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Research Article

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Experimental Investigation of Forced Convection of Al_2O_3 Nanofluid through a Circular Pipe

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Abstract In the present paper, experimental study is performed to investigate convective heat transfer of nanofluids through a circular tube. The Nusselt number of the Al2O3–water nanofluid flowing through a pipe of 2 mm, 4, mm, 6 mm, and 8 mm inner ID and 1 m in length. Experiments are conducted with 50 nm size Al_2O_3 nanoparticle with a volume fraction between 0.1 %, 0.2 %, and 0.3 % and Reynolds number between 2500 and 12500. Experimental results emphasize the heat transfer enhancement with the increase in a Reynolds number or nanoparticle volume fraction. Experimental measurement also shows the considerable increase in the Nusselt number with high nanofluid concentration of base fluid.

Keywords Nusset Number, Nanfluid, Al_2O_3, Circular Pipe

1. Introduction

In the recent years, the research on using heat transfer enhancement methods to achieve high performance has received great attention. Many investigations have been performed on the heat transfer enhancement methods by researchers [1, 2, 3]. A large number of the augmentation techniques have been classified by Bargles. In general, augmentation techniques can be classified as three methods: active methods, passive methods and a combination of them [5, 6-10]. However, passive methods have wider application than active methods because they require no external power. Among these, vortex generators specially wings and winglets have received more attention since 1990. But, winglets have been successfully used for enhancement of heat transfer of modern thermal systems because they can generate intensive longitudinal vortices with less penalties of pressure drop [2].

S. Lee et al. [1] carried out comparisons between experiments work and the Hamilton and Crosser model for measuring the conductivity of Nano fluid. It shown that the model can predict the thermal conductivity of Nano fluids containing large agglomerated Al_2O_3 particles. However, the model appears to be inadequate for Nano fluids containing CuO particles. That suggests not only particle shape but size was considered to be dominant in enhancing the thermal conductivity of Nano fluids.

Dongsheng Wen et al. [2] studied experimentally the convective heat transfer of Nano fluids, made of γ-Al_2O_3 nanoparticles and de-ionized water, flowing through a copper tube in the laminar flow regime. The results showed an enhancement of convective heat transfer using the Nano fluids. The enhancement was particularly significant in the entrance region, and was much higher than that solely due to the enhancement on thermal conduction. Also the classical Shah equation failed to predict the heat transfer behavior of Nano fluids.

S. Zeinali Heris et al. [3] investigated experimentally Nano fluids containing CuO and Al_2O_3 oxide nanoparticles in water as base fluid in different concentrations produced for the laminar flow convective heat transfer through circular tube with constant wall temperature boundary condition. The results emphasize that the single phase correlation with Nano fluids properties was not able to predict heat transfer coefficient enhancement of Nano fluids. The comparison between CuO/ water and Al_2O_3 / water Nano fluids indicates that heat transfer coefficient ratios for Nano fluid to homogeneous model in low concentration were close to each other but by increasing the volume fraction, higher heat transfer enhancement for Al_2O_3 / water can be observed. Salma Halelfadl et al. [9] carried out an experimental investigation to evaluate the thermal resistance and the pumping power in micro channel under laminar flow using aqueous carbon nanotubes based Nano fluid as coolant with weight concentration 0.01%. Also, an analytical approach of optimization scheme was applied. The results shown that use of the Nano fluid as a working fluid reduce the total thermal resistance and enhance significantly the thermal performances of the working fluid at high temperatures.

C.J. Ho et al. [10] investigated experimentally the exploration of the forced convective heat transfer performance by using Al_2O_3/water Nano fluid to replace the pure water as the coolant in a copper mini channel heat sink, with the Reynolds number ranging from 133 to 1515. The results found that the Nano fluid cooled heat sink had significantly higher average heat transfer coefficients and hence outperforms the water cooled heat sink. Meanwhile, the heat transfer efficacy of using the Nano fluid in the heat sink was further evaluated against the accompanied pumping power penalty.

This paper carried out to investigate the effect of nanoparticles (Al_2O_3) (50 nm) concentration on heat transfer through a circular pipe. Four inner diameters are used in this study (2 mm, 4 mm, 6 mm, and 8 mm), three nanofluid consternation (0.1 %, 0.2 %, and 0.3 %) was used as a working fluid. The Reynolds number varied from 2500, 5000, 7500, 10000, and 12500.

2. Experimental Set-up

The experimental set-up used in this study is shown in figure 1, which consists of a heating unit, a cooling unit, a flow circulation unit, a control and the measurement unit. The test section made from aluminum pipe has thermocouples, heater tapes, and pressure gauges. The flow rates were measured with a rotameter flow meter. A pump, a flow meter, a tank, and a collecting tank are used in the flow circulation unit. For the data collection, a computer and a data acquisition card were used.

Flowmeters are used in fluid systems (liquid and gas) to indicate the rate of flow of the fluid. They can also control the rate of flow if they are equipped with a flow control valve.

Rotameters are a particular kind of flow meter based on the variable area principle. They provide a simple, precise and economical means of indicating flow rates in fluid systems. In operation, the rotameter is positioned vertically in the fluid system with the smallest diameter end of the tapered flow tube at the bottom. This is the fluid inlet. The float, typically spherical, is located inside the flow tube, and is engineered so that its diameter is nearly identical to the flow tube's inlet diameter. When fluid gas or liquid is introduced into the tube, the float is lifted from its initial position at the inlet, allowing the fluid to pass between it and the tube wall. As the float rises, more and more fluid flows by the float because the tapered tube's diameter is increasing.

A centrifugal pump with capacity 0.45 hp a centrifugal pump converts rotating mechanical energy to energy within the liquid being pumped as shown in figure 3. The liquid enters through a suction connection concentric with the axis of the impeller which rotates at high speed. Impeller has vanes in radial direction.

There are valves to control of flow rate which pass through tubes and the number of the valves equal 13.

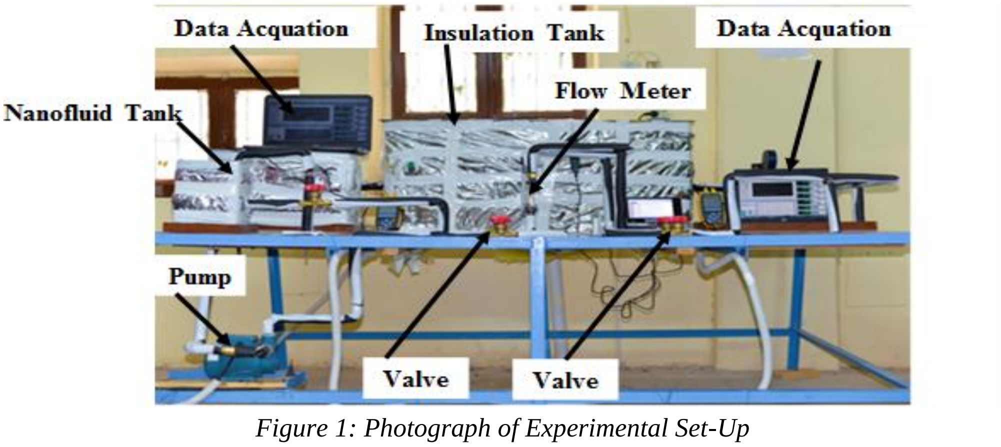

Figure 1: Photograph of Experimental Set-Up

3. Data Reduction

In the present study, Degussa AL2O3 nanoparticles 50 nm in size are dispersed in water with a 0.2 vol.% concentration and are used to investigate the effects of different thermophysical property models on the prediction of the convective heat transfer coefficient of the nanofluid. The convective heat transfer coefficient of flowing nanofluid can be calculated from following equation.
The heat transfer rate from the heating fluid is defined as:

$$Q_w = m_w Cp_w (T_{in} - T_{out})_w \quad (1)$$

where Q_w is the heat transfer rate of the hot water and $\dot{m}_w$ is the mass flow rate of the hot water.
The heat transfer rate into the nanofluid is calculated from the following equation:

$$Q_{nf} = m_{nf} Cp_{nf} (T_{in} - T_{out})_{nf} \quad (2)$$

where Q_{nf} is the heat transfer rate of the nanofluid and ṁnf is the mass flow rate of the nanofluid.
The average heat transfer rate is defined as follows:

$$Q_{ave} = \frac{Q_w + Q_{nf}}{2} \quad (3)$$

where Qave is the average heat transfer rate between the hot water and the nanofluid.
The measure Nusselt number and heat transfer coefficient of the nanofluid are calculated from the following equations; respectively:

$$h_{nf} = \frac{q_{ave}}{T_{wall} - T_{nf}} \quad (4)$$

$$Nu_{nf} = \frac{h_{nf} D}{k_{nf}} \quad (5)$$

where h_{nf} is the heat transfer coefficient of the nanofluid, q_{ave} is the average heat flux between the hot water and the nanofluid, Twall is the average temperature of the wall, Tnf is the bulk temperature of the nanofluid, Nunf is the Nusselt number of the nanofluid, D is the inner diameter of the test tube and knf is the thermal conductivity of the nanofluid.

4. Results and Discussion

4.1. Effect of inner diameter on Nusselt number

Nusselt number which calculated by equation No. (5), uses to evaluated the amount of heat transfer rate in this study. The effect of inner diameter on Nusselt number with differences Reynolds number are shown in Fig. 2, Fig. 3, Fig. 4, and Fig. 5. It observed that, the Nusselt number is increases with increase of Reynolds number for all values of inner diameter. This result due to increase of fluid velocity consequently increase of turbulent intensity. In addition, the value of Nussellt number are increases gradually in Reynolds number region 2500 to 7500. From Reynolds number higher than 7500, the increase of Nusselt number is nearly linearly.
At low Reynolds number (Re = 2500), the value of Nusselt number is 6.5, 13, 19.4, and 25 for based water at inner diameter 2 mm, 4 mm, 6 mm, and 8 mm respectively. For case of high Reynolds number (Re = 12500) these values are increase to 26, 52, 78, and 104 at the same inner diameter. On the other hand the value of Nusselt number improvement by 50 % for high Reynolds number from inner diameter 2 mm to 4 mm fro case of based water.
Also, the for 0.1 % the value of Nusselt number is increases from 4 mm to 6 mm inner diameter by 32 %. For case of nanfluid concentration of 0.3 % the value of Nusselt number are improved by 22.5 %. The value of Nusselt number is high increment at high Reynolds number (Re = 12500) this increment is decreases to 21% for low Reynolds number (Re = 2500). Where the value of Nusslet number is 26, and 33 at low Reynolds number.

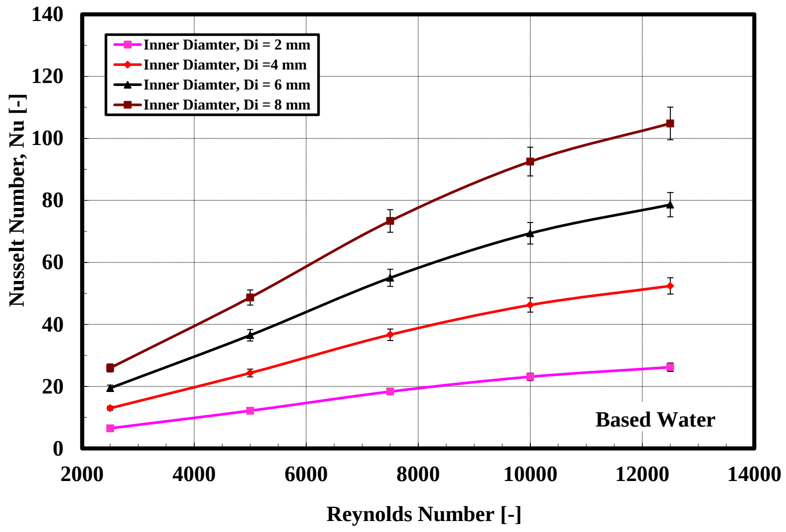

Figure 2: Nuasslet number distribution with differences inner diameter at based water

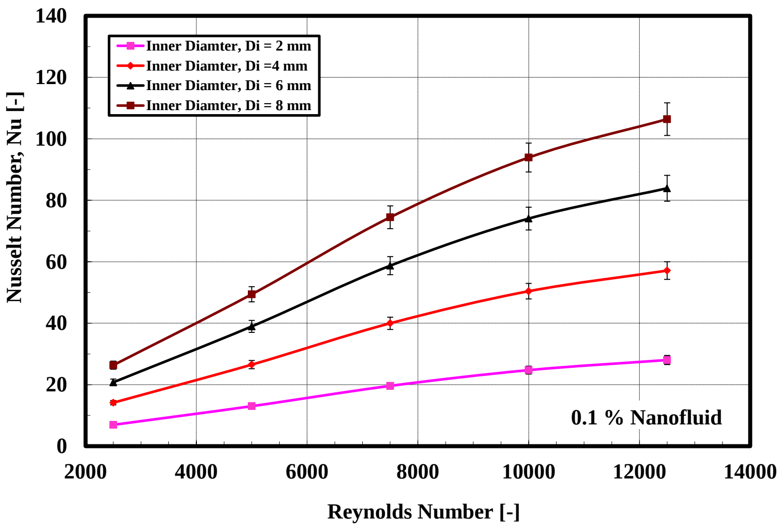

Figure 3: Nuasslet number distribution with differences inner diameter at 0.1 % nanofluid

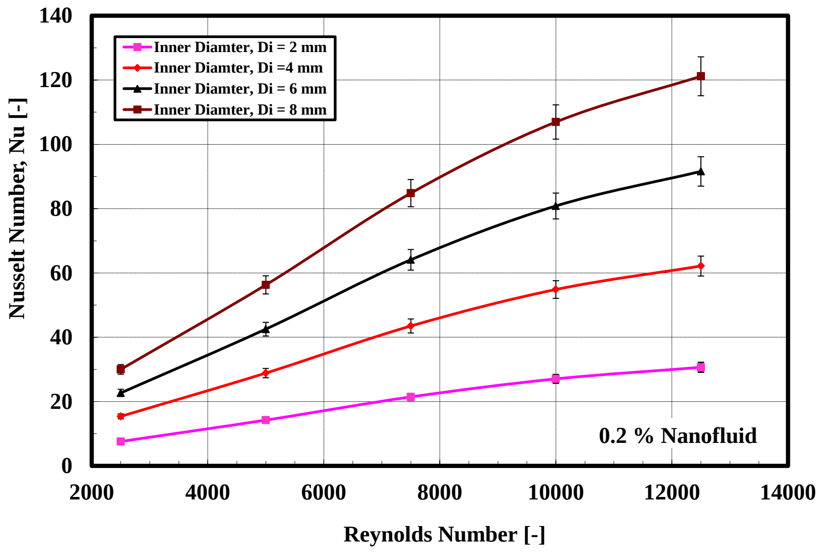

Figure 4: Nuasslet number distribution with differences inner diameter at 0.2 % nanofluid

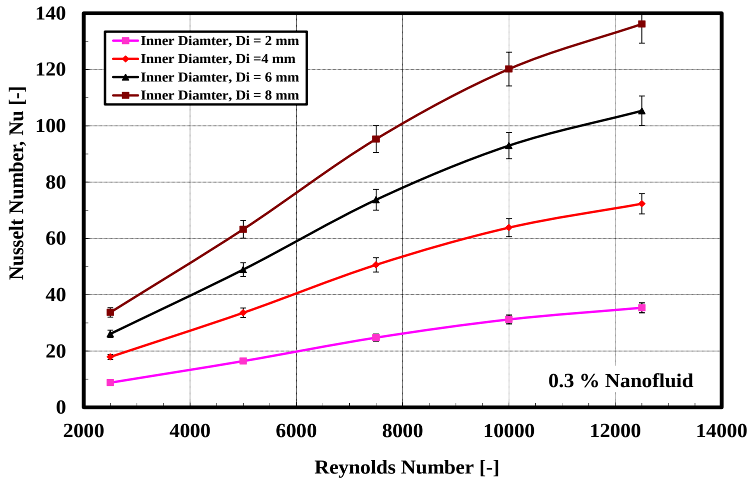

Figure 5: Nuasslet number distribution with differences inner diameter at 0.3 % nanofluid

4.2. Effect of nanfluid concentration Nusselt number

Nanofluid concentration is played important roles in heat transfer process. Therefore, this section explained the effect of nanofluid concentration on Nusselt number at differences inner diameter (d = 2 mm, 4 mm, 6 mm, and 8 mm). In this experimental work, Al2O3–water nanofluid with the loadings of 0.5%, 1%, 2% and 4% were used. The Reynolds number varied from 2500 to 12500.

The variation of the Nusselt number variations versus the Reynolds number is presented in Fig. 6, Fig. 7, Fig. 8, and Fig. 9 for all cases studied. It can be concluded that adding nanoparticles into pure water enhances heat transfer for the cases where the particle volume concentrations are lower than 0.2 vol.%. Up to the particle volume concentration of 0.1 vol.%, the Nusselt number increases with the increase of the Reynolds number as well as the particle volume concentration. The higher values of the particle volume concentration over 0.1 vol.% badly affect heat transfer.

The Nusselt number for volume fraction of 0.1 vol.% is higher than that of pure water and is smaller than that of 0.1 and 0.2 vol.%. Likewise, the Nusselt number for 0.3 vol.% is smaller than that of 0.2 vol.%. The Nusselt number of nanofluid is smaller than that of pure water for 0.3 vol.% at Reynolds numbers over 8000. The concentrations of Al2O3 particles in the base liquid higher than 0.1 vol.% are not suitable for heat transfer enhancement because the particles with higher concentrations than 0.1 vol.% enhance the thermal conductivity and viscosity. By the increase of the particle volume concentration, both thermal conductivity and viscosity continue to increase incrementally. To obtain higher heat transfer rates, high thermal conductivity is desirable. However, the increase of the viscosity intensifies viscous sublayer in which heat transfer is occurred by molecular motion. Therefore, the heat transfer performance decreases. The viscosity increase of the nanofluids was much more effective than the thermal conductivity of the nanofluids for the particle volume concentrations higher than 0.1 vol.% on heat transfer enhancement.

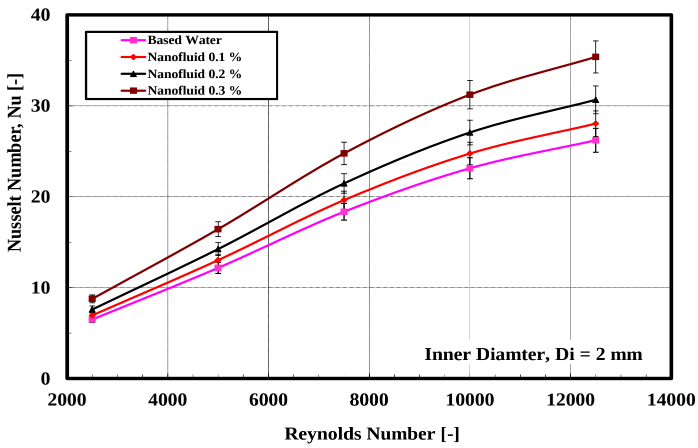

Figure 6: Nusselt number distribution with differences nanfluid at d = 2 mm

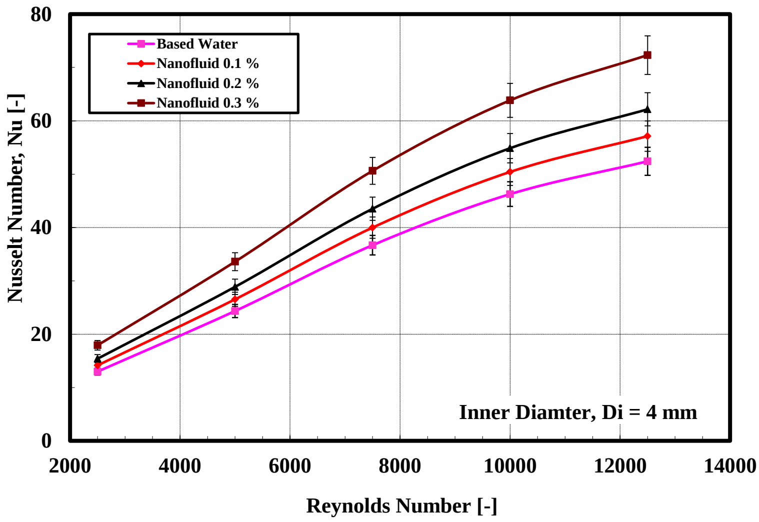

Figure 7: Nusselt number distribution with differences nanfluid at d = 4 mm

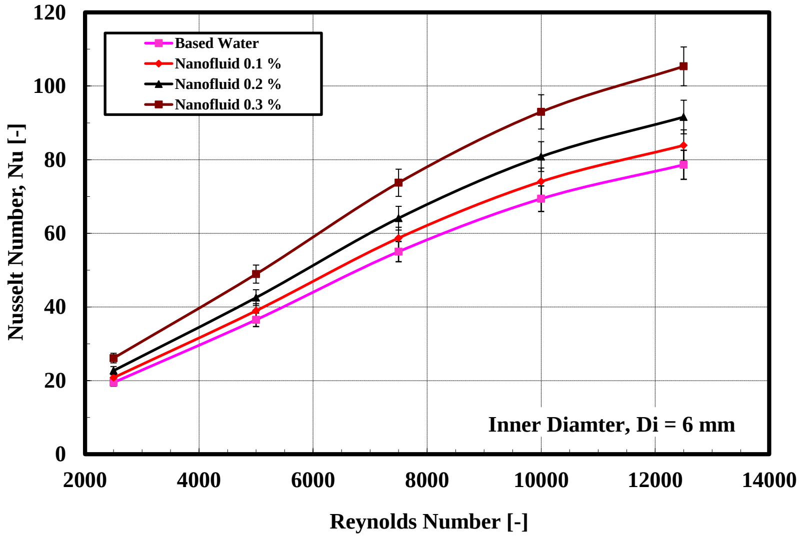

Figure 8: Nusselt number distribution with differences nanfluid at d = 6 mm

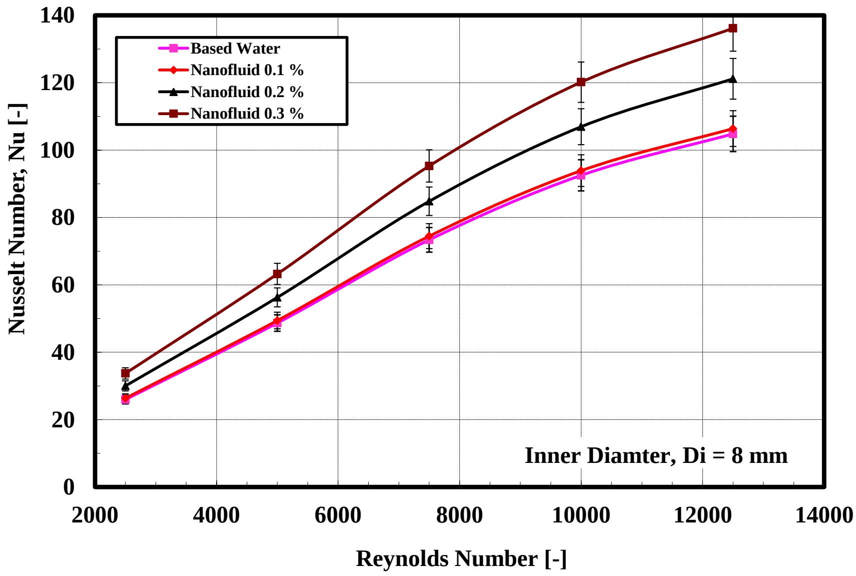

Figure 9: Nusselt number distribution with differences nanfluid at d = 8 mm

5. Conclusions

Experiments were performed to investigate the heat transfer of a Al_2O_3/Water nanofluid mixture containing alumina nanoparticles flowing in a circular pipes with differences inner diameter (2 mm, 4 mm, 6 mm, and 8 mm). The Reynolds number are barred from 2500 to 12500, also the nanofluid concentration are changed 0.1 %, 0.2 %, 0.3 %.

- Heat transfer and frication factor are influence by pipe geometry. Where heat transfer increase with increase inner diameter of pipe. While, the friction factor are also increase with increase on inner diameter of pipe.
- Nusselt number is enhancement with increase of Reynolds number, causes increases of turbulent intensity.
- At high nanofluid concentration (0.3 %) the improvement of heat transfer is increases to 77.1 % and 75.98 % for inner diameter of 2 mm and 4 mm respectively.
- The value of Nusselt number improvement by 50 % for high Reynolds number from inner diameter 2 mm to 4 mm fro case of based water.

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