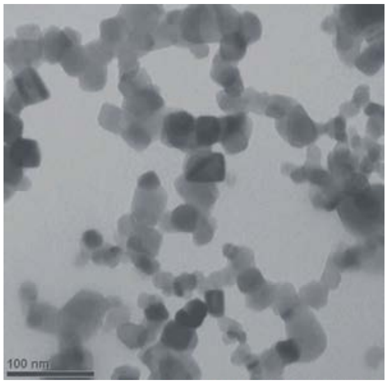

Fig. 2: TEM image of TiO2 nanoparticles.

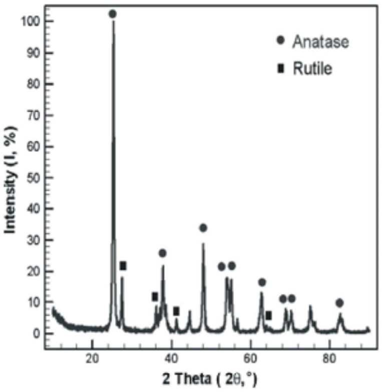

Fig. 3.: XRD spectrum of TiO2 nanoparticles.

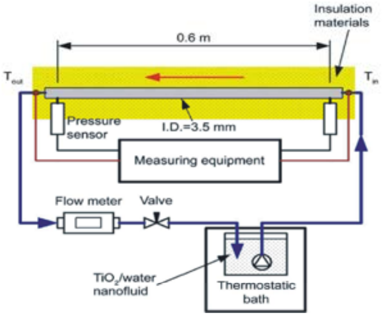

Fig. 4: Experimental setup for measuring pressure drop.

were then used to measure the density and viscosity of the nanofluids of various weight fractions and sample temperatures. In pressure drop experiments in a circular pipe, after 1800 cm^3 of nanofluid was poured into a 2-l stainless steel bucket and the bucket was placed in a thermostatic bath, the nanofluid was pumped to the measurement pipe for circulation. The pressure drop of nanofluid in the pipe was measured. The test pipe consisted of a circular steel tube (å=4.6×10^{-5} m) with the length (L) of 0.6 m and the internal diameter (d) of 0.0035 m. To avoid entrance effect, L/d >>100 was considered for the circular tube. To avoid drastic temperature change, the pipe was wrapped by thermal insulation material at a thickness of 2 cm. Nanofluid flow rate was controlled at a region between turbulent and laminar flow. The temperature of the sample was stabilized at ±0.5 °C of the expected value. The pressure was then measured of the nanofluid of various weight fractions and sample temperatures were taken at the inlet and outlet of the pipe. To guarantee accuracy, all controlled factors were measured ten times and the most concentrated five test results were selected as average values of the experimental results.

RESULTS AND DISCUSSION

The Fig. 5 shows the measured results of the weight fractions of TiO_2 /water nanofluid with the change of density under different temperatures. The increase in added concentration enhances the density of nanofluid, whereas temperature rise reduces the density of nanofluid. The influence of weight fractions on density change appears to be approximately linear. However, the density presented a non-linear trend under different temperatures; the main reason is that the added nanoparticles and bulk liquid have a great difference in the coefficient of thermal expansion.

Fig. 6 shows the measured effect of the weight fractions of TiO_2 /water nanofluid on the change of viscosity under different temperatures. Temperature rise reduces the viscosity of nanofluid, whereas increased weight fraction increases the viscosity of nanofluid and for the different temperatures, the effect of weight fraction on viscosity appears nearly linear.

Fig. 7 shows the enhancement ratio of pressure drop by increasing the solids content of the TiO_2 /water nanofluid. For solids content of 0-1.5 wt% and temperature of 10-40°C, the enhancement ratio of pressure drop is 25.0-63.3 and 5.7-15.3% for laminar and turbulent flow, respectively, the enhancement ratio of pressure drop being larger for laminar flow than for turbulent flow. The results compare well with literature data [24-26].

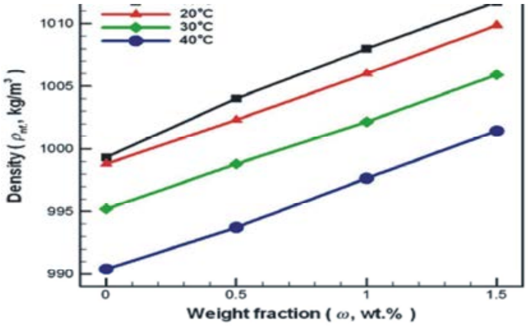

Fig. 5: Experimental results of density measurement.

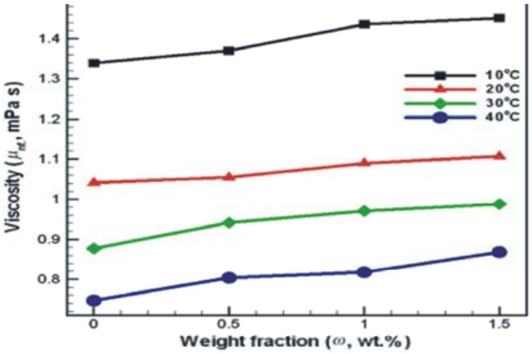

Fig. 6: Experimental results of viscosity measurement.

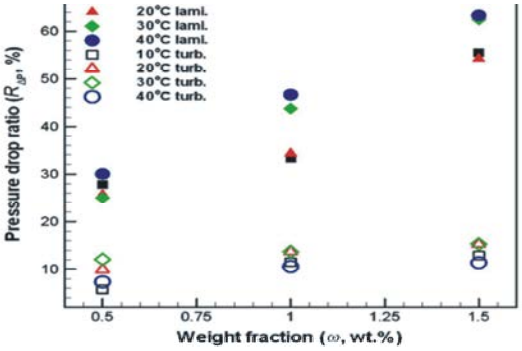

Fig. 7: Enhancement ratio of experimental data of pressure drop.

CONCLUSIONS

The following 3 main concluding remarks can be drawn from this study:

- Increase in solids content of the nanofluid as 0, 0.5, 1 and 1.5 wt% enhanced both its density and viscosity.

- Temperature rise from 10 up to 40°C in this study reduced both the density and viscosity of the nanofluid.
- Enhancement of pressure drop for a nanofluid is lower under turbulent flow in a circular pipe, but higher under laminar flow condition, thus helping to reduce the delivery loss of pumping.

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