STUDY OF HEAT AND MOMENTUM TRANSFER TO COLLOIDAL SUSPENSIONS IN ANNULAR CLOSED CONDUIT FLOW.

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FACULTY OF ENGINEERING
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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF MECHANICAL ENGINEERRING

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ORIGINAL LITERARY WORK DECLARATION

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Field of Study: Energy and Heat Transfer

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STUDY OF HEAT AND MOMENTUM TRANSFER TO COLLOIDAL SUSPENSIONS IN ANNULAR CLOSED CONDUIT FLOW.

ABSTRACT

With the advancement of science and the rapid growth of industries and the improved lifestyles of people, energy consumption has been increasing. Whereas the exploration of energy remained at a slower pace and the energy reservoirs are extinguishing at a faster rate. High energy consumption is also encouraging environmental pollution and global warming. Considering all these issues, scientists and engineers are desperately exploring highly efficient heat exchangers for the conservation of energy and minimize its losses. The present research has focused on obtaining highly efficient heat exchangers. Lots of research have performed on the improvement of heat exchanger materials, alteration of process parameters, and enhancement of surface areas but there are limited works on exploration and use of high thermal performance heat exchanger liquids. The present research was focused on the synthesis and application of high thermal performance nanofluid for efficient heat exchangers of circular concentric annular flow passage configuration. Aluminium oxide nanoparticle-based suspension fluids of low concentrations (0.025 to 0.1 vol. %) were prepared using probe sonicator and applied in the annular heat exchanger for heat transfer and friction loss analyses. No additives were selected to ensure the environmental protection. There were 3.4 to 17% enhancement in heat transfer coefficient over water alone in the Reynolds number range of 2.4 to 4.8×10^3. As the annular flow passage in heat transfer applications is common, so the present findings will provide some information to the researchers and support in the design of more efficient heat exchangers.

Keywords: Heat Exchangers, Heat transfer coefficient, Nusselt Number, Nanofluid.

ABSTRAK

Dengan kemajuan sains dan pertumbuhan industri yang pesat dan gaya hidup manusia yang semakin maju, penggunaan tenaga semakin tinggi. Manakala penerokaan tenaga tetap pada kadar yang lebih perlahan dan takungan tenaga padam pada kadar yang lebih cepat. Penggunaan tenaga yang tinggi juga mendorong pencemaran alam sekitar dan pemanasan global. Dengan mempertimbangkan semua masalah ini, para saintis dan jurutera dengan tekun meneroka penukar haba yang sangat efisien untuk penjimatan tenaga dan mengurangkan kerugiannya. Penyelidikan ini telah menumpukan dalam mendapatkan penukar haba yang mempunyai kecekapan yang tinggi. Banyak penyelidikan telah dilakukan mengenai peningkatan bahan penukar haba, perubahan parameter proses, dan peningkatan luas permukaan tetapi ada pekerjaan yang terbatas untuk penerokaan dan penggunaan cecair penukar haba berprestasi tinggi. Penyelidikan ini difokuskan pada sintesis dan penggunaan nanofluid berprestasi terma tinggi untuk penukar haba yang cekap dari konfigurasi laluan aliran anulus sepusat bulat. Cecair penggantungan berasaskan nanopartikel aluminium oksida dengan kepekatan rendah (0,025 hingga 0,1 vol.%) Disediakan menggunakan sonicator probe dan digunakan dalam penukar haba anulus untuk pemindahan haba dan analisis kehilangan geseran. Tidak ada bahan tambahan yang dipilih untuk memastikan perlindungan alam sekitar. Terdapat peningkatan 3.4 hingga 17% dalam pekali pemindahan haba berbanding air sahaja dalam bilangan bilangan Reynolds dari 2.4 hingga 4.8×10^3. Oleh kerana jalan aliran anulus dalam aplikasi pemindahan haba adalah biasa, maka penemuan ini akan memberikan beberapa maklumat kepada penyelidik dan sokongan dalam reka bentuk penukar haba yang lebih cekap.

Kata kunci: Penukar haba, pekali pemindahan haba, Nusselt Number, Nanofluid.

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LIST OF SYMBOLS AND ABBREVIATIONS

DPT	:	Differential Pressure Transmitter
Al_2O_3	:	Aluminium Oxide
h	:	Heat transfer coefficient, W/m2 K
k	:	Thermal conductivity, W/m K
Nu	:	Nusselt number
q	:	Heat flux, W/m^2

CHAPTER 1: INTRODUCTION

Heat transfer improvement in today's world is an interesting topic that has been widely practiced and worked on by many scientists and students as it helps in improvement of performance for various heat transfer applications in the various industries like heating ventilation and air conditioning (HVAC), automotive, aerospace and power plants. These industries are using nanofluid and nanoparticles to improve heat transfer characteristics, due to the fact that these particles don't have the clogging, erosion and noticeable sedimentation in pipes during the flow. Furthermore, these particles have high thermal conductivity compared to other types of conventional base fluids. The heat transfer application also varies depending on various factors like weight and size.

1.1 Working Fluid

The working fluid also called as base fluid used inside the heat exchangers is water, oil and ethylene glycol. These fluids have a lot of advantages in regards to disposing, recycling, easy to handle, cost effective, low vapor and viscosity resulting in less friction flow inside the tubes. While they may have their advantages there are some disadvantages like low thermal properties. To increase the thermal conductivity, the introduction of the new type of fluids were introduced called as nanofluids.

Nanofluids are high thermal conductivity fluids which are made up of nano particles, which are sized in the nanometer range and are used suspended inside as a colloidal suspension. The nanoparticles used are in less quantity and less concentration which help in the smooth flow of the nanofluids inside the pipe of a heat exchanger, unlike the micrometer and millimeter range particles which tend to cause clogging, abrasion and high pressure drop inside the pipes.

In this study, we used Al_2O_3 nanofluid to perform our tests and improve the efficiency of the heat exchanger. This overall helps in increasing the heat transfer rate.

1.2 Heat Exchanger

Heat exchangers are special type of devices which help in transfer of heat by using different fluids of high thermal conductivity away from the high temperature region. This device helps in reducing the heat generated by a system and helps in increasing the efficiency of a system as a whole. The emergence of heat exchangers have helped the scientists to design and develop new machines and systems which were not possible before, as the heat generated by the system would affect the surroundings and had low overall efficiency especially in thermal power plants, milk industry, and HVAC (Heating, Ventilation and Air Conditioning) related industries.

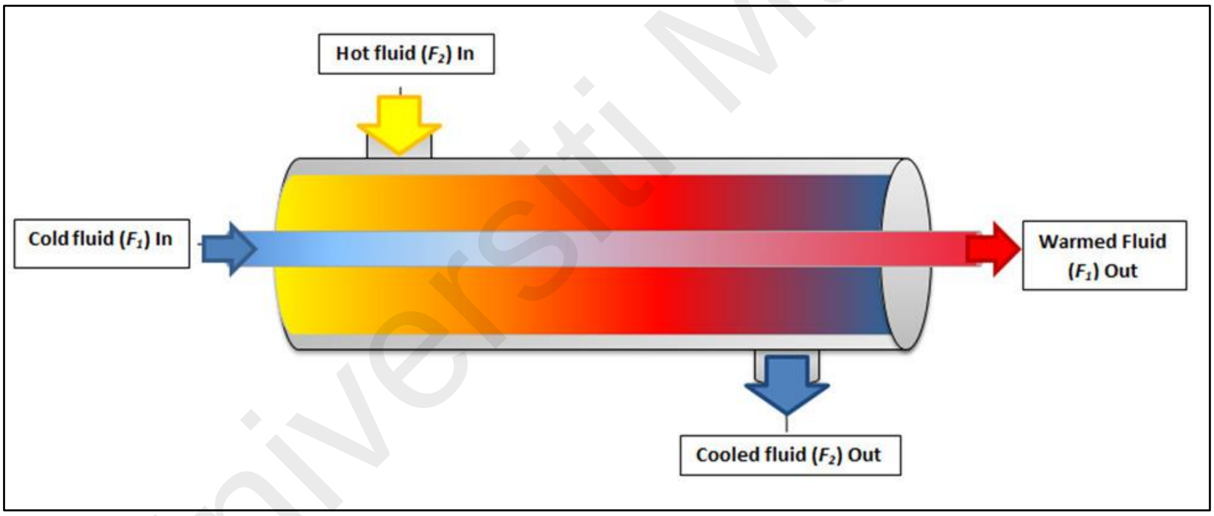


Figure 1. 1: Simple schematic diagram of a heat exchanger

With ever increasing demand for energy, heat exchangers can help us in reducing power usage and reduce the carbon footprint. The followings are the ways in which heat exchangers can benefit us:

1. Effective reduction of heat from the surrounding areas.
2. Increase the efficiency of the system.

3. Reduce carbon emission, as the system uses less fuel.

Even though the heat exchangers provide us with a lot of benefits to many industries, the constant quest for more efficient systems has made scientists to develop new heat exchangers with the following objectives:

1. Reduce the time required to remove heat from the system.
2. Use of new materials which help in effective heat transfer.
3. Lower the cost of the heat exchangers.
4. Increase the overall efficiency and energy usage.

1.3 Turbulent Flow

Turbulent flow is chaotic or irregular movement of particles in a fluid, this is different than laminar flow where the particles travel in a straight path. Turbulent flow is measured by its Reynolds number and it's above 4000. The abnormal flow of fluids results in higher velocities, which in turn helps in high heat removal rate.

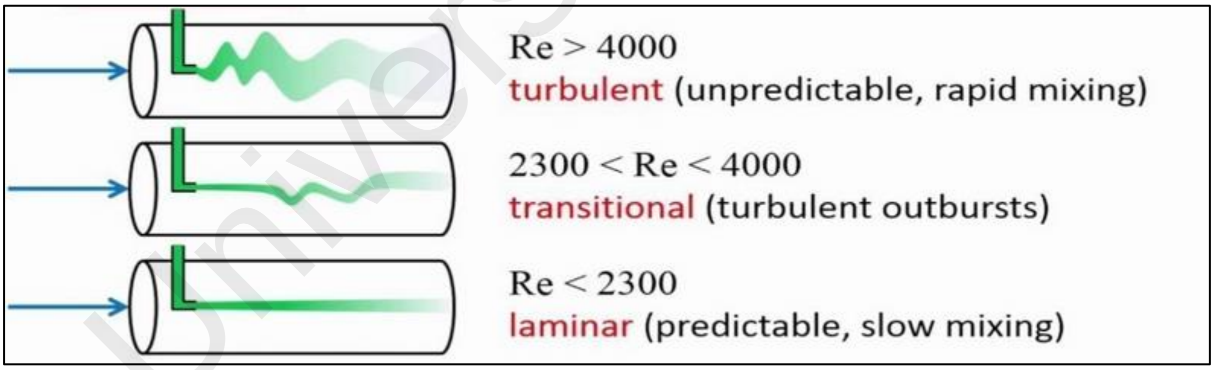


Figure 1. 2: Types of Flow and its Reynolds number.

1.4 Simulation

For the simulation, we will be using Computational Fluid Dynamics (CFD) to compare the experimental and the numerical studies. ANSYS Fluent is used for the numerical analysis to create the mathematical model. The created mathematical model was the actual representation of the rig on which the experimental study was performed. The results obtained from the simulation was compared with graphical and experimental data. The thermo-physical properties of the nanofluids used were calculated using the analytical formulas.

1.5 Experimental

The experimental study was done by a set-up made in University of Malaya, CFD Lab. The working fluid used in this study was Al_2O_3 nanofluid. In this experiment, the nanofluid passes through the annular space of the pipe. The inner diameter of the pipe is 0.037 m and the outer diameter is 0.04 m. The surface of the pipe was subjected to heat flux generated by using tape heater wrapped along the surface of the pipe.

1.6 Problem statement:

Under the global energy crisis and environmental degradation issues efficient energy transportation will save energy losses and consumption of energy. Thus, it needs to explore highly efficient heat exchangers. Sufficient works on different aspects of heat exchanger performance enhancement has been done but there is lack of investigation on heat transfer liquid improvement. Present research will focus on means to enhance thermal performance of heat exchanger liquids. Nanofluids will be used as heat transfer liquids in heat exchangers. The nanoparticles will be covalent and non-covalent functionalized by eco-friendly means to retard environmental impact and achieve high thermal performance. Metal and non-metal based nanofluids will be examined in annular passage heat exchangers for performance study in application.

1.7 Objectives:

Current research will perform the following tasks after intensive investigation on synthesis of eco-friendly heat exchanger nanofluids and test their performance in annular passage heat exchangers.

i. To synthesize functionalized carbon, metal oxides and hybrid nanofluids for applications in heat exchangers for the enhanced performance.
ii. To determine the correlation of heat transfer performance with particle characterization, concentration and momentum transfer etc.
iii. To simulate heat transfer and friction loss data with the variations of nanofluids and concentrations for comparison with the experimental observations.

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Review

Efficient use of energy is a major concern for the most industries and technologies in milk industries, chemical industries, thermal power plants etc. If the use of coolant has low thermal conductivity (water, propylene glycol, ethylene glycol and oil) then it can limit the effectiveness and applications of heat transfer. To overcome this problem, the need for a highly efficient heat transfer fluid is required. An innovative way to increase the thermal conductivity is to use solid particles which can be easily be dispersed within the base fluid [1]-(Ding et al., 2006). Nanofluids, are special type of solid-liquid based mixture containing material which are solid and in the nanometer range and it can be available in the form of particles, tubes, rods and fibers (Mohamoud et al.), these particles and materials provide us with a good solution of addressing the issue of low thermal conductivity of base fluids and help us in increasing the heat transfer rate and get high thermal conductivity of the conventional base fluid. The nanofluids show a remarkable improvement in terms of stability when we compare it with the various fluids in micrometer and millimeter range, as the nanoparticles are smaller and due to Brownian motion of the nanoparticles present in the liquids, it influences thermophysical characteristics of the suspension (Mohamoud et al.).

There are many types of nanoparticles available which are carbon-based nanomaterials and metal oxides like (aluminum oxide (Al_2O_3), Iron(III) oxide (Fe_2O_3), copper oxide(CuO) and silicon dioxide (SiO_2)) are being tested and used to develop new nanofluids and improve the thermal conductivity. With the research done in this field, it was found that carbon based nanofluids were showing great improvement in heat transfer and thermo-physical properties (Ding et al., 2006; Singh & Gupta, 2016; Zubir et al., 2015). Carbon nanostructures are carbon allotropes with at least one dimension in the nanometer range. Among different nanoparticles, carbon nanotubes (CNTs) in multi-walled, double or single types as one dimensional carbon nanostructures and graphene nanoplatelets (GNPs) as two dimensional carbon nanostructures have gained special interest caused by unique thermal, mechanical and electrical characteristics which make them suitable candidate for heat transfer issues (Fan, Zhang, & Liu, 2016).

Preparation of a homogeneous nanoparticle suspension is still imposing a handle for the researchers because the strong van der Waals interactions force between particles always is resulted in formation of aggregation. A Stable nanofluid is obtained by the application of some methods including chemical or physical treatment. In order to modify hydrophobic behaviour of nanomaterials and enable dispersion in an aqueous media, the propagating surface-active agents are loaded to the aqueous suspensions (Evans et al., 2008; Y Hwang et al., 2006; H. Zhu et al., 2007). Without any treatment, there will be clogging, aggregation and sedimentation of the particles in the nanofluid suspension, which can lead to lower thermal conductivity and dynamic viscosity and increases specific heat. To overcome this issue there were many methods used to enhance the stability of graphene which was in aqueous form and by using various physical methods by covalent and non-covalent functionalizing graphene pH control and ultra-sonication. Present research will focus on bio-based covalent functionalization of carbon-allotropes nanofluids.

The primary interest in nanofluids is the possibility of using these fluids for heat transfer purposes. So, the nanofluids are expected to be used under flow condition. The majority of these studies have used a pipe flow set up (Anoop, Sundararajan, & Das, 2009). These studies agreed that the nanofluids heat transfer coefficient has significantly improved. Anoop et al. (Anoop et al., 2009) found 25% increase in alumina nanofluids, with even greater increases in the entrance region. However, an increase in thermal conductivity does not necessarily imply an increase in heat transfer coefficient. Wang et al. (X. Wang, Xu, & S. Choi, 1999) found out that the viscosity of Aluminum Oxide Al_2O_3 and Copper Oxide (CuO) nanoparticles when they are added into working fluids like water, engine oil, pump fluid and ethylene glycol resulted in

30% better results with Al_2O_3/water nanofluid at 3% volume concentration. Suresh et al. (Suresh, Chandrasekar, Selvakumar, & Page, 2012) experimentally investigated the heat transfer in convective form and friction factor values in plain and spiralled rods inserted in a plain tube with laminar flow and constant heat flux with Al_2O_3-water nanofluids.

Numerical investigations on nanofluids reported in the literature are classified and accumulated on the basis of single and multiphase models. Single-phase model considered as the best and appropriate as the nanofluid characteristics is adequately assessed with higher conformity simulation involving less computational time and complexity. On the other hand, in multiphase flow both the solid particles and the liquid movement are considered at various velocities with various factors such as turbulent, Brownian and gravitational effects. The relative motion concept provides relative friction which can lead to many other external impacts like turbulent damping as the resultant forces acted on the particles. There are many other factors like diffusion which also introduces changes to the mechanism inside of flow. Due to which the nanoparticles dynamics can be visualized by the flow field and can be determined quantitively. Simulation of nanofluids based on single-phase model under constant thermo-physical properties was done by Maiga et al. (El Bécaye Maïga et al., 2006; Maiga, Palm, Nguyen, Roy, & Galanis, 2005) researched the convection of nanofluid on heated discs, parallel, coaxial systems and heated tubes. The study was done on laminar and turbulent regions and it was found that the heat transfer process was better under uniform Re, which was changed by varying the transport variables and particle concentration. Palm et al. (Palm, Roy, & Nguyen, 2006) first investigated the effect of temperature dependent properties in nanofluid convective performance and he introduced formulas which had temperature variables on dynamic viscosity and thermal conductivity calculations in addition to the particle loading

Many studies are made on the experimental and theoretical part of nanofluids inside the internal flow in various geometries and flow regions but there are a few available investigations considered annular pipes. Moreover, there is no comprehensive study on green nanofluids flow in annular pipes, so the present work will concentrate on heat transfer to flowing nanofluids in intensively used annular passage heat exchangers.

2.2 Nanofluid Preparation

The first step while carrying our study was the synthesis of nanofluid. This can be carried out in two different methods:

1. Single-Step Method
2. Two-Step Method

In Single-Step method requires producing the nanofluid and nanoparticles from the physical vapour deposition method. But, this process has some limitation as it can be used for low vapour pressure fluids (Y. Li, Zhou, Schneider, Tung, & Xi, 2009).

Single-step physical method has other disadvantages as it cannot be used to synthesize nanofluid in a big-scale and the cost of synthesizing is too high. Another disadvantage is that the incomplete stabilization can cause reactants to remain inside the nanoparticles, and impurities can cause results of the nanoparticles to vary greatly during analysis.

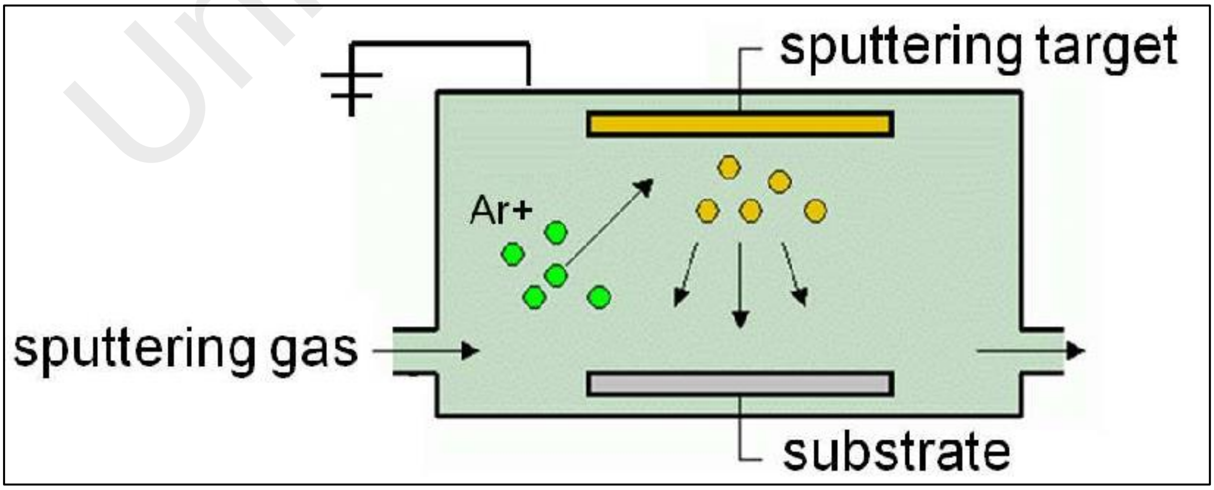


Figure 2. 1: Physical Vapour Deposition Method

In two-step method requires the mixing of nanoparticles in the base fluid, dry nanoparticles are produced from different methods like vapour deposition, mechanical alloying, inert gas and condensation. After successfully producing the dry nanoparticles we can disperse them into a liquid. During the agglomeration process the nanoparticles tend to bind together to form a lump, due to which it can reduce the thermal conductivity and cause sedimentation and clog the passage which can result in decline of thermal properties.

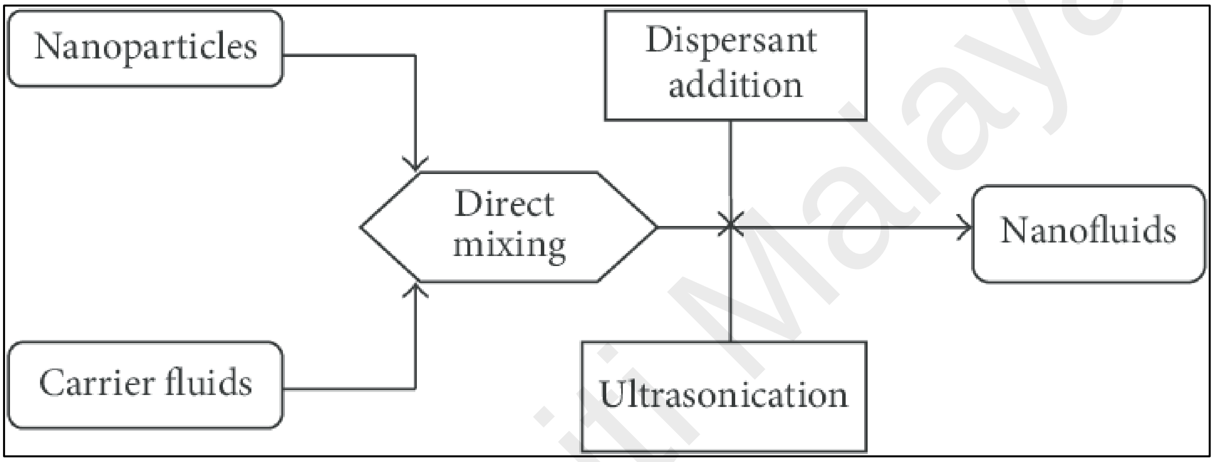


Figure 2. 2: Two-Step Method

To remove the agglomeration and improve dispersion we can use surfactant to the mixture, which increases the charge of the particle with the functionalization of nanoparticles. In the industry, large quantities of nano powder are being synthesized to reduce cost by using the two-step method (Hong, Hong, & Yang. 2006).

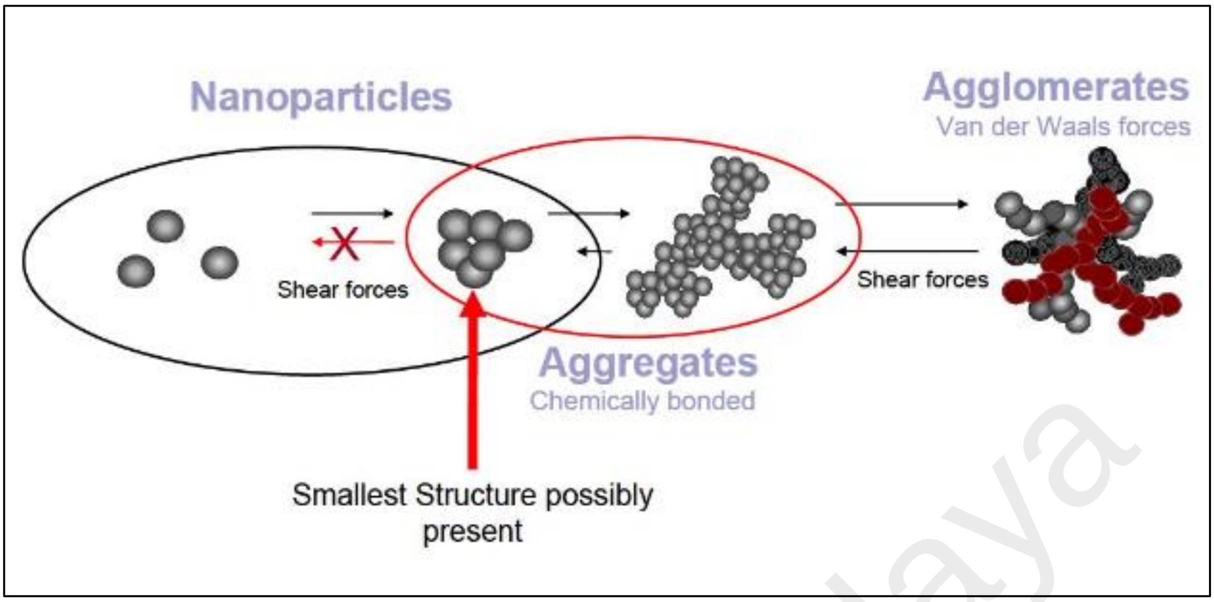


Figure 2. 3: Agglomeration Process

2.3 Stability of Nanofluid

Nanofluids are usually in a colloidal suspension, due to which they tend to agglomerate. They also tend to use a lot of surface area compared to the volume ratio and have a high surface energy. During the process of minimizing the energy, the particles agglomerate. Very high Van der Walls forces around the particles is the main reason for uncontrolled agglomeration. A study conducted to test the aggregation which contributes to the enhcancement of thermal conductivity creates a link with both the thermal conductivity and stability of the fluid (Evans et al., 2008).

There are many studies and ways to enhance the stability of nanofluids (Ghadimi, Rahman, & Metselaar, 2011) are as follows:

1. Surfactant Addition
2. Surface Chemical Treatment
3. Ultrasonic Vibration

2.3.1 Surfactant Addition

As the nanoparticle's nature of settling down in an aqueous solution, use of surfactant can help prevent the accumulation of nanoparticles in the emulsion. Due to which, the stability of the nanofluid is improved. Surfactants can also be considered as dispersants. The easiest and cheapest way to improve the stability of nanofluids is by adding the dispersants in two phase system.

A study done by Hao Peng et al. found that using surfactant can enhance the heat transfer rate in the nanofluid. It was found that the heat transfer rate drops significantly and the performance also decrease with higher surfactant concentration (Peng, Ding, & Hu, 2011). Also, it was later found that the minimal amounts of surfactant added with required coating can help reduce or remove the repulsive forces acting (Jiang, Gao, & Sun, 2003).

There are many disadvantages by using surfactant into the nanofluid solution like:

1. The functionality of surfactants is limited to only 60℃.
2. Usage above 60 ℃ can cause the fluid to denature and result in weakening of bonding between the nanoparticles, which further leads to agglomeration (Assael, Metaxa, Arvanitidis, Christofilos, & Lioutas, 2005: Wang & Mujumdar, 2008).
3. Increases viscosity values.

2.3.2 Surface Chemical Treatment

The enhancement of surface charge density, strong repulsive force with the presence of electro kinetic properties can be the major reason effecting the stability, it can help in stabilizing a homogeneous dispersed suspension (X,-j, Wang, Zhu, & yang, 2009). In a research study done found that the surface chemical effects were the main contributing factor for thermal conductivity of nanofluids (X. Li, Zhu, & Wang, 2007).

Chemical treatments like the use of acids can stabilize the suspension as the nature of surface changes from hydrophobic to hydrophilic due to the presence of a hydroxy functional group (Xie, Lee, Youn, & Choi, 2003). The theory of Isoelectric Point (IEP) says that higher the pH of nanofluid from the IEP point, more will be the surface charge. Thoroughly dispersed nanofluids with strong repulsive forces can be achieved by the help of high surface charge density (X. Li et al., 2007).

2.3.3 Ultrasonic Vibration

Figure 2. 4: Probe Sonicator

Probe sonication is a well-known process which was performed by using a probe sonicator which was inserted in the mixture of nanoparticles in base fluid. The technique was used by Gupta et al. to prepare a nanofluid colloidal suspension (Gupta, Narendar, Krishnaiah, & Satyanarayana, 2017). This process helps in obtaining a stable homogeneous nanofluid. If we compare with the surface chemical method, this method helps in breaking the surface properties of particles and to overcome aggregation. Which further leads to achieve a stable nanofluid. The energy released by the probe sonicator to the nanofluid mixture makes the agglomeration of the nanofluid to be fully dispersed and get homogenised.

2.4 Thermo-physical properties

It is one of the main criteria for selection of a nanofluid to be used on different applications, the following are the parameters used during our study:

1. Thermal Conductivity
2. Density
3. Viscosity
4. Specific Heat Capacity

2.4.1 Thermal Conductivity

It was found that adding small amounts of nanoparticles can lead to a increase in thermal conductivity of a base fluid. Renowned scientists like Maxwell and Hamilton theories along with the aggregation of particles and Brownian motion were used to explain this rise of thermal conductivity. We have 4 prominent methods to measure the thermal conductivity of nanofluids.

1. 3w Technique.
2. Thermal Constant Analyzer.
3. Temperature Oscillation.
4. Transient Hot Wire.

A study on addition of copper and alumina found that there was about 60% increment of thermal conductivity compared to its base fluid (S. Choi, Eastman, Li, J. Thompson, & Lee, 1996). In another study, it was found that using carbon as a nanoparticle in the base fluid saw the largest increase of thermal conductivity (Zhang, U. S, Choi, Yu, E. Lockwood, & Grulke, 2001). While, a single walled carbon nanotube showed an increase of 125%.

2.5 Numerical Analysis

To conduct the numerical analysis, ANSYS software was used to run simulation for heat transfer problems. This software runs on the FLUENT code which uses finite volume method to calculate it's given problem. Studies were conducted to run simulation for backward step flows in ANSYS (Kazi, Oon, Togun, Badarudin, & Sadeghinezhad, 2013). A study was done on annular passage simulation with nanofluid (Oon et al., 2013). The focus of this study will be to run Ansys simulation on annular tubular heat exchanger with thermal properties of water and Al_2O_3 nanofluid.

CHAPTER 3: METHODOLOGY

This section will comprise of the set up and preparation that was required before and after experimental and simulation works were done.

3.1 Nanofluid Preparation

The two-step method was used to prepare the Al2O3 nanofluid solution. First, in this preparation the nanofluid was weighed in the weighing boat and measured the weight of the nanoparticles. Then the nanoparticles were kept inside the beakers, and then distilled water was added as conventional base fluid. The solution of the water and nanoparticles are then kept inside the probe sonicator for the proper mixing and to reduce the clogging of the nanoparticles inside the solution. The probe sonication is set for 02 hours and 30 minutes with 03 ON and 02 OFF pulse with 60 kHz frequency. The ice blocks are kept along with the solution inside the probe sonicator to avoid the temperature to raise inside. After completion of sonication, nanofluid solution were kept for 24 hours to observe the stability of the nanoparticles inside the solution. This solution resulted with a stable condition of nanoparticles. Then the nanofluid concentrations of 0.1, 0.075, 0.05 and 0.025 vol.% were prepared. These solutions were experimented on the test-rig to investigate the heat transfer.

3.2 Experimental Setup

The experimental setup was made in the CFD lab of University of Malaya. The setup rig consists of various parts with mechanical and electronic parts for data collection and observation. Figure 3.1 is the schematic representation of experimental set up made for this thesis. Figure 3.2 shows the photograph of the rig setup made on to which the study was conducted. There are set-up rig includes the following parts;

1. Annular flow test section
2. Heated test section
3. Data Acquisition system
4. Pump
5. Reservoir tank
6. Chiller (used for cooling purpose)
7. Differential pressure transmitter (DPT)
8. Flow meter

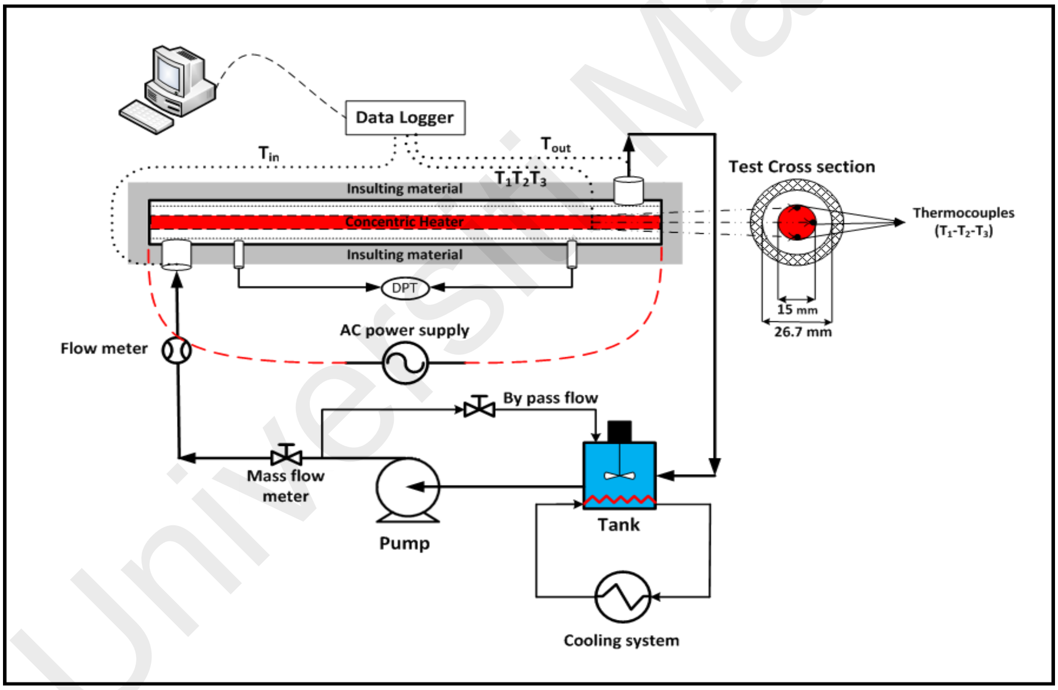


Figure 3. 1: Schematic diagram of the experimental set-up

Figure 3. 2: Photograph of the experimental rig set-up

3.3 Annular Flow Test Section

This section was made using a hollow stainless-steel pipe of 1.38-meter length (Figure 3.3 (a)) and a stainless-steel rod of 1.38-meter length (Figure 3.1(b)) kept inside the hollow pipe in the centre, to form an annular section.

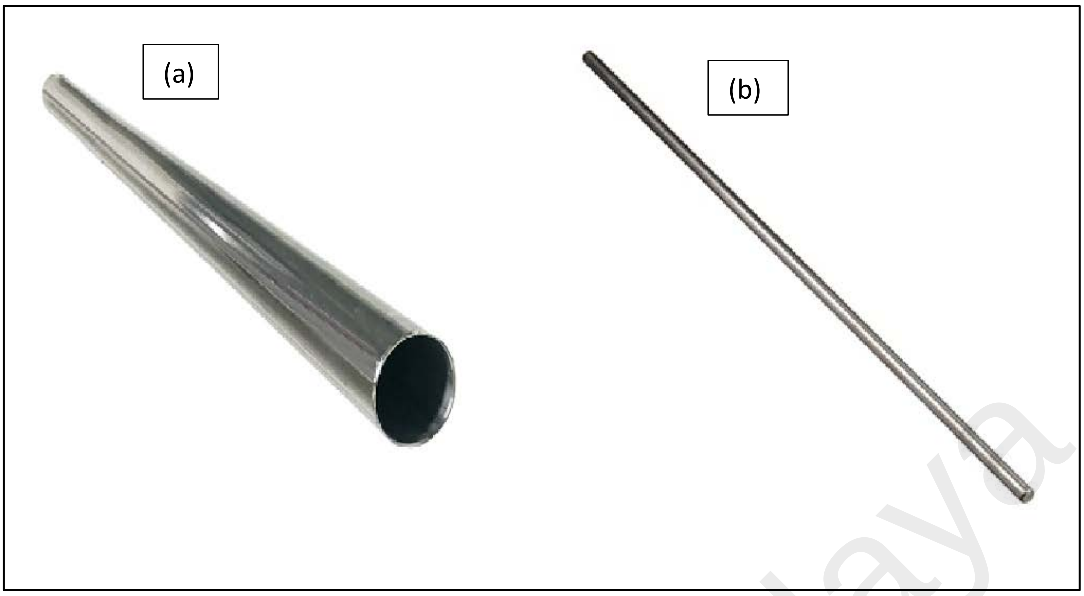


Figure 3. 3: (a) Hollow Stainless-steel pipe (b) Stainless-steel rod

The annular section was attached with small 5 thermos wells holding 5 thermocouples inside them and located about 2.5 cm length apart, then high temperature epoxy glue was applied around them for permanent fixture. Allen keys were used as a support using a transparent tape. (Figure 3.5) shows the Allen keys held vertically using transparent tape and the thermocouple slots held in the middle. A total of 5 such Allen keys and thermocouple slots were used and kept in a distance of 0.2 meters from each other on the main steel pipe. (Figure 3.6) shows the arrangement of the 5 thermocouple slots using the Allen keys.

Figure 3. 4: Photograph of thermocouple slot holded in place using Allen key and transparent tape.

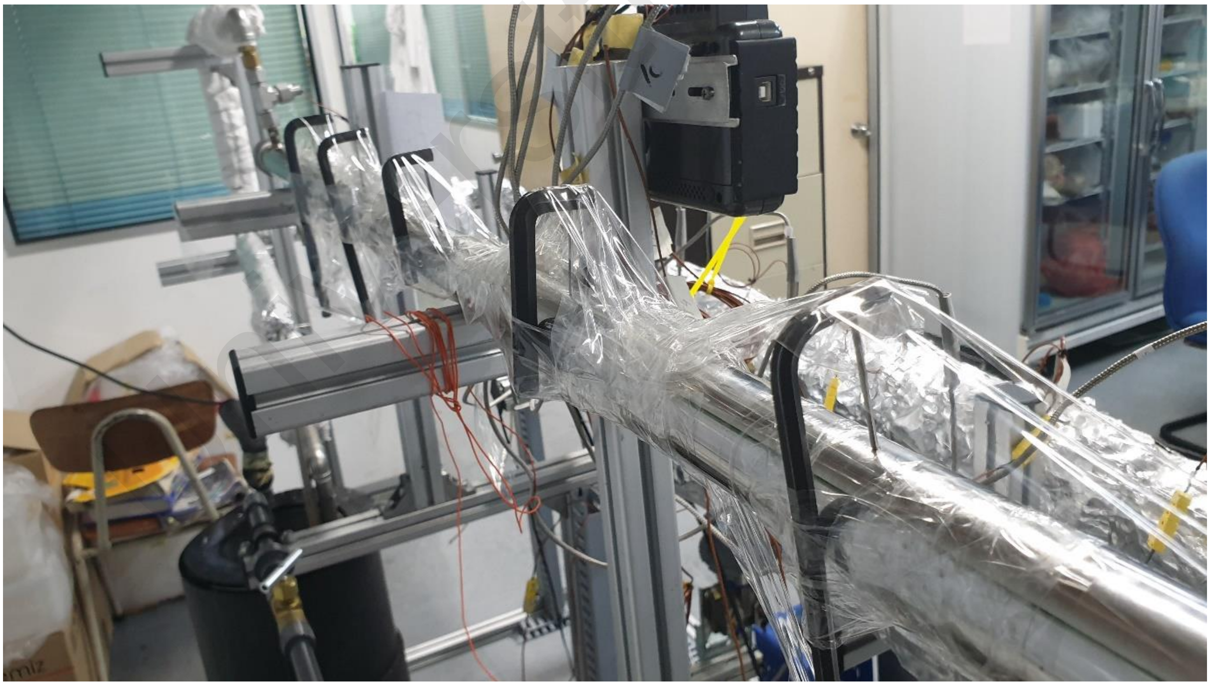


Figure 3. 5: Photograph of 5 Allen Keys holding thermocouple slots using tape.

After applying the high temperature resistant epoxy glue around the thermocouple slots, the Allen keys and transparent tape were removed. 5 K-Type thermocouples (Omega Engineering Inc., USA) were inserted in their respective thermocouple slots to collect temperature data of the main stainless-steel pipe.

2.3.1 Heated Test Section

The heating on the outer surface of the stainless-steel pipe was done by using tape heaters, wrapped around the pipe. (Figure 3.7) shows tape heaters wrapped along the full length of the steel pipe. The voltage of the tape heaters was regulated by using a variable voltage transformer (Success Electronics & Manufacturer Sdn. Bhd., Malaysia). The voltage and current were regulated as per the required heating power. The K-Type thermocouples were placed inside the thermocouple slots and the data were relayed to the data acquisition system (Data logger).

Figure 3. 6: Photograph of Tape heater wrapped along the whole length of the stainless-steel pipe.

Furthermore, to prevent heat loss and proper heat transfer to the stainless-steel pipe, cotton fiberglass insulation was wrapped around the pipe along the full length of the pipe. Figure 3.8, shows cotton fiberglass insulation wrapped along the surface of the pipe. To hold the cotton and prevent further thermal loss, aluminium foil was used to cover the cotton fiberglass insulation. Figure 3.9, shows aluminium foil wrapped around over the cotton fiberglass insulation.

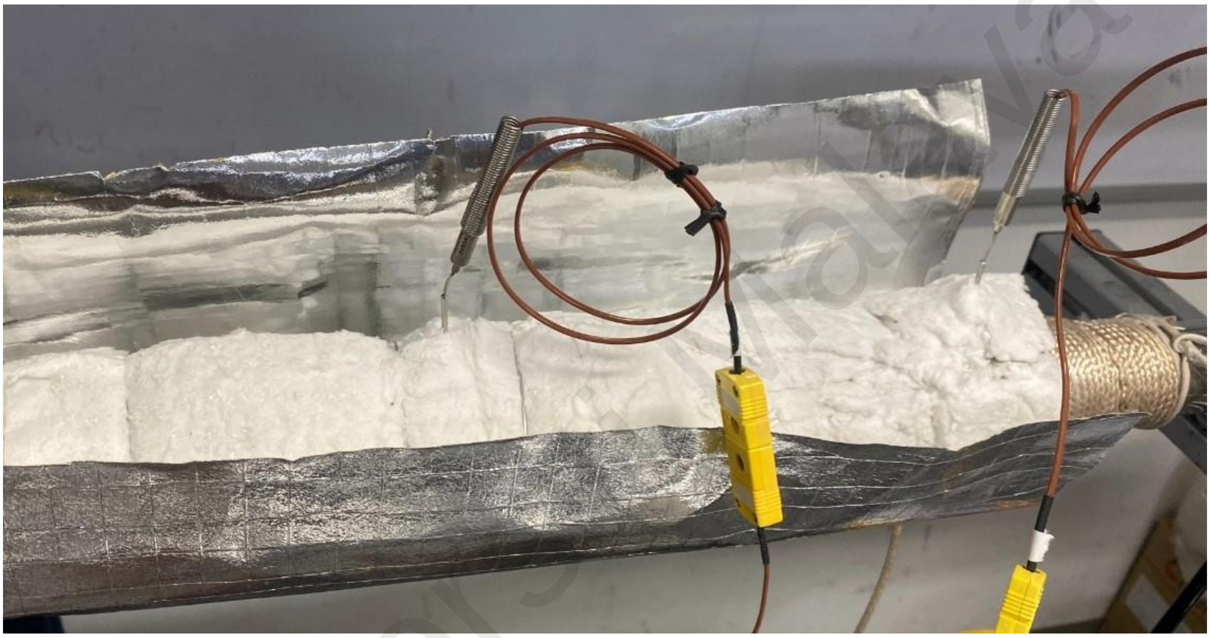


Figure 3. 7: Photograph of cotton fiberglass insulation wrapped over the tape heater to prevent heat loss.

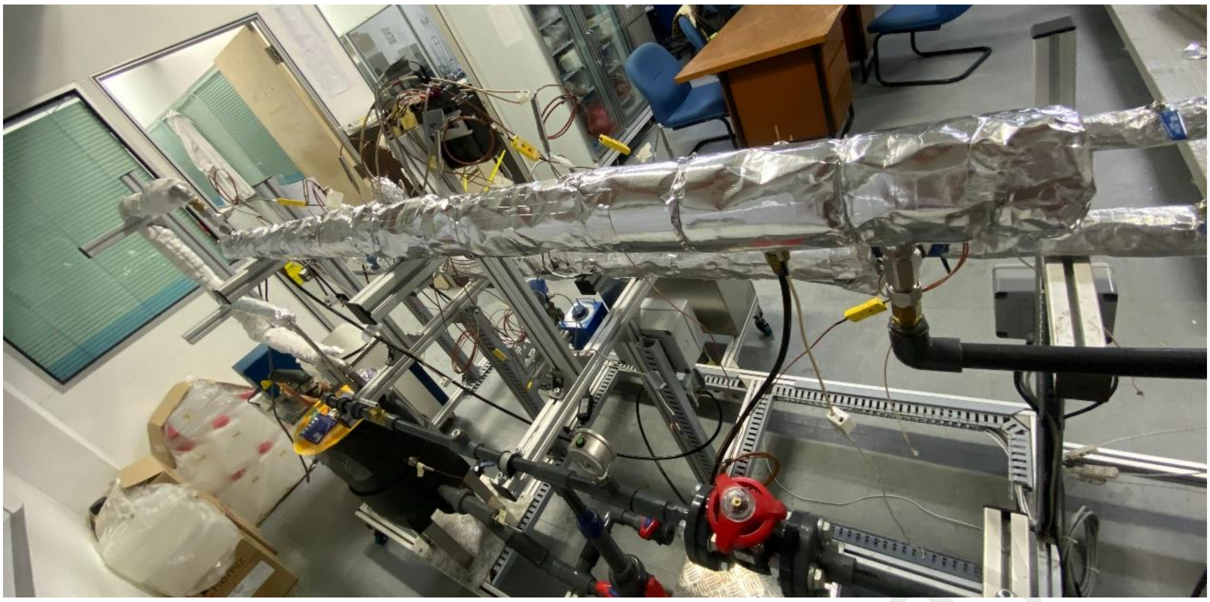


Figure 3. 8: Aluminium foil wrapped over the cotton fiberglass insulation along the full length of the stainless-steel pipe.

2.3.2 Data Acquisition System

Graphtec midi Logger GL220 (Figure 3.9) was used to record the surface temperature of the test channels. 5 K-Type thermocouples were attached to the data logger and temperature rise and drop were monitored in real-time. The maximum of 10 thermocouples can be attached and monitored simultaneously in this model. This data logger is able to record data at an interval of 10 milliseconds to 1 hour.

For the flow rate meter, Burkert Electromagnetic Flow meter was used to monitor continuous monitor and control of the flow measurement of the working fluid. A pressure transducer was also fitted onto the test channel at inlet and outlet to measure the values of pressure drop across the whole rig by the DPT.

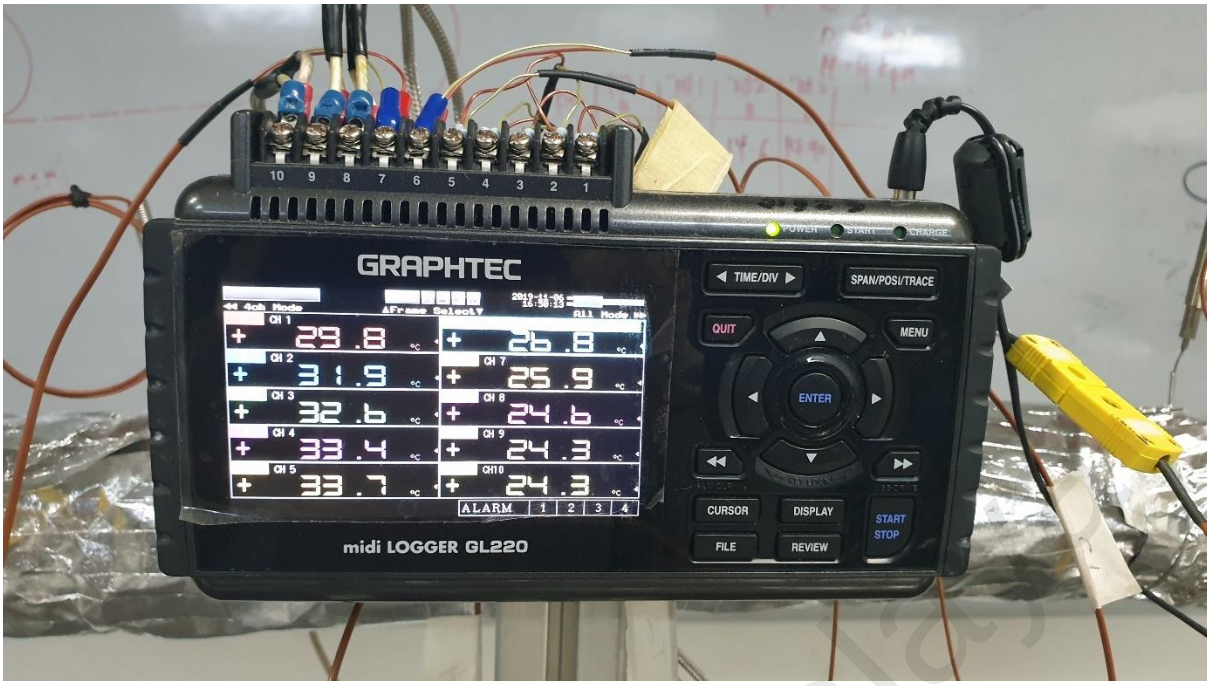


Figure 3. 9: Photograph of GRAPHTEC midi Logger GL220 used to record the surface temperature of test channel.

3.4 Experimental Procedure

The rig ensured that there is no sedimentation deposit in it and was cleaned thoroughly. Then the reservoir was filled with water and Al_2O_3 nanofluid. The chiller was connected to the reservoir and made sure that the heat was removed before the nanofluid or water was pumped into the system again. The pump was used to change the flowrate into the tubes.

A total of 5 thermocouples were used in this experiment with each being placed at an increasing distance of 0.2m from the end of the tubes. There were 5 equal distant locations where the thermocouples were installed for this study. Those are 0.2 m, 0.4 m, 0.6 m, 0.8 m, and 1 m apart. An alternating current of up to 180 V was regulated and supplied to the system heater.

Concentric heater was used to heat the tube with a constant heat flux. A DPT was installed to study the pressure drop from one end to another end of the annular tube. Graphtec midi Logger GL220 was used to record the temperature reading at the surface of the tubes from T1 to T5.

3.5 Nanofluid properties

The thermo physical properties of a colloidal suspension can be enhanced by nanofluid dispersion. A lot of research has been done by researchers to enhance the thermophysical properties of fluid with suspensions.

Crosser and Hamilton studied that the effect of size, volume percentage, type of nanoparticles base fluid as per the equation (1).

$$K_{nf} = \frac{K_{bf}\left[K_p + (n-1)K_{bf} - (n-1)\emptyset_p\left(K_{bf} - K_p\right)\right]}{K_p + (n-1)K_{bf} - \emptyset_p\left(K_{bf} - K_p\right)} \quad (1)$$

K_{nf} = Nanofluid thermal conductivity

K_p = Nanoparticle thermal conductivity

K_{bf} = Base fluid thermal conductivity

β = Ratio of thickness of nanolayer to original radius of particle

$$n = \frac{3}{\varphi}$$

Where, φ = Nanoparticles sphericity

The common value that is slected to compute the nanofluid thermal conductivity for β is 0.1. Then the thermophysical properties for density would be computed by the equation (2)

$$\rho_{nf} = \left(1 - \emptyset_p\right)\rho_{bf} + \emptyset_p\rho_p \quad (2)$$

ρ_{bf} = Host fluid density

ϕ_P = Fractional volume of solid nanoparticles

ρ_p = Density of particle

The formula was improved further by Xuan. Y and W. Roetzel (Xuan & Roetezel. 2000) as per equation (3).

$$C_{p,nf} = \frac{[(1-\emptyset_p)\,\rho_{bf}C_{bf} + \emptyset_p\,\rho_p C_p]}{\rho_{nf}} \tag{3}$$

After calculation density, the most important property for nanofluid in this study is viscosity. The pumping power, pressure drop, heat transfer rate is heavily relied on viscosity. A study done by Sharma, K et al. (M Hussein, Sharma, Abu Bakar, & Kadirgama, 2013) to identify the properties took into account diameter of particle, temperature and account volume portion as of equation (4)

$$\mu_{nf} = \left[(1+\varphi_p)^{11.3}\left(1+\frac{T_{nf}}{70}\right)^{-0.038}\left(1+\frac{d_p}{170}\right)^{-0.061}\right]\mu_{bf} \tag{4}$$

Table 3. 1: Thermo-physical properties of conventional GNP nanofluid with varying concentration.

Heat Transfer Fluids	Thermo-physical Properties			
	k (W/m.K)	μ (Pa. s)	Cp (J/Kg. k)	ρ (m^3/kg)
Distilled-water	0.607	0.000891	4105	997.1
AL_2O_3-water Nanofluids (% vol.)				
GNP 0.025%	0.6075	0.0008915	4175.51	997.8
GNP 0.05%	0.6081	0.0008921	4176.38	998.5
GNP 0.075%	0.6087	0.0008926	4177.25	999.3
GNP 0.1%	0.609	0.0008932	4178.13	1000

The average convective heat transfer coefficient value can be obtained from equation (5)

$$h = \frac{NuK}{D} = \frac{q}{T_s - T_b}$$

Where,

q = heat flux

Ts = Surface Temperature

Tb = Bulk Temperature

Nu = Nusselt Number

D = Hydraulic Diameter

K = Thermal Conductivity

3.6 Numerical Analysis

The software used to run the simulation for this study was ANSYS Fluent. The model for the annular tube was made using the Design Modeler. Initially, a mesh independence study was conducted to determine the best mesh that can produce minimal changes to the results in the shortest possible time. The simulation was run based on the thermo physical properties of the nanofluid that was obtained through analytical equations in sub chapter 3.4.

The cylinder shape was modelled to study the interior of the cylindrical tube. Figure 3.10 shows the cylinder simulation.

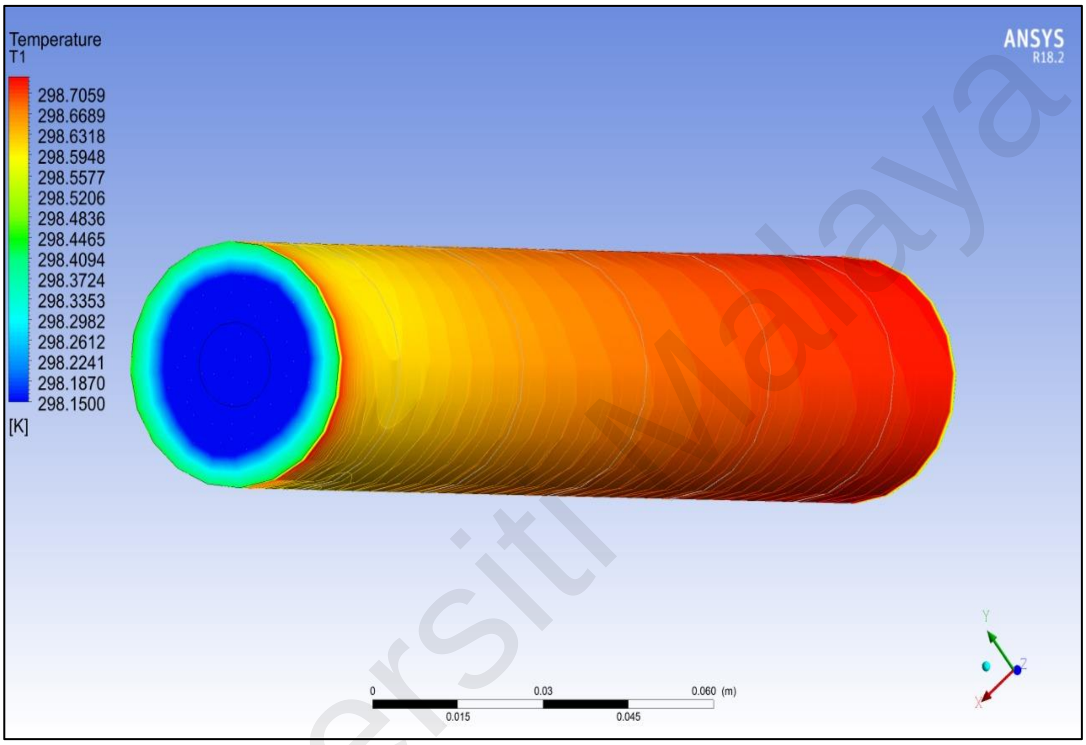


Figure 3. 10: Cross sectional view of the inlet of circular tube.

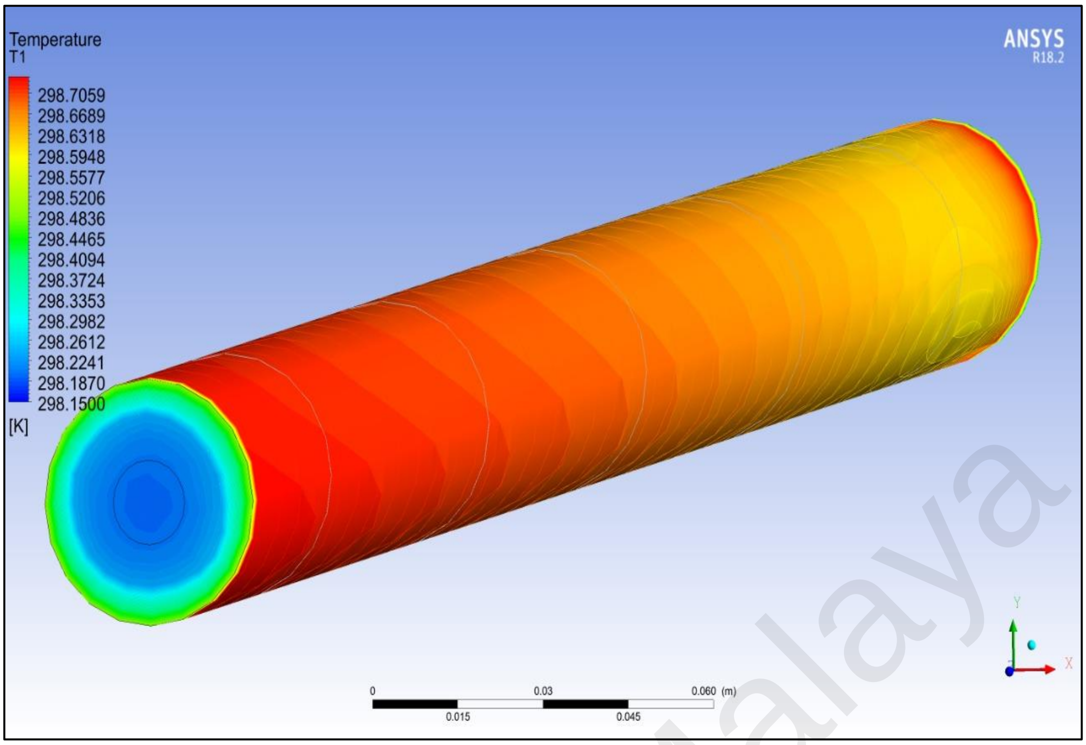


Figure 3. 11: Cross sectional view of the outlet of circular tube.

CHAPTER 4: RESULTS AND DISCUSSION

4.1: Experimental Study and Results

The study focuses on the effect of Nusselt number and convective heat transfer coefficient by varying the concentration of Al_2O_3-nanoparticles in nanofluids solution inside an annular flow pipe. The convective heat transfer coefficient data from water run, were compared with the data of Al_2O_3-water nanofluid at 0.1%, 0.075%, 0.05% and 0.025% concentration. The flow rates were varied at different rates, such as 5L/minute, 7L/minute, 9L/minute and 10L/minute.

4.2 Nu Validation for the DI-Water

Figure 4. 1: The graph shows water (Experimental) is compared with the different correlation methods with Reynolds number against Nusselt number.

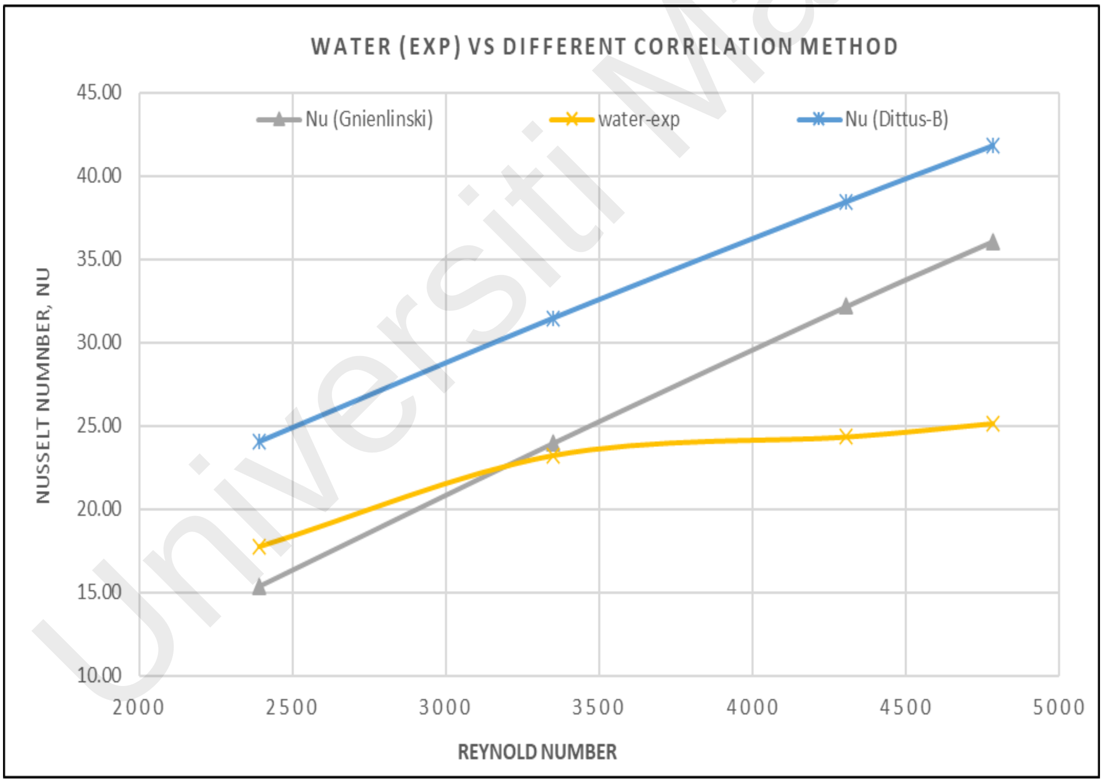
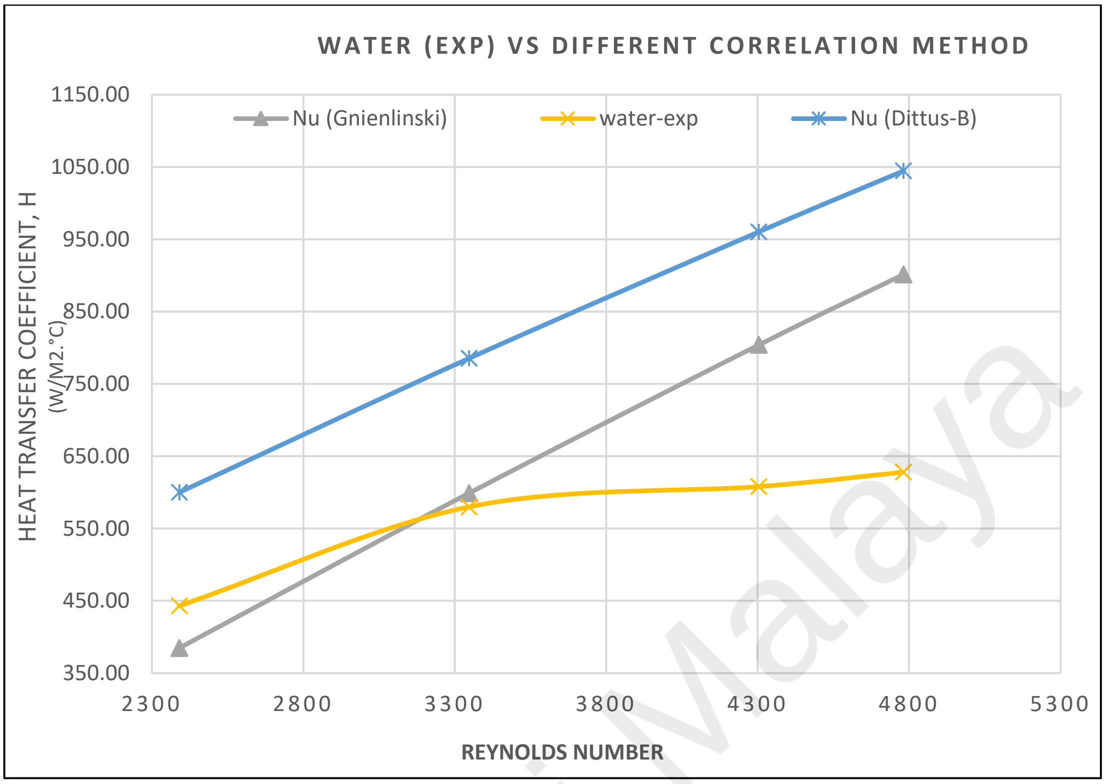


Figure 4. 2: The graph shows water (Experimental) is compared with the different correlation methods with Reynolds number against Heat transfer Coefficient.



In the figure 4.1 and figure 4.2 it shows that the distilled water experimental data were validated with two different correlations, where the experimental data showed a good correlation at the low turbulent Reynolds number. Dittus-Boelter equation showed higher Nusselt number than Gnielinski and experimental data.

Table 4-1: Water Data inside an annular flow pipe.

Flow Rates (Lit/Min)	Velocity (m/s)	Reynolds Number
5	0.088	2391
7	0.123	3347
9	0.158	4304
10	0.176	4782

Initial Data		
h (W/m2.°C)	Nu	f
443.17	17.74	0.0206
580.00	23.22	0.0166
608.00	24.34	0.0052
628.00	25.14	0.0110

Considering the Pipe as smooth							
Reynolds Number	f (Roughness)	Nu 1 (Chilton Colburn)	Nu 2 (2nd petukhov)	NU 3 (Gnienlinski)	h1 (Colburn)	h2 (2nd Petukhov)	h3 (Gnienlinski)
2396.044	0.039	21.28	22.65	13.49	531.65	565.68	337.08
3354.462	0.036	27.86	30.30	21.76	695.88	756.95	543.64
4312.879	0.035	34.06	37.66	29.61	850.84	940.76	739.71
4792.088	0.034	37.06	41.25	33.42	925.66	1030.48	834.85

Considering the Pipe Roughness Friction factor								
f (Roughness)	Nu 1 (Colburn)	Nu 2 (2nd petukhov)	NU 3 (Gnienlinski)	NU (DB)	h1 (Colburn)	h2 (2nd Petukhov)	h3 (Gnienlinski)	h4 (D-B)
0.047	26.05	25.90	15.41	24.02	650.62	646.87	384.88	600.03
0.042	32.25	33.42	23.98	31.44	805.54	834.86	598.94	785.37
0.039	38.60	40.97	32.18	38.44	964.18	1023.35	803.88	960.27
0.038	41.57	44.58	36.08	41.82	1038.43	1113.55	901.35	1044.71

4.3 Al2O3-water data with 0.1% concentration of nanoparticles.

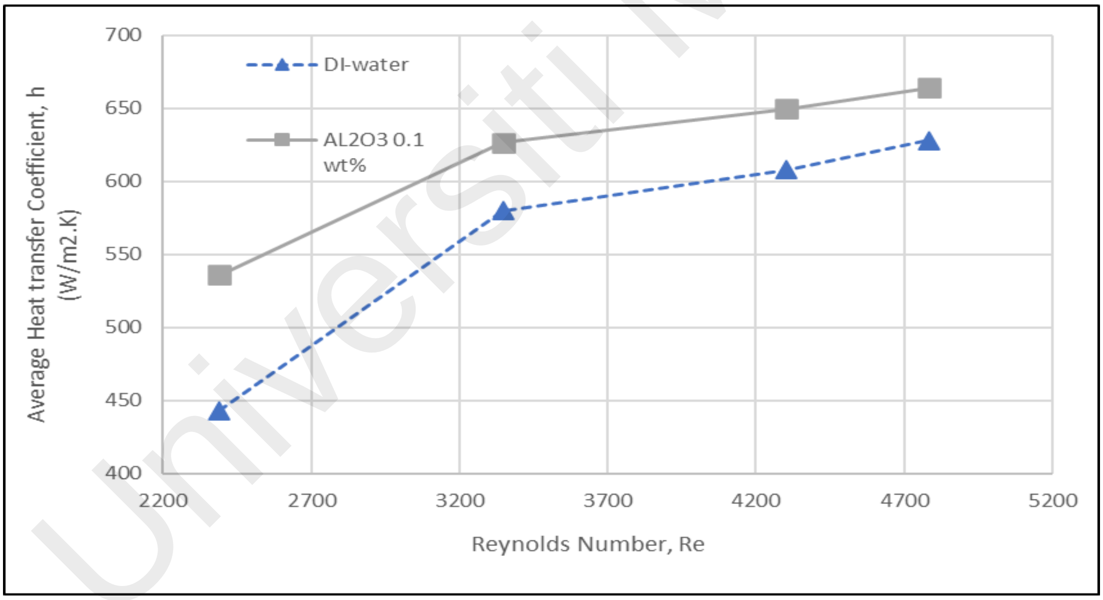


Figure 4. 3: Graph of Average Heat transfer coefficient of DI-water and Al_2O_3-water with 0.1% concentration against Reynolds Number

From the graph, it can be observed that the maximum heat transfer coefficient enhancement resulted 17.33% for the Al_2O_3-water than the experimental data of water alone. The results show that Al_2O_3-water nanofluid at 0.1 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher heat transfer with the nanoparticle solution.

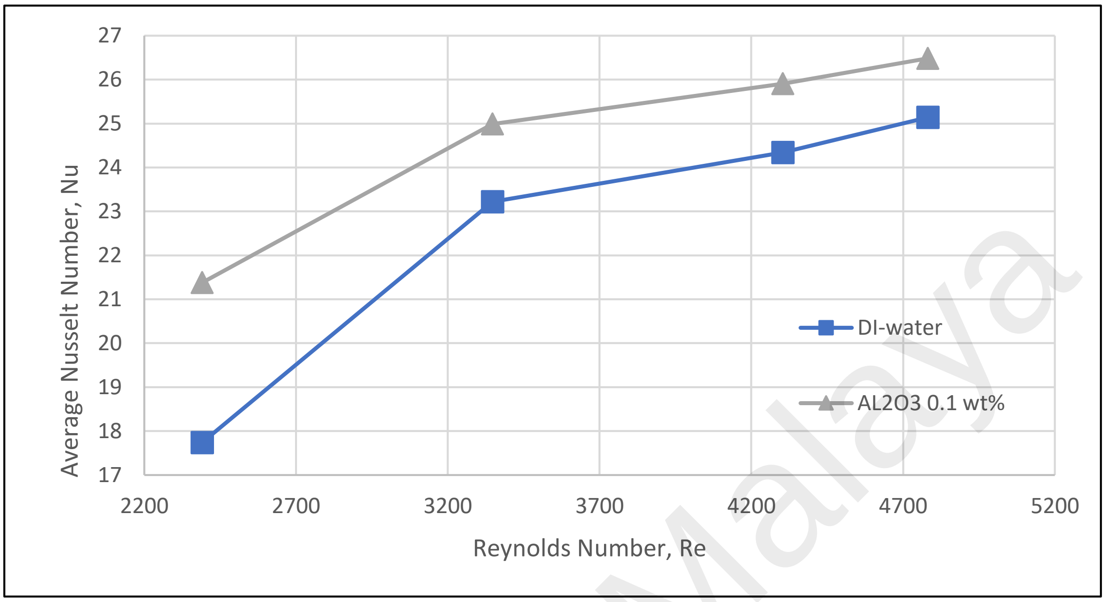


Figure 4. 4: Graph of Average Nusselt Number of DI-water and Al_2O_3-water with 0.1% concentration against Reynolds Number

From the graph, it can be observed that the Nusselt Number resulted 17% enhancement for the Al_2O_3-water than the water experimental data. The results show that Al_2O_3-water nanofluid at 0.1 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at a constant heat flux boundary condition. By varying the Reynolds number, we can gain higher Nusselt number with the nanoparticle solution.

4.4 Al_2O_3-water data with 0.075% concentration of nanoparticles

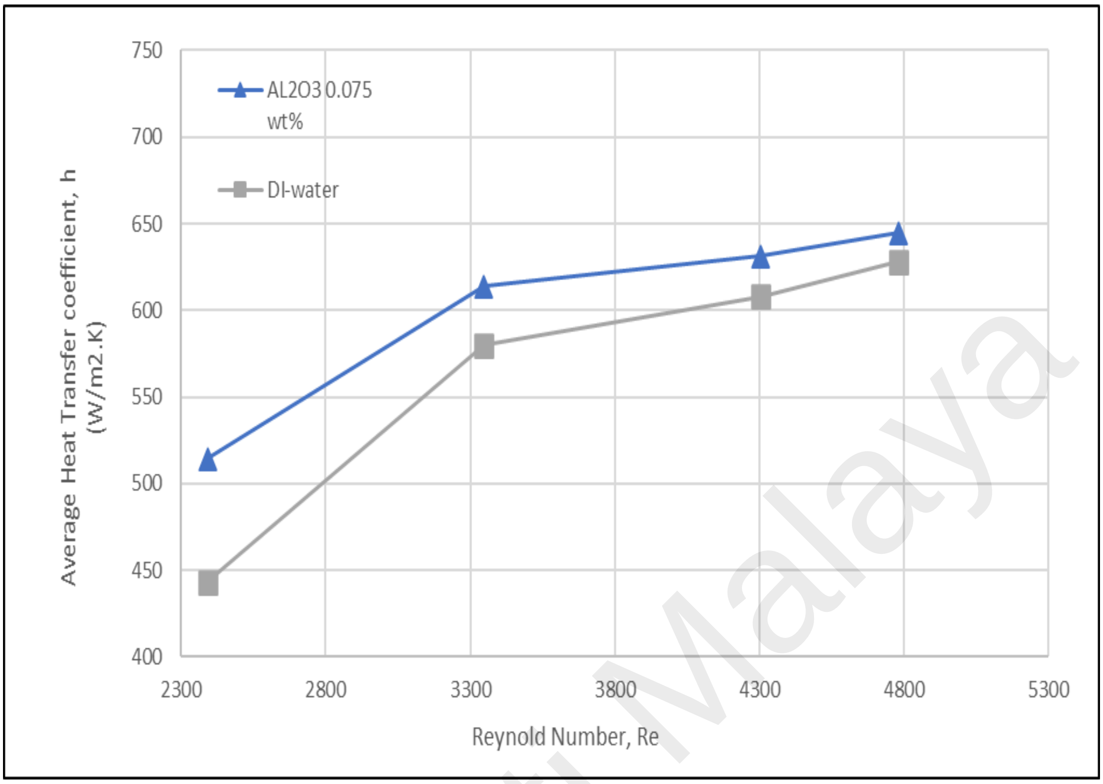


Figure 4. 5 Graph of Average Heat transfer coefficient of DI-water and Al_2O_3-water with 0.075% concentration against Reynolds Number

From the graph, it can be observed that the maximum heat transfer coefficient resulted 13.84% enhancement for the Al_2O_3-water than the water experimental data. The results show that Al_2O_3-water nanofluid at 0.075 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher heat transfer with the nanoparticle solution.

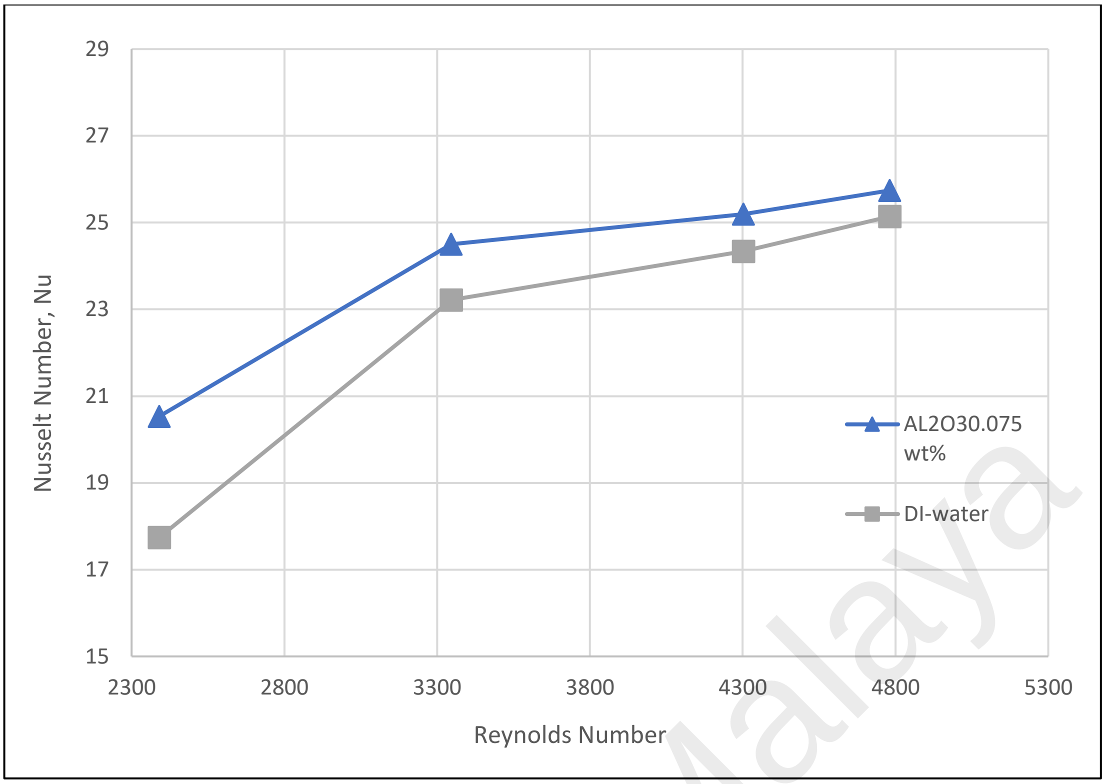


Figure 4. 6: Graph of Average Nusselt Number of DI-water and Al_2O_3-water with 0.075% concentration against Reynolds Number

From the graph, it can be observed that the Nusselt Number resulted 13.6% for the Al_2O_3-water than the water experimental data. The results show that Al_2O_3-water nanofluid with 0.075 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher Nusselt number with the nanoparticle solution.

4.5 Al_2O_3-water data with 0.05% concentration of nanoparticles.

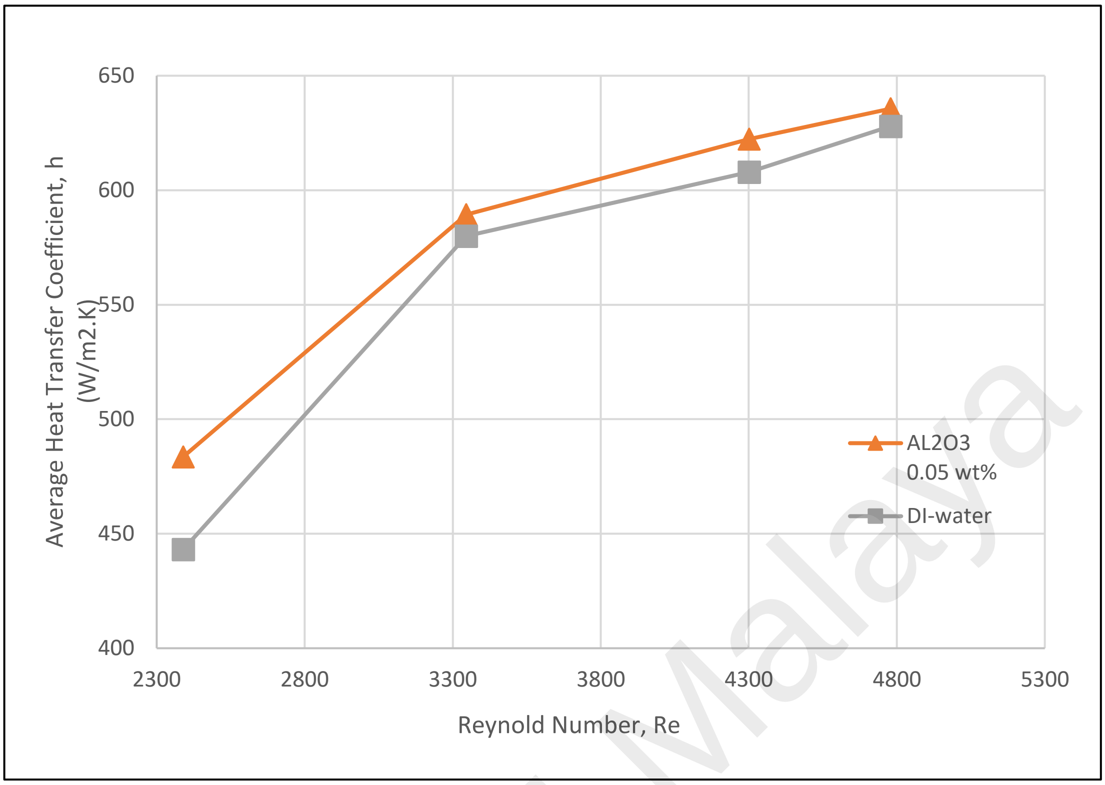


Figure 4. 7: Graph of Average Heat transfer coefficient of DI-water and Al_2O_3-water with 0.05% concentration against Reynolds Number

From the graph, it can be observed that the maximum heat transfer coefficient resulted 8.37% enhancement for the Al_2O_3-water than the water experimental data. The results show that Al_2O_3-water nanofluid at 0.05 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher heat transfer with the nanoparticle solution.

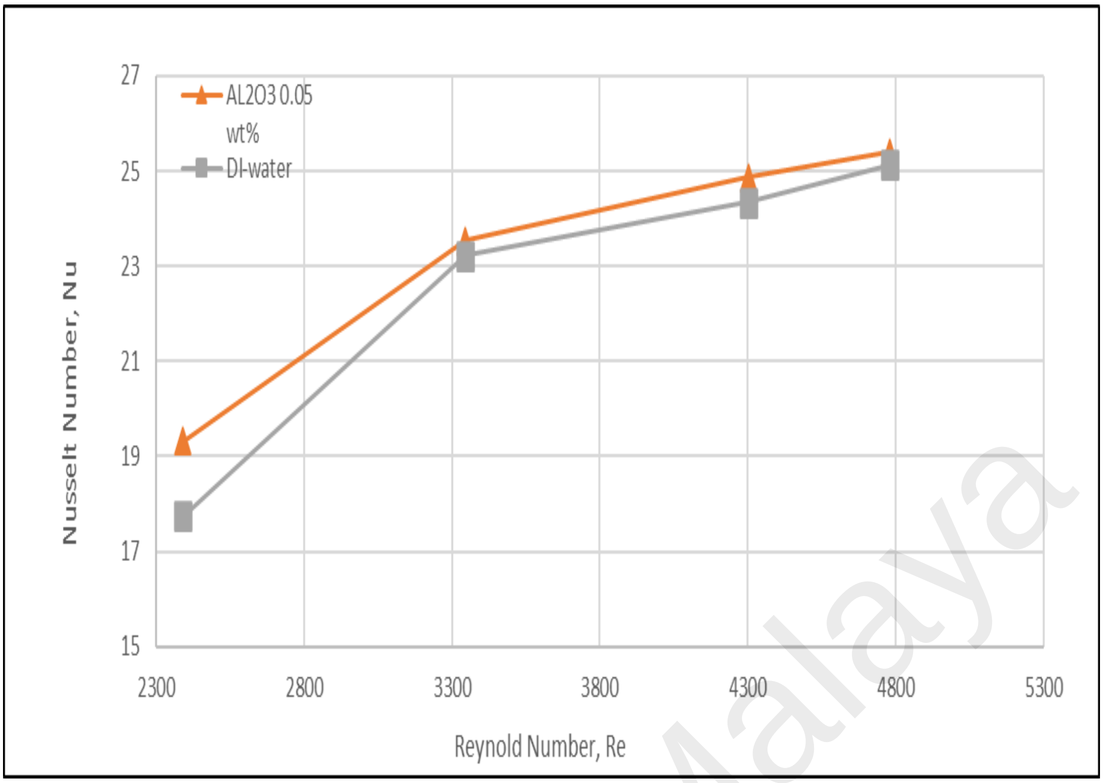


Figure 4. 8: Graph of Average Nusselt Number of DI-water and Al_2O_3-water with 0.05% concentration against Reynolds Number

From the graph, it can be observed that the Nusselt Number resulted 8.19% enhancement for the Al_2O_3-water than the water experimental data. The results show that Al_2O_3-water nanofluid with 0.05 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher Nusselt number with the nanoparticle solution.

4.6 Al_2O_3-water data with 0.025% concentration of nanoparticles.

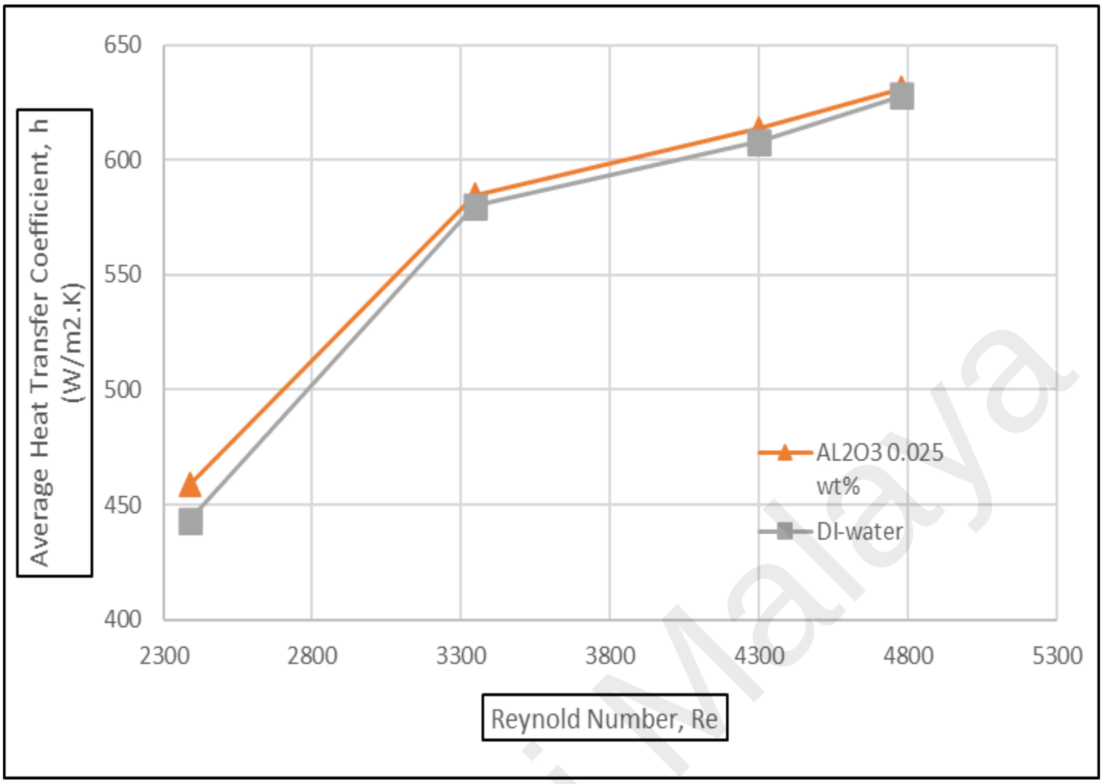


Figure 4. 9: Graph of Average Heat transfer coefficient of DI-water and Al_2O_3-water with 0.025% concentration against Reynolds Number

From the graph, it can be observed that the maximum heat transfer coefficient resulted 3.39% enhancement for the Al_2O_3-water than the water experimental data. The results show that Al_2O_3-water nanofluid with 0.025 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher heat transfer with the nanoparticle solution.

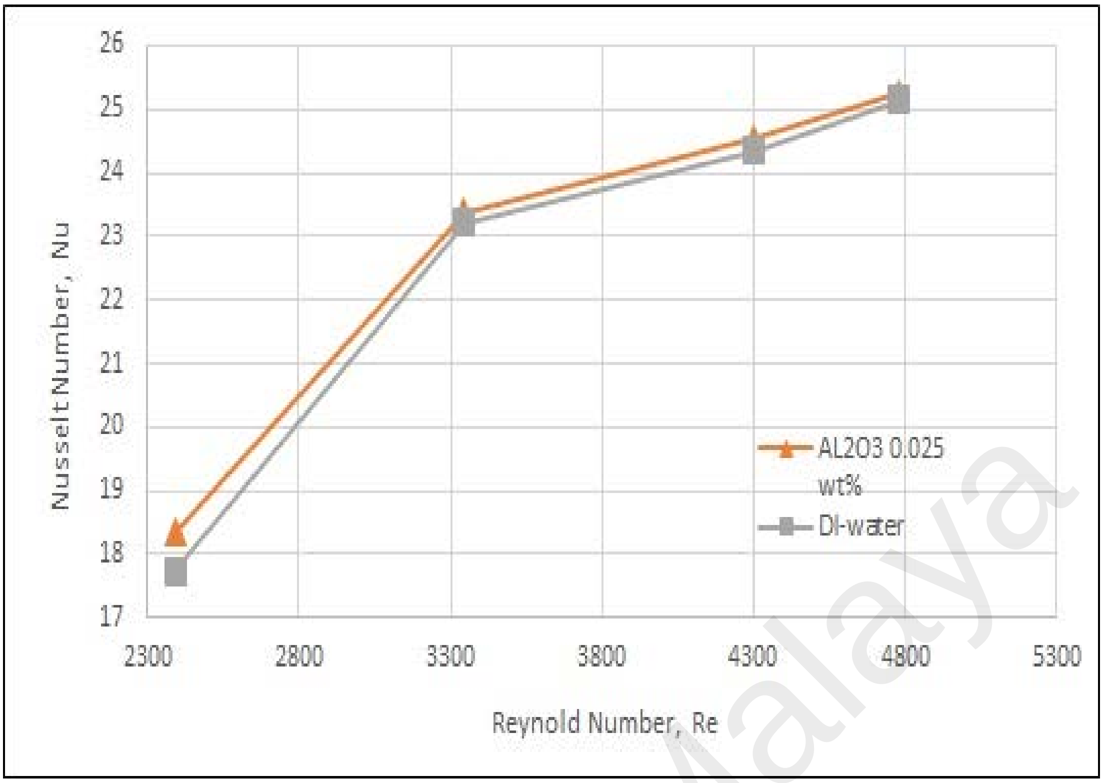


Figure 4. 10: Graph of Average Nusselt Number of DI-water and Al_2O_3-water with 0.025% concentration against Reynolds Number

From the graph, it can be observed that the Nusselt Number resulted 3.29% for the Al_2O_3-water than water experimental data. The results show that Al_2O_3-water nanofluid with 0.025 wt.% of nanoparticle achieved higher heat transfer coefficient under fully turbulent regime flow at constant heat flux. By varying the Reynolds number, we can gain higher Nusselt number with the nanoparticle solution.

4.7 Comparison of Nanofluids concentrations and DI-water

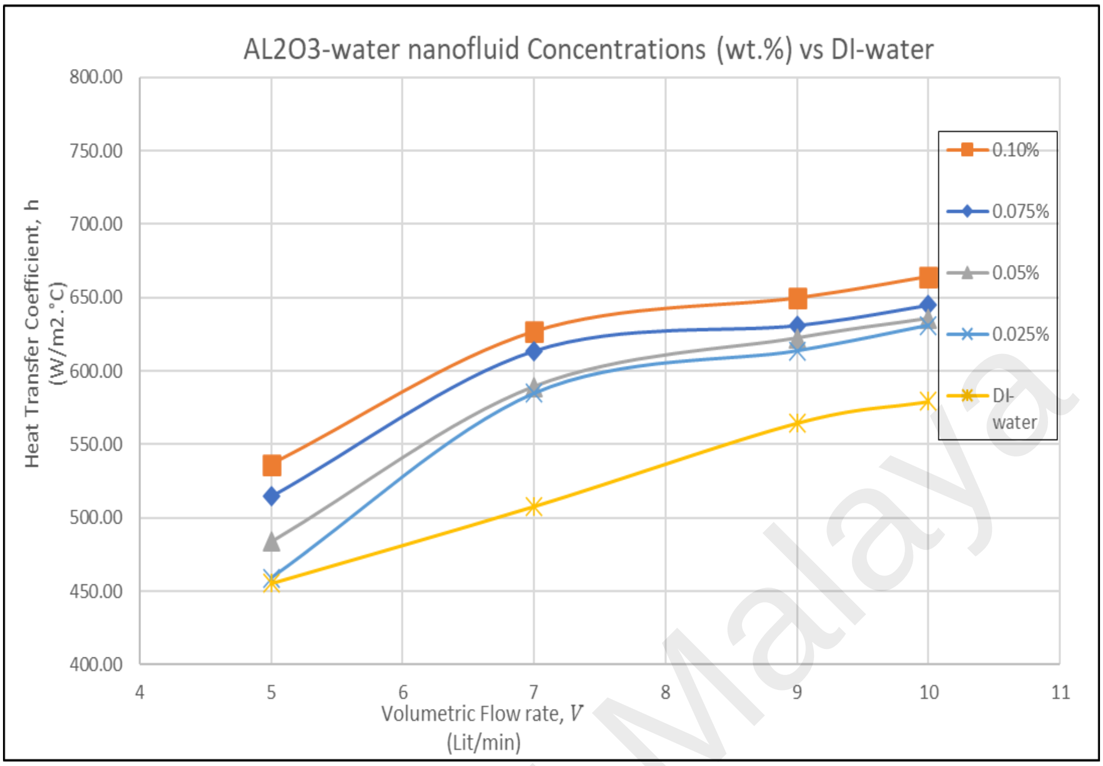


Figure 4. 11: Graph shows the Heat Transfer coefficient of Al_2O_3-water nanofluid concentrations versus distilled water against Volumetric flow rate

The graph shows that the addition of nanoparticles into the base fluid, we can achieve higher heat transfer cofficient than the conventional fluid (water) and by varying the volumetric flow rate we can gain higher heat transfer values. The highest value were achieved with higher concentration values of Al_2O_3-water nanofluid of 0.1% vol. nanoparticles at the maximum flow rate compared to the corresponding water data.

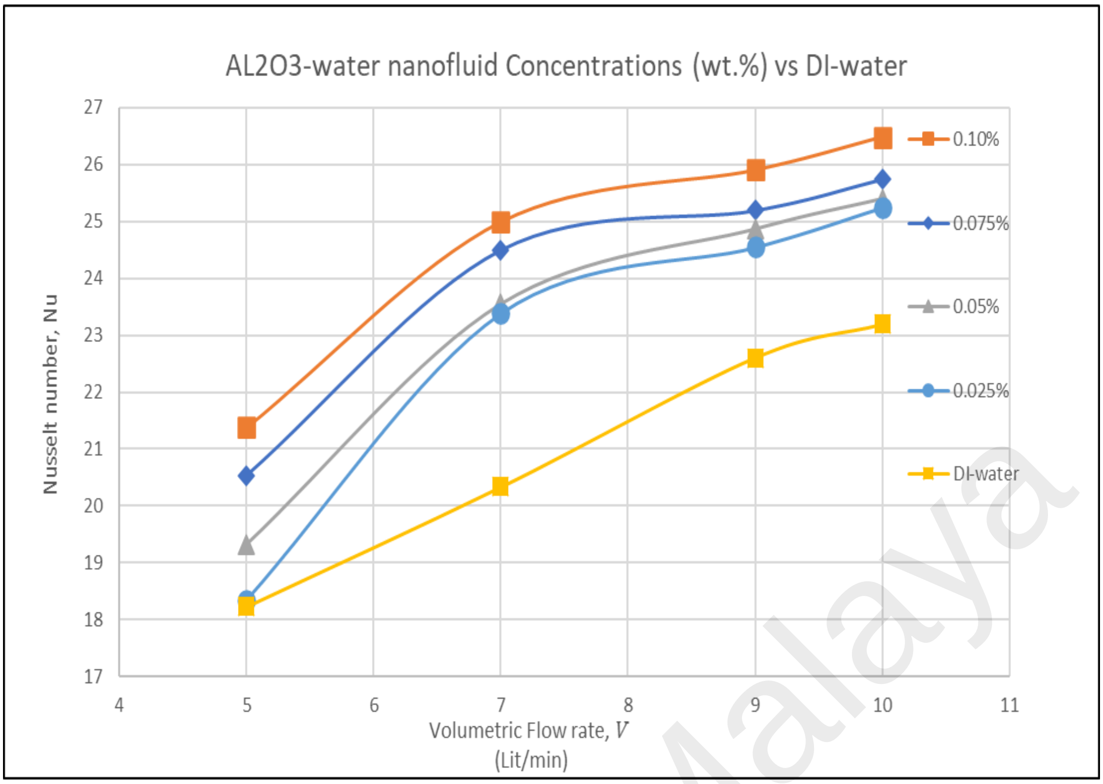


Figure 4. 12: Graph shows the Nusselt number of Al_2O_3-water nanofluid concentrations versus distilled water against Volumetric flow rate

The graph shows that the addition of nanoparticles into the base fluid, we can achieve higher Nusselt number than the data from conventional fluid and by varying the volumetric flow rate we can gain higher Nusselt number values. The highest value were achieved with higher concentration values of Al_2O_3-water nanofluid at 0.1% vol. nanoparticles at the maximum flow rate compared to the corresponding data from water.

To summarize, it can be observed that the highest heat transfer coefficient and Nusselt Number were represented by the Al_2O_3-water nanofluid at 0.1% concentration. This is due to the presence of nanoparticles in the nanofluid which increases the thermal conductivity of the fluid.

Meanwhile, the same principles could be applied for the comparison between Al_2O_3-water concentrations and the distilled water data. The Nusselt number for the 0.05% and 0.025% of the Al_2O_3-water is higher compared to the distilled water data. This shows that the presence of nanoparticles in nanofluid enhances the heat transfer properties of the working fluid

When comparison is done between different concentrations of Al_2O_3-water nanofluid, the highest concentration exhibits the best heat transfer capability with the highest Nusselt number. This is evident, that the gradient for the 0.1% is the highest, then followed by 0.05% and 0.025%.

The same result was obtained through the ANSYS simulation obtained data. The results are clearer in simulation data as there were no external factors that were involved such as insensitive thermocouples and improper insulation that causes heat loss to the surrounding.

CHAPTER 5: CONCLUSION

All the objectives of this study were addressed in the Results and discussion about the data from nanofluids and plain water.

After designing and implementing the construction of a new test-rig with a heat exchanger of circular concentric annular flow passage configuration for this study, it was found that in the annular flow passage Al_2O_3-water nanofluid showed better Nusselt number compared to other flow passage configuration considered by other researchers.

Higher thermal behaviour of the heat exchanger fluid was obtained by the application of low volume percentage of Al_2O_3 nanoparticles, where the synthesis of the nanofluids were performed by probe sonication.

From the study, it can also be concluded that the concentration of Al_2O_3-water nanofluid does have an positive effect to the heat transfer capability of the working fluid. The higher the concentration, the better the heat transfer capability. It was proven through the evaluation of Nusselt Number and Heat Transfer coefficient of Al_2O_3-water nanofluid at 0.1% vol. nanoparticles concentration which was higher than the other lower concentrations.

Application of Al_2O_3 based nanofluids enhanced the heat transfer coefficient about 17% (at 0.1 vol.% Concentration) than that of water alone as heat exchanger fluid which could be the backup of performing design of higher performance heat exchangers.

To support this argument, simulation was done using ANSYS Fluent, where the outcome also indicates that nanofluid at higher concentrations have better thermal properties which can help in enhancement of heat transfer rate.

5.1 Future Work

Current work only focused on improving the working fluid. More research can be done to study the most suitable base fluid such as ethylene glycol or any other oil-based fluid which may improve the overall heat transfer. The future works could explore the betterment of heat exchanger shape (S-shape, dimples, grooves etc.) for further improvement of heat transfer. Besides that, the material used to fabricate the heat exchanger can be looked into. Materials with better heat conductivity shall be used for much improved cooling. We can also look into increasing the concentration of nanoparticles and explore optimization of the nanofluid concentration as it can help in improving the effective heat transfer rate.

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