SYNTHESIS OF ECO-FRIENDLY NANOFLUIDS FOR ENHANCEMENT OF HEAT TRANSFER AND APPLICATION IN DIFFERENT FLOW CONFIGURATION PASSAGES

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SYNTHESIS OF ECO-FRIENDLY NANOFLUIDS FOR ENHANCEMENT OF HEAT TRANSFER AND APPLICATION IN DIFFERENT FLOW CONFIGURATION PASSAGES

ABSTRACT

Since the invention of the heat exchangers, the working fluids such as water, ethyl glycol, oil and many others were used, however, they reveal relatively low thermal conductivity. Eco-friendly nanofluids and the cost-effective annular heat exchangers were introduced in this research to overcome the problem. In the present work, heat transfer coefficient and friction loss analyses of (TiO_2 and GNP) water-based nanofluids were compared with DI-water flowing in annular conduit under turbulent flow regime. The nanoparticle weight concentrations of 0.1, 0.075, 0.05 and 0.025 wt.% were prepared by using a simple two-step method. The DI-water simulations were conducted by using ANSYS Fluent 18.2 (CFD commercial package) under steady turbulent flow conditions at high Reynolds number and constant heat flux boundary conditions with the varied inner flow passage configuration of the annular heat exchanger. The CFD analyses used the finite volume method, uniform surface heat flux boundary condition and SST-k-ω model for the solver. The DI-water simulation demonstrated, the increase of the inner wall temperature in the square passage incomparison to the circular inner geometry. The experimental results exhibited the convective heat transfer coefficient enhancement with the increase of nanoparticles concentrations in the base fluid. The maximum Nusselt number and insignificant increment of friction factor resulted in the addition of nanoparticle into the base fluid. The remarkable enhancement of the heat transfer achievement were, 21.75% and 11.72% for the 0.1 wt.% of GNP-water and TiO_2-water nanofluids over the base fluid in the turbulent flow regime. The results concluded that varying inner shape of the annular conduit and addition of nanoparticles enhances the rate of heat transfer and retards the energy consumption.

Keywords**:** Nanofluid, Heat transfer coefficient, Nusselt number, annular heat exchanger, nanoparticle concentration

ABSTRAK

Sejak penciptaan alat penukar haba, yang cecair kerja seperti air, etil glikol, minyak dan banyak lagi telah digunakan, namun, ianya menunjukkan kekonduksian terma yang agak rendah. Nanofluid mesra alam dan alat penukar haba annular yang menjimatkan kos telah diperkenalkan dalam penyelidikan ini untuk mengatasi masalah tersebut. Dalam penyelidikan ini, perbandingan pekali pemindahan haba dan analisis kehilangan geseran bagi (TiO_2 dan GNP) nanofluid berasaskan air dengan DI-air yang mengalir dalam saluran anulus di bawah rejim bergolak telah dikaji. Kepekatan berat nanopartikel 0.1, 0.075, 0.05 dan 0.025 wt.% telah disediakan dengan menggunakan kaedah mudah dua langkah. Simulasi DI-air dilakukan dengan menggunakan ANSYS Fluent 18.2 (pakej komersial CFD) dalam keadaan aliran gelora yang stabil yang mempunyai bilangan nombor Reynolds yang tinggi pada keadaan fluks haba yang berterusan dan bentuk dalaman penukar haba anular yang pelbagai. Analisis CFD menggunakan kaedah isipadu terhingga, keadaan sempadan fluks haba permukaan seragam dan model SST-k-ω untuk penyelesaian. Hasil simulasi DI-air menunjukkan taburan kenaikan suhu dinding dalam di segi empat sama dengan geometri dalaman bulat. Hasil eksperimen menunjukkan bahawa pekali pemindahan haba konvektif meningkat dengan penambahan pecahan berat nanopartikel ke atas cacair asas. Nombor Nusselt maksimum dan kenaikan faktor geseran yang tidak signifikan hasil dari penambahan nanopartikel ke dalam bendalir asas. Peningkatan pemindahan haba yang luar biasa mencapai 21.75% dan 11.72% untuk 0.1% wt% berat GNP dan TiO_2-air nanofluid berbanding cecair asas di bawah rejim aliran bergelora. Keputusan yang diperolehi menyimpulkan bahawa bentuk dalaman saluran anular yang berbeza dan penambahan nanopartikel meningkatkan kadar pemindahan haba dan menurunkan penggunaan tenaga.

Kata kunci: Nanofluid, pekali pemindahan haba, nombor Nusselt, penukar haba anular, kepekatan nanopartikel

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LIST OF ABBREVIATION

nm	:	Nanometer
HVAC	:	Heating ventilation and air conditioning
GAGNPs	:	Gallic acid-treated graphene nanoplatelets
ANL	:	Argonne National Laboratory
CFD	:	Computational fluid dynamics
GNPs	:	Graphene Nanoplatelets
HT	:	Heat Transfer
Nu	:	Nusselt Number
NPs	:	Nanoparticles
CNT	:	Carbon nanotubes
DI	:	Deionized
MWCNT	:	Multi-walled carbon nanotube
GO	:	Graphene Oxide
mm	:	Millimeter
DPT	:	Differential Pressure Transmitter
LPM	:	Liter Per Minute

CHAPTER 1: INTRODUCTION

In the wake of energy demand and conservation of the environment, transportation and preservation of energy have become one of the essential matter of concern. Heat exchangers are extensively being used in different sectors such as industries, automobiles, power sectors, nuclear reactors and refineries for the heat exchange and utilization of energy. There is a rapid growth of energy consumption with the development in the above-mentioned sectors, saving energy is a day-to-day campaign and resolving the issue of maximum thermal loads has become important. For such scenarios, energy efficiency should be enhanced for the performance of heating and cooling systems to save energy for being utilized by the above-stated sectors. Transfer of heat from one regime to another regime during operation of cooling or heating a system is called heat transfer fluid. The energy-efficient operation needs to replace conventional heat transfer fluids (such as water, mineral oils and ethylene glycol) with the enhanced thermal conductive fluids. Conventional heat transfer fluids have low thermal properties which are not efficient for the heat transfer equipment, so there is always an obstruction on the performance and demand for the new working fluids. The conventional heat transfer fluids are used in a large scale in different sectors such as Energy sectors, chemical sectors, and oil refining, however in specific usages like microprocessors and laptop cooling, electronic gadgets, space application cooling, sensitive medical equipment applications and many other areas where the small size of the heat exchanger is a need. Enhancement of heat transfer requires to improve the system of mechanical design for heat exchangers and improve the working fluid thermal properties. However existing heat transfer systems being developed such as improving heat transfer attributes of fluid, size of the system to a smaller heat exchanger, such studies result for lower capital costs and higher energy efficiency of the system. Micro-size heat exchanger might have been developed in Heating ventilation and air conditioning (HVAC) and automobile industries with effective space-saving and lighter for weight features. Such advantages might bring out as an effective leading to sectors in saving more materials and capital investment. Base liquids (i.e. water, oil and ethylene glycol) having low thermal conductivity might reduce heat transfer coefficient. An efficient heat exchanger is a demand for the proper transportation and utilization of energy while conventional heat exchanger fluids have the limitation on thermal conductivity and heat capacity. Many researchers have been researching convenient techniques to improve the thermal conductivity of heat transfer fluids. Research outcomes became successful in the earlier period with the basic concept of dispersing solid particles (i.e. micrometer-sized or millimeter-sized) in the working fluid to enhance thermal conductivity (Xie, Lee, Youn, & Choi, 2003). Solid particles (Metallic) have higher thermal conductivity than the conventional base fluids for instance at room temperature, copper has 700 and 3000 times greater thermal conductivity than the water and engine oil (Xie, H., Lee, H., Youn, W., & Choi, 2004). Despite the increased thermal conductivity of solid particles, it might not be practiced in real application due to numerous problems associated with the fouling, erosion, pressure drop and sedimentation in the inflow channel and clogging of the channel which might be faced by poor suspension stability when dispersed in the base fluid, usually flow inside the mini and microchannels (Trisaksri & Wongwises, 2007; Wang & Wei, 2009). Over several laboratories research attempted by scientists and engineers to develop a new fluid, which has better heating or cooling measure for the different types of thermal systems in comparison with the base fluid. An experiment for the first time Choi et al. (J. A. Choi, S. U., & Eastman, 1995) at the ANL (Argonne National Laboratory) implemented the particles of nanometer-size (nanoparticle) suspended in solution (as nanofluid) which exhibited a significant increase in the nanofluid thermal conductivity. The improve solubility and dispersibility of nanoparticles size in the conventional base fluid will obstruct immediate sedimentation and lower the clogging with the heat exchanger's boundaries during operation. Such improvements in the thermal conductivity of nanofluids (nanoparticles suspensions) precedes with the efficient performance, energy-efficiency and economical for the system design. Better thermal performance of the working fluids can minimize the energy consumption of the system. Nanofluid can play a vital role in better cooling or heating in a variety of new innovative mechanical miniaturize systems. Small capacity heat transfer systems can be lighter and need less power while using the nanofluids and it will save energy. In Automobile (Vehicles) industries, light design components of the radiators will cause fuel saving, lower NOx, and develop ecofriendly environmental for living. Moreover, Nanofluids suspension is based on the enhancement of thermal characteristics at low concentration and great stability. Improved thermal conductivity of the nanofluids deals with energy saving benefits and better applications like minimized pumping power, lighter and mini cooling system design, higher heat transfer, reduction of mass handling of heat transfer working fluids, improved wear resistance and reduced friction coefficients. These characteristics encouraged the researchers to prepare nanofluids for the different applications where enhancement of thermal energy (like lubricants, metal cutting fluids, coolant, and hydraulic fluids) is the requirement for operation (Saidur, R., Leong, K. Y., & Mohammed, 2011). Particle size of nanofluids does not carry too giant a motion as in case of micro-fluids, which decreased wear and erosion in tube and channel, Figure 1.1 comparison of the effect of nanoparticles and micro-particles with equal volumetric concentration in a cooling method.

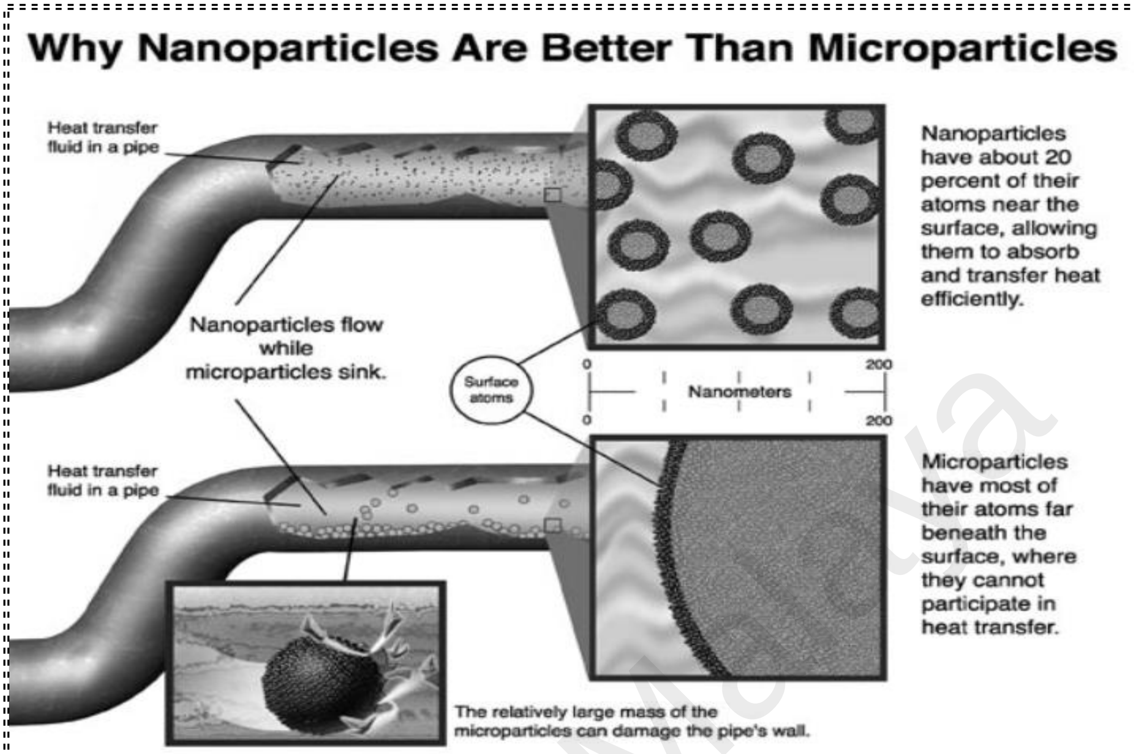

Figure 1. 1: Nanoparticles and Microparticles Effects in a Cooling system

The nanofluids, are the suspension of fluids having comparatively smaller particles less than 100 nm dimension (Ding, Y., Alias, H., Wen, D., & Williams, 2006).

Higher thermal properties of nanofluids continuously became under investigation of the researchers since the past decades, especially their convective heat transfer and thermal conductivity were taken care of incomparison to the conventional base fluids. Numerous experimental studies about nanofluids were conducted and observed great improvement of nanofluid's thermal conductivity (Abareshi, M., Goharshadi, E. K., Zebarjad, S. M., Fadafan, H. K., & Youssefi, 2010; J. A. Choi, S. U., & Eastman, 1995; Duangthongsuk & Wongwises, 2009; Sadri et al., 2014). Convective heat transfer enhancement of nanofluids was recorded by Pak and Cho (Pak, B. C., & Cho, 1998) while experimentally investigated the thermal performance of TiO_2 and γ-alumina (γ-Al_2O_3) with nanoparticle size (diameters of 13 and 27 nm) dispersed in water and inflow through a horizontal round tube under constant heat flux and turbulent flow regime. The experimental results exhibited increasing nanoparticle concentration and Reynold number enhances the Nusselt number of the dispersed fluid. For the better enhancement of heat transfer, the researcher recommended a new correlation in turbulent convective heat transfer of dispersed fluid[1]. Annular heat exchangers are significantly employed for heat transfer applications in different sectors owing to their efficient design and performance. Heat transfer played a vital role in the automobile industries for the efficient design of radiators. Heat exchangers also enriched in chemical industries as stated by Shah and Sekulic (Shah, R. K., & Sekulic, 2003). Weerapun Duangthongsuk et al. (Duangthongsuk, W., & Wongwises, 2009) experimentally researched the convective heat transfer performance and friction factor of TiO_2 (0.2 vol.% concentration) aqueous suspensions under turbulent conditions in a horizontal double-tube counter flow heat exchanger. Their experimental results exhibited that the heat transfer coefficient of the nanofluid does not have any considerable effect by heating fluid's temperature. They found great improvement about 6-11% higher convective heat transfer coefficient of nanofluids than that of the base fluid and it increased by lowering the fluid temperature. Rad Sadri et al. (Sadri, R., Hosseini, M., Kazi, S. N., Bagheri, S., Ahmed, S. M., Ahmadi, G., ... & Dahari, 2017) studied environmentally friendly and facile functionalization approach to synthesize highly dispersed GAGNPs in the water, which is a cost-effective method to use as heat transfer fluids. They observed significant stability of the dispersed solution about 63 days. Heat transfer results exhibited great enhancement in the Nusselt number and convective heat transfer up to 18.75% and 38.58%, at 0.1% weight concentration and constant heat flux condition under fully developed turbulent conditions. Moreover, they resulted in friction factor and pumping power increase as slightly lower and recommended eco-friendly

[1] Dispersed fluid: are related to nanoparticles suspended with base fluids to prepare nanofluid.

nanofluids for vast applications as heat exchanger liquids. Xing Yuan et al. (Yuan, Tavakkoli, & Vafai, 2015) investigated horizontal concentric annuli of varying inner-shape under free convection process while keeping the outer shape fixed. Simulation models were developed and studied with varying inner shape on the flow field and heat transfer analysis. They observed the enhanced heat transfer in the square and triangular annuli higher than in the cylindrical annulus inner shape, also radiation employed vital role in the overall heat transfer under natural convection. The TiO_2 nanofluids were highlighted due to their efficient chemical performance and physical properties towards many researchers. TiO_2 was used in many applications like cosmetics industries, air purification systems, printing cooling system, etc., and globally considered non-hazardous material for living environmental life. However, TiO_2 nanofluids preparation required high consideration of its physical properties for heat transfer related applications (Yang & Hu, 2017). The stability of nanofluids have amazed in the field of heat transfer enhancement, to avoid aggregation and sedimentation of nanofluids. Numerous research is required for the preparation of nanofluids stability and moreover, the limitations of stability measurement and improved techniques are main concern about stability challenges of nanofluids (Javed et al., 2019), because all the mentioned procedures typically perform in very problematic and toxic rection conditions.

1.1 Problem statement

Conventional heat exchangers are not efficient enough to perform the task of cooling load in many specific vocations by their compact design and working fluid. The synthesized nanofluids of high thermal conductivity have been introduced by scientists to meet the challenge of the high demand for transportation of energy, but in most cases, the nanofluids and conventional fluids are processed with corrosive and environmentally hazardous chemicals. The present work focuses on developing an environmentally friendly procedure to synthesize nanofluids for heat exchangers and accomplish relevant characterization. Hence, the green synthesized (eco-friendly) working fluids might be a considerable choice to have superior thermal performances and energy saving (Sadri, R., Hosseini, M., Kazi, S. N., Bagheri, S., Ahmed, S. M., Ahmadi, G., ... & Dahari, 2017) for use in a heat transfer application to achieve aforementioned challenges.

1.2 Scope of Study

This study presented the development of an eco-friendly and industrially processable technique for the synthesizing of TiO_2 and GNPs covalently functionalized with gallic acid, and a cost-effective process to determine the performance of the modeled technique in enhancing forced convective heat transfer in small annular heat exchanger in comparison to the distilled water. The TiO_2 and GNPs nanofluids were prepared by using water as the base fluid at four different nanoparticle concentrations. Compare the results obtained experimentally and ANSYS Simulation with the data of DI-water. The nanoparticles concentrations, 0.1%, 0.075%, 0.05% and 0.025 wt.% of TiO_2-water and GNPs-water nanofluids studied during the experimental work. The results were based on heat transfer (HT) and Nu (Nusselt number) of nanofluids under turbulent conditions using constant heat flux in the annular pipe. The simulations were conducted under steady turbulent flow conditions where the Reynolds number varied from 2300 to 5000. Computational fluid dynamics (CFD) commercial package ANSYS FLUENT 18.2 software was used to obtain the heat transport in the annular geometry and varying the inner geometer (cylindrical to the square bar) under hydrodynamically constant conditions. The CFD analysis used the finite volume method, uniform surface heat flux boundary condition and SST-k-ω model for the solver.

1.3 Objectives

To meet the required demands of synthesis of high-quality heat exchanging liquids, the present research has focused on the following objectives.

1. To synthesis of nanofluids applying a process of environmentally friendly approach, functionalization of the nanoparticles were achieved by bio-based and eco-friendly methods.
2. To investigate thermo-physical attributes of nanofluids comparison for heat exchanging liquids. Experimental investigation and simulation in a modified test rig to compare the synthesized liquid performance in heat transfer application.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Throughout history, researchers worked on the area of heat transfer phenomenon in the enhancement of heat transfer performance, which highly affects the need for their life. Heat exchangers devices, heat transfer fluids or other components related to heat transfer invented and become more important to a better work environment. The design of the device is being advanced and heat exchange plays an important role in the device in the industry.

Most industrial sectors and technologies are facing major issues for energy saving in different applications operations such as heat exchangers systems, solar heater collectors and heating or cooling devices. However, the conventional fluids (mineral oil, water, ethylene glycol, and propylene glycol) use for the cooling or heating in heat transfer applications with low thermal conductivity which affects the effectiveness of the system. Though, this phenomenon demands to search for the high-efficiency heat transfer fluid and resolve the challenges. Based on previous methods, highly conductive solid particles are dispersed within the base fluid to enhance the thermal conductivity of liquid (Ding, Y., Alias, H., Wen, D., & Williams, 2006).

In 1985, Argon National Laboratory started research to develop for the enhancement of heat transfer fluid applications. Masuda et al. (Masuda, Ebata, Teramae, & Hishinuma, 1993) initially, studied viscosity and thermal conductivity characteristics of ultra-fine powders TiO_2, Al_2O_3 and SiO_2 dispersed with water by electrostatic repulsion technique in Japan experimental lab. However, their results found that TiO_2-water and Al_2O_3-water were exhibited effective thermal conductivity increase with more particle concentrations, while SiO_2-water didn't seem effective. Choi (J. A. Choi, S. U., & Eastman, 1995) followed Masuda's research and stated the outcome of nanoparticle colloidal dispersion to gain improved thermal conductivity which invented to form nanofluids. Based on earlier researchers' findings of the effective thermal performance of nanofluids, it fascinated the existing scientists and industrial specialists to utilize the growth of nanofluid in heat transfer applications. The fascination and effective performance of this field is noticeable from the progress report on the publication about nanofluids in the different fields, Figure 2.1.

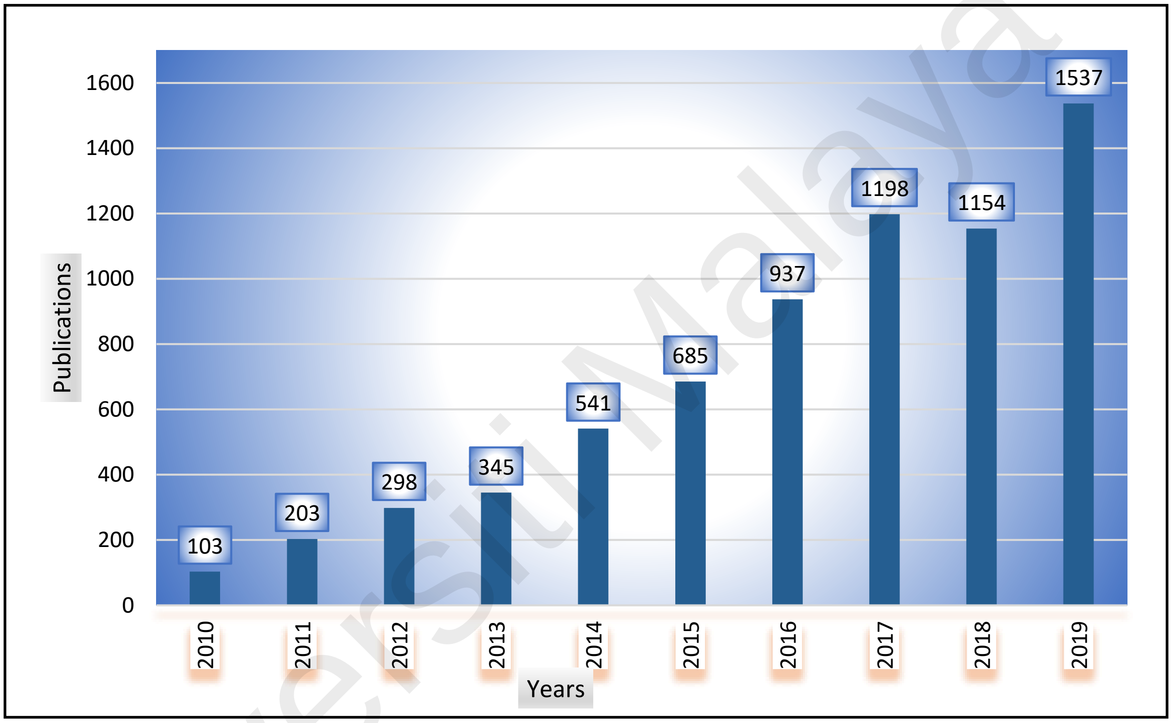

Figure 2. 1: Nanofluids publications (*Web of Science, *2019)

Many researchers and engineer specialization reviewed the fiscal method of nanoparticle production and formulation of nanofluids for experimental and application purposes. Moreover, they highly experimented with the efficient process of viscosity, thermal conductivity and heat transfer of nanofluids suspensions such as production techniques of nanoparticle, nanoparticle size, and weight concentration, disperse base fluids, temperature, etc. In this chapter, review and discussion on the synthesis of nanofluids, properties of nanofluids like thermal properties and heat transfer are stated.

2.2 Nanofluids

In the past two decades, scientists and engineers have been of great interest for the enhancement of heat transfer fluids efficiency. Conventional heat transfer fluids are water, mineral oils and ethylene glycol (EG), which have poor characteristics of heat transfer than solid particles (nanometer-sized). In recent years of research, nanofluids have been investigated as potential heat transfer fluids. Suspension of nanometer-sized particles in the base fluids (water, EG and mineral oils) are termed as nanofluids (Sidik, N. A. C., Mohammed, H. A., Alawi, O. A., & Samion, 2014).

Nanofluids are being formed by the engineering colloidal suspension procedure of nanometer-sized (range less than 100 nm) materials whichever in the shape of nanorods, nanotubes, nanoparticles, or nanowires in the conventional-fluids[2]. Nanofluids are the new type of engineering fluids in the heat transfer process, exhibiting several applications having great thermal conductivity, efficient cooling, and lubrication which makes appreciable in many heat transfer applications (Devendiran, D. K., & Amirtham, 2016).

Choi et al. (J. A. Choi, S. U., & Eastman, 1995) proposed Nanofluids with great thermally potential for being a new class of working fluid. Thermal conductivity is an important factor for nanofluids to enhance the heat transfer, while many factors such as pH scale, nanometer-sized particle and zeta potential can affect the nanofluids thermal conductivity properties, which are not promising to better thermal conductivity value, moreover experimental outcomes stated developing region have higher heat transfer coefficient than the developed region (Anoop, K. B., Sundararajan, T., & Das, 2009). Nanoparticles size is a key factor to restrict the clogging and sedimentation, while ultrafine size nanoparticles nanofluids might flow efficiently in the microchannel and heat transfer system size might be downsized for

[2] Conventional-fluids: this is base fluids (Water, oil, ethylene glycol etc.)

the usage of nanofluids with high efficiency. Different kinds of nanoparticles like metal oxides (Titanium dioxide (TiO_2), zinc oxide (ZnO), copper oxide (CuO), aluminum oxide (Al_2O_3), silicon dioxide (SiO_2) and iron(iii) oxide (Fe_2O_3)) have been experimented to form nanofluids with enhanced thermal conductivity. Newly, carbon-based nanofluids were observed with considerable enhancement in various rheological, thermo-physical and heat transfer properties in the novel (Ding, Y., Alias, H., Wen, D., & Williams, 2006; Zubir et al., 2015). Most common nanoparticles and conventional base fluids exploited in synthesis are followed in Figure 2.2.

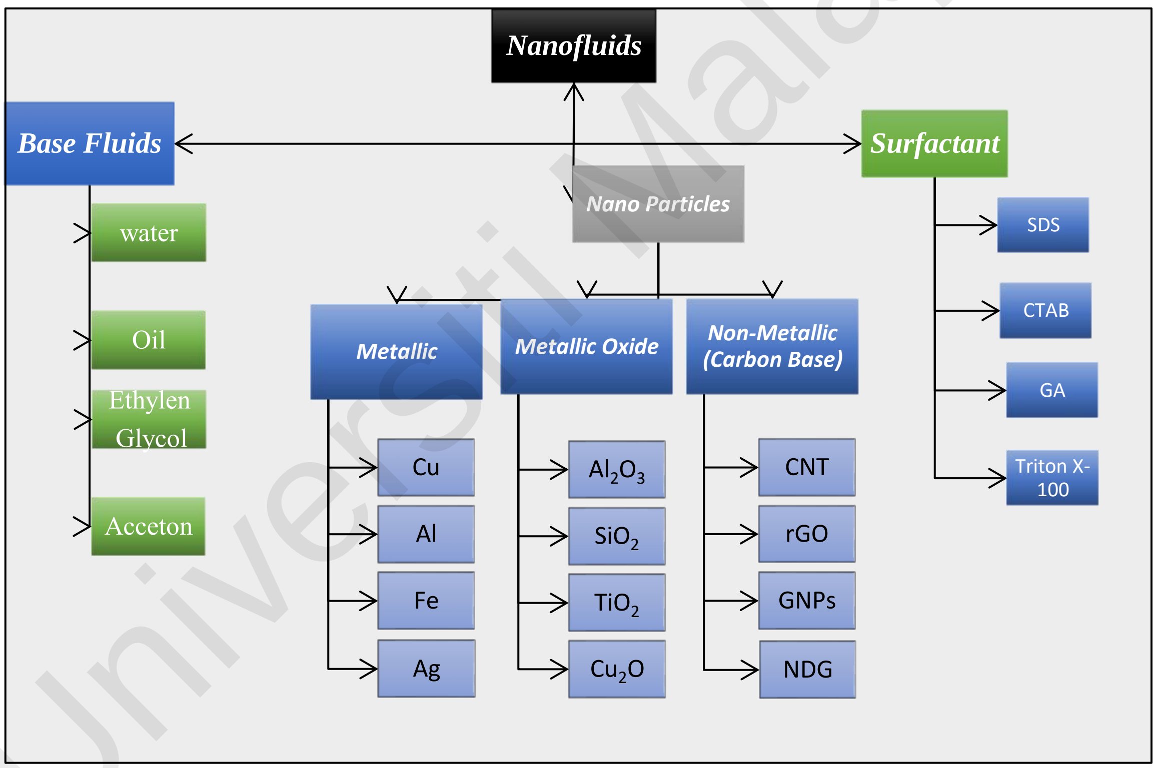

Figure 2. 2 Base fluid, nanoparticles and Surfactants for Synthesis Nanofluids

2.2.1 Metal-Oxide Materials

Metal-oxides are used in many fields of physics, chemistry and materials science, while metal oxide-based nanofluids are being employed mostly for heat transfer applications and higher thermal performance. The higher thermal conductivity of pure metals, easy to produce economically to use metal-oxide nanoparticles. The most eco-friendly metal oxide-NPs (Al_2O_3, TiO_2, ZnO, Si_2O and Fe_2O_3) result in remarkable chemical and thermo-physical properties (Hendraningrat, L., & Torsæter, 2015).

2.2.1.1 Titanium dioxide (TiO_2)

Titania (TiO_2) is found in white oxide ceramic and being formed in three various crystalline shapes such as anatase, rutile and brookite structures (Figure 2.3), meanwhile, anatase and rutile structures of TiO_2 are available commercially. Most of the usage on rutile TiO_2 pigments due to its high scatter light performance, stability and efficient durability than anatase pigments(Alireza, K., & Ali, 2011). Titanium dioxide (TiO_2) nanomaterials have considerable great scientific research invention since 1972 and have been broadly being employed in many applications like the eco-friendly removal of pollutants and sustainable energy generation (Kang, X., Liu, S., Dai, Z., He, Y., Song, X., & Tan, 2019). TiO_2 nanoparticles are generally researched photocatalytic anti-bacterial study among other nanoparticles and used in semiconductor photocatalyst applications. Manuel et al. (Nuño, Ball, & Bowen, 2016) analyzed the TiO_2 powders commercially available in anatase power, efficient photocatalyst (Aeroxide P25) and aqueous phase and gas phase, moreover, TiO_2 is also capable to decompose of CO_2 for the environmental safety. TiO_2 is widely used for hydrophilic coatings and self-cleaning devices applications and sometimes it's being used for the waste treatment (waste-water pollutants). TiO_2 is also used to produce hydrogen (H_2) fuel from the source of renewable energy and natural energy resources by its photocatalysis properties.

Figure 2. 3 TiO_2 nanoparticles shapes and applications

Many researchers have been experimentally investigated TiO_2 nanoparticles in different heat transfer systems and studied the effects of their thermal performance. Usage of titanium oxide nanoparticles with base fluid exhibited enhancement in the thermal conductivity of the nanofluids in many heat transfer applications such as heat sinks, automobile systems and heat exchangers and pressure loss was not significant in the presence of nanoparticles, saving the pumping power with high thermal performance (Kang, X., Liu, S., Dai, Z., He, Y., Song, X., & Tan, 2019). TiO_2 is globally recognized eco-friendly material without being hazardous for living environmental and generally used in air purification, printing, solar collector, etc. applications.

2.2.2 Carbon base materials

Carbon nanostructures are carbon allotropes not less than 1_D (One dimension) in the nano-meter range. Carbon allotropes and compounds dominate highly attention in terms of their performance to conduct heat. The graphene nanoplatelets (GNPs), carbon nanotubes (CNTs) and nanostructured carbon materials have achieved remarkable interest by their efficient mechanical, thermoelectric properties and thermal performance which bring them to commercial applications for heat transfer (Balandin, 2011).

2.2.2.1 Graphene nanoplatelets (GNPs)

Graphene nanoplatelets have received more consideration towards scientists by their remarkable mechanical and thermoelectric attributes, moreover having atomically thin and two-dimensional lattice of Sp^2-hybridized carbon,(Figure 2.4) has shown unique thermo-physical performance (Sadri, R., Hosseini, M., Kazi, S. N., 2017). Such properties of nanoparticles have gained high attention in the application of heat transfer and various applications such as conductive thin films, inkjet printing, solar cells, polymer composites, and heat exchangers. Using GNPs is needed because these are being synthesized easily and inexpensively compared with graphene or CNT (Bahiraei & Heshmatian, 2019). Though, the attributes of nanofluid might not be accomplished by dispersing the nanoparticles with conventional liquids. Moreover, to high specific surface area, graphene keeps movement to gather by strong π-π stacking interaction, while dispersibility of graphene-water is kept one of a key character in heat transfer system (Yang, Y., Qiu, S., Xie, X., Wang, X., & Li, 2010). Therefore various researches were conducted by scientists to get better stability of graphene in different organic and base-fluids under physical and chemical approaches on the covalent and non-covalent functionalization of graphene.

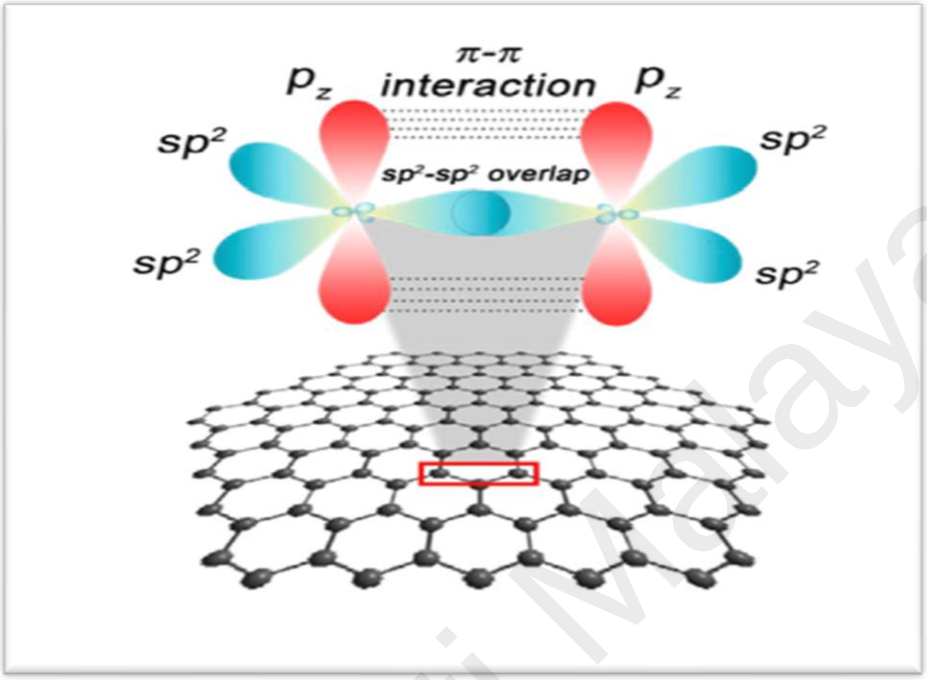

Figure 2. 4 Graphene nanoplatelets structure

2.3 Nanofluids Preparation

The preparation of nanofluid is an important procedure to achieve better stability and thermophysical performance. Nanoparticles are dispersed with base fluids by using two well-known techniques such as one-step method and two-step method. The presence of strong reactive van der Waals forces in the suspension of nanoparticles with base fluid is the challenge for the preparation of nanofluids. The size of nanoparticles is caused the colliding, clustering effects and sedimentation during flow in a microchannel. The appropriate method of dispersion of nanoparticles in base-fluid is the stability of suspensions, durability and stable thermal conductivity of nanofluids which are performing vital characteristics in the preparation of nanofluids. The eco-friendly and fiscal method of nanofluids preparation makes more remarkable growth to use nanofluids. Xuan and Li (Xuan, Y., & Li, 2000) stated for stabilizing the suspensions of nanofluids, used listed techniques:

1. Modifying the pH-value of the suspension
2. Adding surface-active substance in the solution
3. Applying ultrasonic vibration

Techniques might improve the surface attributes of the suspended nanoparticles and might be manipulated to avoid the aggregation of particles in the fluid, moreover, applying these techniques required for mostly unstable nanofluids condition.

Usually, Nanofluids are mostly formed by the suspension of nanoparticles like metals (Fe, Cu, Ag, Au), metal-oxides (ZnO, TiO_2, Al_2O_3, SiO_2, SiC) and carbon-based materials (Graphite, Diamond, MWCNT) into conventional fluids by formulated in two techniques: one-step method and two-step method

2.3.1 One-step method

The single-step techniques implemented the suspension of nanoparticles into the required base fluid associated with their generation process via a single method. So that the different processing such as drying, storage, transportation, and dispersion are sidestepped in the one-step, while the dispersion of NPs in the fluid in improved and clustering is lowered as compared to other methods. This method is processed further based on physical methods and chemical methods under various materials properties. Physical methods are directly contacted with the preparation of nanofluid, which are well known as vapor deposition, laser ablation and submerged arc methods (Yang & Hu, 2017). Choi (Choi, S. U., & Eastman, 2001) invented this 'direct-evaporation' method having a closed system with a cylinder filled with conventional fluid that is being circulated the centroid source materials and vaporized in the middle of the system. The condensation of material being gathered with cooled liquid, as shown in figure 2.5.

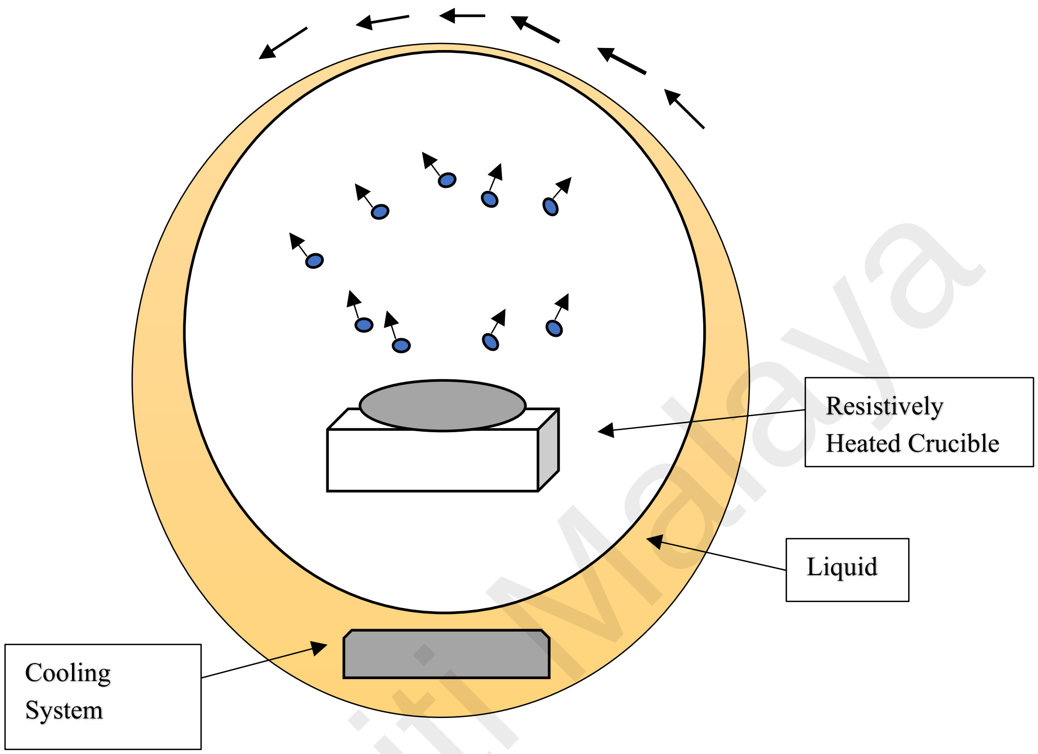

Figure 2. 5: Schematic of Single-step (vapor-deposition) method

The vapor deposition method is being used most of the time for lab experiments for the preparation of nanofluid. The preparation of nanofluid was too small quantity by using the single-step method and only performed for the lab research work. However, the major drawbacks of single-step methods are slow production and energy consumption required for the processing while more cooling required for the system and this was the main reason for the reduction of mass production.

2.3.2 Two-step method

The two-step method is the easiest way to produce nanofluid due to the advancement of technology. Nanoparticles are initially available in dry powders (which was prepared by sol-gel methods, hydrothermal synthesis or other well-known procedure) in different sizes by the manufacturer and suspend the NPs into the desirable base fluid. The two-step technique (figure 2.6) is mostly employed for the preparation of TiO_2 nanofluids since the synthesis procedure has utilized by the industrial mass production of TiO_2 nanoparticles.

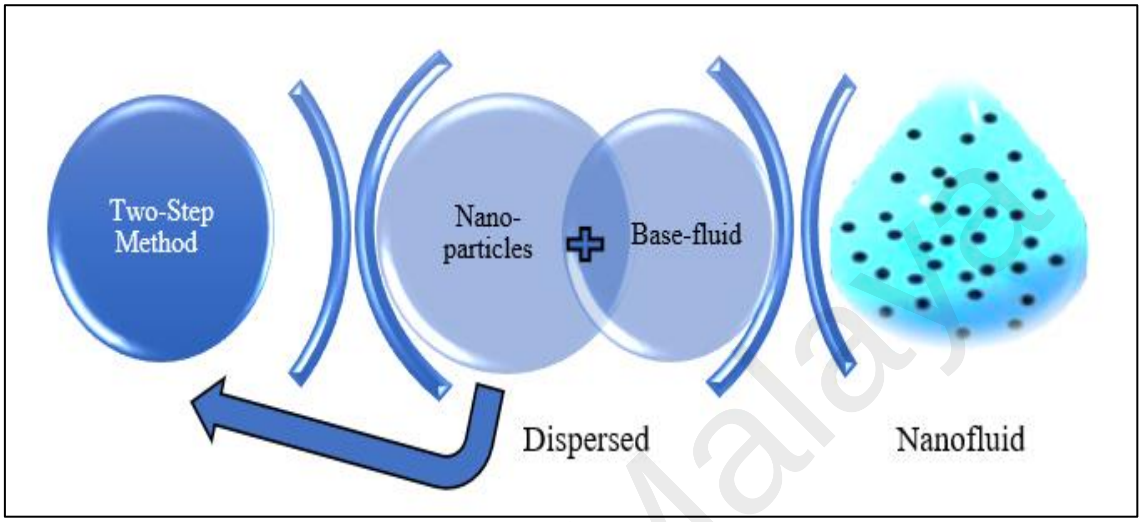

Figure 2. 6: Schematic of Two-step method

The rapid growth of this technique is the mass production of nanofluids on the industrial sectors and the main disadvantage is sedimentation and clustering of nanoparticles in the liquid caused by internal van der Waals forces effect. Ultra-Sonication or other advanced machining devices are employed to the proper preparation of nanoparticles and achieve the clustering effect challenges, moreover, consideration of sonication time should keep the nanoparticles higher stability loading to reduce the viscosity and enhance the thermal conductivity of nanofluid (Choi, 2009). This method is more commercialized to prepare nanofluids with low processing costs and availability of nanoparticle manufacturers as compare to the single-step method.

2.4 Stability of nanofluids

The Preparation of nanofluids has faced important concerns towards the stable nanofluid. The nanoparticles can gather caused by the high van der Waals forces assembling between them. The stability of nanofluid is achieved with additional processes in physical or chemical treatment. The procedures are involved in the improvement of nanoparticle surfaces by adding the surfactant with dispersed fluid or applying capable forces to meet cluster challenges of nanoparticles. Untreated higher nanoparticles size will be create clogging, sedimentation and aggregation which can affect the thermal conductivity performance and higher the viscosity cause more pumping power and inclined the specific heat of the suspension fluid (Arshad, A., Jabbal, M., Yan, Y., & Reay, 2019).

Numerous experimental research conducted by scientists and engineers to keep the stability of nanofluids and efficient thermophysical attributes of the fluid. Various stability evaluation techniques were studied in the field of nanofluids as listed:(Ali, N., Teixeira, J. A., & Addali, 2018; Bahiraei & Heshmatian, 2019).

1. Zeta potential measurements
2. Transmission Electron Microscopy (TEM)
3. UV-Vis spectrophotometer
4. Thermal conductivity measurement
5. Scanning Electron Microscopy (SEM)
6. Sedimentation balance method
7. 3ω method

Moreover, 0.1 wt.% concentration experimented and resulted in long-term stability excluding the addition of surfactant and formed the better dispersion of nanofluids by settling the desired pH-value of liquid. TiO_2 nanofluid might maintain the stability for months through settling the pH-value up to 11 employing ultrasonication vibration (He, Y., Jin, Y., Chen, H., Ding, Y., Cang, D., & Lu, 2007). Graphene-based materials are employing to enhance the stability challenges while preparing nanofluids to disperse the nanoparticles in the conventional liquid. The property of hydrophobic in the graphene materials might not be dispersed in stable conditions for a long time in the liquids and exhibits to cluster after a while. The covalent and non-covalent functionalization techniques have been experimentally applied to improve the stability with different fluids of graphene materials (Bahiraei & Heshmatian, 2019).

2.5 Ultra-sonication vibration

The ultra-sonication is a physical method which widely used for the stability of nanoparticles in the nanofluid preparation to apply ultrasonic sound waves. This pulse generated method is disturbed the solution of nanoparticles and base fluids that formed to reduce the nano-sized aggregation through un-bonding intermolecular interactions. Various instruments such as (processor, homogenizer, and ultrasonic (bath and prob types)) being used by researchers for disintegrating the clusters or agglomerations related to the previous experienced like high shear and magnetic stirrer. Though the sonication method is mostly employed by the nanofluid two-step method preparation with optimum sonication time and effective pulse to reduce the aggregation of nanoparticles (Ali, N., Teixeira, J. A., & Addali, 2018). Palabiyik et al. (Palabiyik, I., Musina, Z., Witharana, S., & Ding, 2011) experimentally found that the TiO_2 nanoparticles sized reduced by raising the sonication time and achieved the stability of solution after completing the stated sonification time.

Tavman et al. (Tavman, I., Turgut, A., Chirtoc, M., Hadjov, K., Fudym, O., & Tavman, 2010) experimentally resulted that thermal conductivity of TiO_2 nanofluid was enhanced without the addition of any type surfactant while being prepared by the ultrasonication with various concentrations 0.2, 1.0, 2.0 vol.% in DI-water.

Rad Sadri et al. (Sadri et al., 2014) studied the impact of the surfactant types, ultrasonication time and temperature on the thermal conductivity and viscosity characteristics of carbon-based materials (MWCNT) nanofluids. The experiments exhibited the enhancement of thermal conductivity improved and CNT nanoparticles aggregated into the weaker size and dispersed fully with fluids due to influences of sonication time. Moreover, viscosity was found low by subjecting the maximum sonication time and such results are useful for the heat transfer applications commercially.

2.6 Thermo-physical characteristics of nanofluids

Nanofluids have some key parameters of thermo-physical properties for the convective heat transfer application which are noticed for the present project based on the nanofluids thermo-physical performance for instance viscosity, thermal conductivity, density and specific capacity.

2.6.1 Thermal conductivity

Thermal conductivity is a key characteristic for improving the heat transfer performance of a nanofluid. Revising various factors such as heat flux, differential temperature, surface area and coefficient heat transfer can enhance the heat transfer application in the flowing fluids. The heat transfer coefficient is generally based on the function of Nu and thermal conductivity of the flowing fluids. Though nanofluids having high thermal conductivity plays a vital role in the development of nanofluid growth. Many researchers have conducted studies for the enhancement of thermal conductivity of nanofluid based on various methods. In 1995, Choi (Choi, S. U., & Eastman, 1995) studied firstly that the thermal conductivity of the base fluid could be enhanced with the dispersion of nanoparticles. The results exhibited that the prepared nanofluid has gained higher thermal conductivity than the conventional fluids and saved the heat exchange pumping power due to remarkable heating or cooling performance.

The thermal conductivity of the base fluid can be improved by the dispersing of solids (such as metals, metals and nonmetal-oxides), composites, etc. in nanometer-sized into the conventional base fluid. The heat transfer application is widely used in different sectors in the heat exchanger system, however, most of the researchers have been employing the different nanofluid to various heat exchangers to improve the thermo-physical performance (Hajatzadeh Pordanjani et al., 2019). Hence, thermal conductivity is influenced by the mostly temperature, particle volume concentrations, and dispersed base fluids, as the results stated by the numerous experiments using TiO_2 nanofluids with the water as base fluid instead of ethylene glycol exhibited remarkable improvement in thermal properties. The temperature and variation in nanoparticle concentrations have influenced the thermal conductivity of TiO_2 (Ali et al., 2018). Rashidi et. al (Hajjar, Z., morad Rashidi, A., & Ghozatloo, 2014) studied the enhancement of thermal conductivity of graphene oxide using the modified Hummers technique with the influences of GO temperature variations and concentration. The results exhibited that enhancement of thermal conductivity improved with a high concentration of graphene oxide and as well as enhancement achieved with dependent of temperature variation. An eco-friendly procedure for the synthesizing the functionalized GNPs for the use of heat transfer application by the Sadri et. al (Sadri, R., Hosseini, M., Kazi, S. N., Bagheri, S., Ahmed, S. M., Ahmadi, G., ... & Dahari, 2017) during experimental research. The GAGNPs-water suspension with various concentration results showed the excellent increase in the thermophysical properties (Nusselt number and convective heat transfer coefficient) and slightly increase in the pumping power and friction faction as compared to water.

2.6.2 Viscosity

Viscosity comes into play due to the internal friction of flowing fluid that is involved in the computation of the pumping power in the heat transfer system. The dynamic property of nanofluid is the force of the suspension to create obstacles in the flow. Nanofluid heat enhancement is affected by the inclination of effective viscosity due to the addition of nanoparticles in the conventional fluid. The growth of viscosity performance in the nanofluids indicates the major pressure losses and creates maximum load on the pump. The important measures that create the viscosity in the nanofluids are the NPs concentrations, particle structure, dynamic behavior of base fluid, temperature, pH-value and shear rate (Ali, N., Teixeira, J. A., & Addali, 2018). Under low Reynold number flow conditions, the convective heat transfer coefficient, pumping power and pressure deficiency caused by the viscosity characteristics of nanofluid. As previous studies resulted that the viscosity of TiO_2 nanofluids is being more influence by the addition of nanoparticle size and concentration than in thermal conductivity performance, however, the viscosity of nanofluids declined s the temperature raised with various particle solution (Yang & Hu, 2017). Several studies were investigated by the researchers on the viscosity of graphene nanofluids. The outcomes of reports on the interrelation between the nanoparticle concentration and temperature, increasing the temperature could be declined in the viscosity of nanofluids. Many standard models are applied to characterize the viscosity such as Einstien viscosity model, power Bingham plastic model and Herschel-Bulkley model (Karimi-Nazarabad, M., Goharshadi, E. K., Entezari, M. H., & Nancarrow, 2015).

2.6.3 Specific heat capacity

The specific heat capacity (C_p) is another important characteristic for the fluid that is derived as the heat added the body under a specified procedure to raise the temperature of 1 mole. The thermal performance of the nanofluid is evaluated by the specific heat value in the fluid. Though, it seems in some research findings stated that the addition of nanoparticles into the base fluid improves the thermal conductivity, and caused to lower the heat capacity of nanofluid, which obstructs the growth of nanofluid in the field of heat transfer (Higano, M., Miyagawa, A., Saigou, K., Masuda, H., & Miyashita, 1999). The enhancement of the heat capacity of the nanofluid can make the process of heat transfer cost-effective and efficient.

The C_p of nanofluids exhibits that the structure of nanoparticles including shape, size, concentration employs a key parameter in the specific heat capacity. Two well-known C_p-models have been explained to numerically and experimentally derive the specific heat of nanofluid (Angayarkanni, S. A., & Philip, 2015).

Model (i): Comparable to ideal gas mixtures theory the nanofluid specific heat is described as:

$$C_{p,nf} = \phi C_{p,n} + (1-\phi) C_{p,bf} \tag{2.1}$$

Where, $nf = nanofluid, bf = basefluid\ and\ n = nanoparticle$, moreover equation (2.1) has applied to many experimental and numerical simulations for the heat capacity of nanofluid.

Model (ii): This model is based on the thermal equilibrium assumption between the base fluid and nanoparticles, applying classical and statistical mechanics, $C_{p,nf}$ is described as:

$$C_{p,nf} = \frac{\phi(\rho\, C_p)_n + (1-\phi)(\rho C_p)_f}{\phi\rho_n + (1-\phi)\rho_f} \tag{2.2}$$

Where ρ_n and ρ_f are the densities for the nanoparticles and fluid in the equation (2.2), and the ρnf densities described as:

$$\rho_{nf} = \frac{m_{nf}}{V_{nf}} = \rho_n + (1-\phi)\rho_f \tag{2.3}$$

equation (2.3), m_{nf} and V_{nf} are the ratio of mass and volume of nanofluid.

2.6.4 Density

Density is the main property of nanofluid, the importance of the study related to the various phase of the nanofluid mixture such as solid particles and base fluid. The density of solid is a concern with the ratio of mass and volume while fluid density relates to the temperature behavior. In the nanofluid relationship, characteristics like volume fraction of nanoparticles and temperature affect density. The density of fluid has to affect like viscosity, which has to affect the over the pumping power as well as increase the friction factor and pressure drop and also the behaviour of flow parameters such as Nusselt number, Reynolds number and performance of convective heat transfer coefficient of heat transfer fluid operation. Nevertheless, researchers stated that dual-phase medium (particles and fluid) density is calculated with the help of weight fraction or volume concentration of a fluid. However, the nanofluid density rises with a higher concentration of nanoparticles under constant temperature (Arshad, A., Jabbal, M., Yan, Y., & Reay, 2019). Though, research on the density of graphene was reported by Liu et al. (Liu, J., Wang, F., Zhang, L., Fang, X., & Zhang, 2014) to investigate the thermodynamic properties and thermal stability of graphene-water based nanofluid with weight (wt.%) 0.03% and 0.06%. The finding exhibited that density and specific heat capacity of graphene-water nanofluid reduced with the increase of (wt.%) of graphene nanoparticles.

2.7 Pressure drop and heat transfer of nanofluid

The heat transfer parameter is an important need for the growth of nanofluid to use in the heat exchanger application. So, the application of nanofluid in heating or cooling is based on the performance of heat transfer flow conditions. The nanofluid is selected on the performance of heat transfer features in different applications. The microscopic motion of heat transfer between the surface of the equipment and working fluid without being mixed with a source of heat energy is known as convective heat transfer. The effectiveness of nanofluid heat transfer is termed as heat transfer coefficient (h), which is measured as thermophysical characteristics of the fluid heat transfer, including features such as thermal conductivity (k), viscosity (μ), density (ρ), and heat capacity (C_p). He et al. (He, Y., Jin, Y., Chen, H., Ding, Y., Cang, D., & Lu, 2007) investigated the flow behavior of TiO_2-aqueous nanofluid and heat transfer with varying the particles sizes and volume concentration. The result exhibited the convective heat transfer improved with the adding of nanoparticle concentration, moreover, enhancement of heat transfer was better under the turbulent condition of flow and pressure drop of nanofluid raised with adding of nanoparticles in the base fluid.

The pressure drop of nanofluid was caused by several characteristics such as nanoparticle structure, thermophysical properties, fluid flow conditions, internal pipe flow design, etc., which can affect the pumping power for energy usage. The potential benefits of nanofluid in the industrial application include a heat transfer fluid that has efficient heat transfer performance and little effect on the pressure drop during the process. Duangthongsuk et al. (Duangthongsuk, W., & Wongwises, 2010) experimentally studied the pressure drop and heat transfer performance under turbulent flow in a double-tube counter flow heat exchanger, TiO_2-water nanofluid with varying volume concentration 0.2-2vol.%. The findings stated that the volume concentration of ≤1.0 vol.% TiO_2-water has gained drastically around 26% higher heat transfer than the base fluid, while the pressure drop of the nanofluid affects by the increase of flow behavior (Reynolds number) and small rise with the addition of particles.

So, these features of nanofluid are important for the application of heat transfer.

2.8 Simulation study of flow

The simulation method uses advanced computer-based software to find out the results of the experiments. The numerical findings on the nanofluids subjected in the novel are substituted in terms of single and multiphase models. The single-phase model is one of the efficient techniques if there is less process complexity and minimum computational converge time requiring high simulation conformity of the nanofluid characteristics. While the multiphase flow with the fluid and solid particles are measured by the flow factors such as turbulent, gravitational effects and Brownian under varying the velocities. The relative motion inside the flow and define the boundary function of nanofluids for the simulation.

Oon et al. (C. S. Oon et al., 2012) numerically simulated that to examine the heat transfer and flow behavior of air under sudden expansion in an annular pipe. The constant heat flux method and changing the Reynold number are kept for the heat transfer observing. The numerical simulation resulted in the local Nusselt number (Nu) rises with the growth of Reynolds number (Re) in the separation flow. The diffusion process is also noticed for the changes in the transport method of the flow in the simulation. The simulation keeping the single-phase model with constant thermophysical characteristics on nanofluids was a remarkable success. Sean Oon et. al (Cheen Sean Oon et al., 2015) simulated that to investigate the thermal performance of TiO_2 nanofluid in a horizontal double-tube heat exchanger under the turbulent condition at different step height ratios. The quantifying defined mesh for the symmetrical geometry and well-known model k-epsilon 2nd order implicit method was applied for the higher Reynold number under constant heat flux. The results exhibited that TiO_2 nanofluids indicate with remarkable improvement in heat transfer performance as associated with water, moreover, higher the Reynolds number raises the Nusselt number and the heat transfer coefficient of the working fluid.

CHAPTER 3: METHODOLOGY

The methodology chapter includes the different stages of the experiment. Firstly, the preparation of new design test-rig for the experiment setup, installation of various equipment as per required data calculation.

3.1 Description of Experiment Study

The new design of the experiment test-rig system was introduced in the mechanical lab for the study, where the fabrication of the test-rig was carried out in the workshop. The following steps were carried out to prepare the test-rig for the study:

3.1.1 Test-rig Experimental Setup

The new setup for the test-rig was carried out inside the mechanical workshop at the University of Malaya. The straight stainless-steel tube and stainless-steel circular rod were cut according to the measurement of 1380 mm length. The stainless steel tube diameters are 40 mm of outer diameter and 37 mm of internal diameter while the circular rod diameter is 12.7 ±0.05 mm, however, the sharp edges of the cutting area were polished to keep the surface smooth without any visual roughness. The five grooves were cut on the surface of stainless steel at the distance 200 mm each as shown in figure 3.1 and kept both ends grooved with 135 ±0.5 mm for the thermo-wells placement.

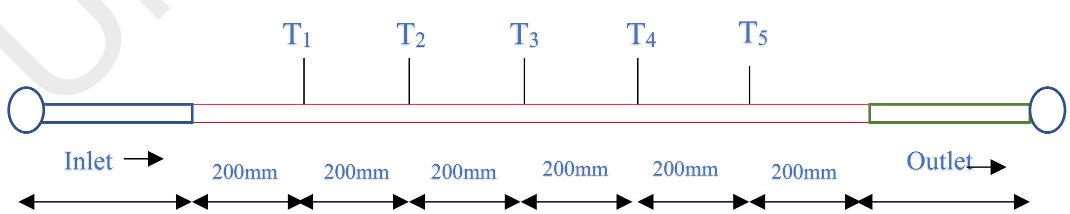

Figure 3. 1: Sectional view of tube surface

The thermo-well slots were equally cut as per the measured design requirements and the nipples were welded at the pressure-measuring tube slots for inlet and outlet pressure tapping.

Both ends cap were prepared with internal and externally threaded provision from stainless steel bars. The circular rod was placed inside the stainless-steel tube and connected with both endcaps using the Teflon flange which might seal the pressure inside the flow. The threaded sides were wrapped with Teflon tape and tightened after checking and rectifying the leakages from pressurized flowing liquid.

3.1.2 Thermocouple mounting

Completion of testing for pressure leakage inside the lab and resulted in no leakage under high pumping pressure of water flow. The grooves were already cut with measuring distance as per design data, furthermore, the thermo-wells were placed at the groove. The grooves were cut deep to ensure the minor surface thickness interaction with fluid temperature. The thermo-wells were positioned straight and parallel to keep the accuracy of temperature data shown in figure 3.2 and bonded with high-temperature adhesives & sealants (figure 3.3) at the outer surface of the stainless-steel tube.

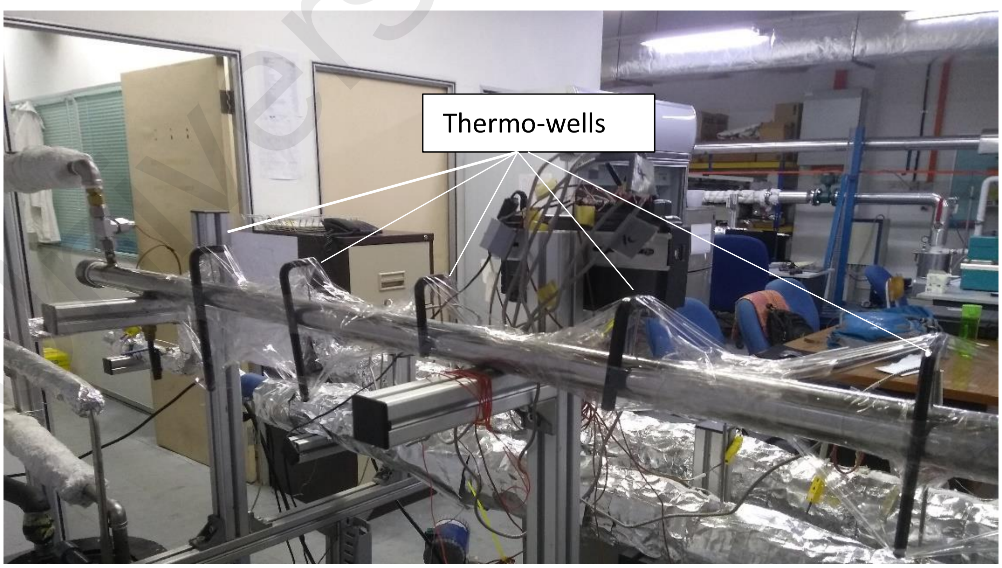

Figure 3. 2: Thermo-wells position

While bonding was carried out to keep the metal-to-metal joints at room temperature for 24 hours which was permanently bonded at designated groove positions.

Figure 3. 3: High Temp. Adhesives & Sealants up-to 150 ºC

The five thermocouples were used on the surface of tube and two thermocouples used for the bulk fluid inlet & outlet temperature, although the type of thermocouple used K-type (Omega, Model: KMTXL-125G-6). Then the data acquisition unit was used to display the actual temperature data which was measured by the thermocouples.

3.1.3 Heater

The designed experimental setup was heated by two Ultra-high Temperature Tapes (Omega Model: STH102-080) which were connected in series and wrapped around the outer surface of the tube within 1000 mm length (Figure 3.4). The heaters have the specification of (1254 W, 240V, 5.23A) maximum capacity, and then heater connected to the Variable auto-transfer designed for regulating the heat input to the system. The heat input was managed by the

Figure 3. 4: Heater rounded surface

clamp-meter to calculate the voltage and ampere ranges. The heating surface and overall tube were fully covered with fiberglass wool to reduce the heat loss from the heat-surroundings (Figure 3.5).

Figure 3. 5: Insulated Heat Section

3.1.4 Data logging system

The various data collection instruments were used to display the flow characteristics and temperatures of the working fluid. The Graphtec (midi logger gl220) was used to display the surface temperatures data and bulk temperatures (inlet & outlet) as shown in (figure 3.6). The differential pressure of fluid was observed by using the differential pressure transmitter (OMEGA: PX154 wet/wet low) and the displayed value in (Pascal). Moreover, the transferring of heat was regulated with a source of variable voltage transformer (Model: QPS VT2-1) and data were adjusted by setting the voltage and ampere ranges using Clamp-meter. The adjustable of fluid were followed by the shut valve and data were displayed in digital flow meter (SE 32 inline Paddle Wheel Transmitter), however, a bourdon pressure was placed before the shut valve to keep the actual flow data.

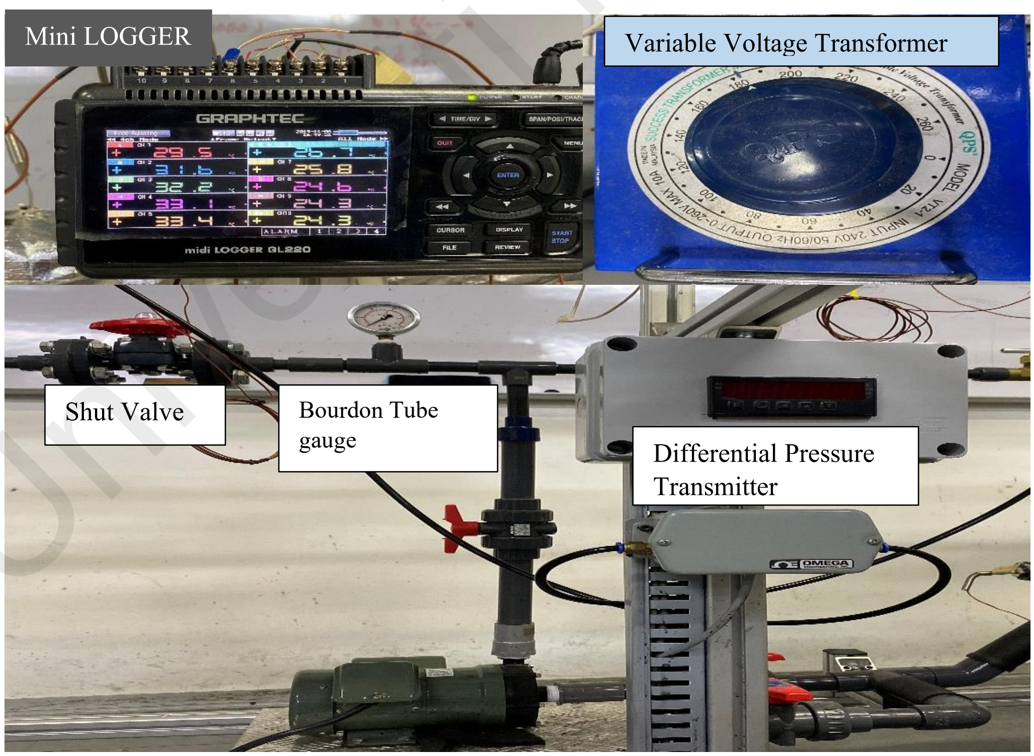

Figure 3. 6: Display monitor of experiment data

3.2 Nanofluids preparation

The preparation of nanofluids is performed by using two well-known methods (single-step and two-step) as briefly described in the literature review. The selection of the nanoparticles were based on the eco-friendly and easily available in the mass production in the market as well as not costly. Titanium Dioxide (TiO_2) and GNPs nanoparticles were chosen for the study and dispersed into distilled (DI) water as base fluid. The selection of base-fluid was preferred on the free availability and non-toxic for the environment as well as the experimental system. The usage of TiO_2 has been widely employed in engineering applications by their remarkable thermo-physical attributes and non-toxicity (Ali et al., 2018). Moreover, Graphene-based nanoparticles have been given highly usable nanoparticles than others by its efficient thermal conductivity, long-period stability, less corrosive and non-toxic characteristics in different heat transfer applications (Arshad, A., Jabbal, M., Yan, Y., & Reay, 2019). Both nanoparticles have unique properties for different applications and eco-friendly for the industrial application, furthermore, the preparations were carried out using the simplest two-step method. The preparation of nanofluid is not an easy method to disperse the nanoparticles into base-fluid while this process required high stability, propagation of nanoparticles and appropriate mixing.

3.2.1 Synthesis of TiO_2 nanoparticles

The dry titanium dioxide (TiO_2) nanoparticles in the form of nano-powders were available inside the lab which was purchased from the manufacturer (ALDRICH, USA) with 21nm particle size (TEM). The electronic weight balance was set to zero after keeping the weight boat and then measured the required concentration for the TiO_2 nanofluid which was put into weight-boat with the help of a spatula. Then TiO_2 nanoparticles and distilled water were dispersed with each other inside the beakers. The procedure contained 7000 mL of distilled water with 7 grams of TiO_2 nanoparticles for the making of 0.1% weight concentration. The solution of TiO_2-water was placed in the ultrasonication probe at a 60 kHz frequency for 2 hours and 30 minutes with a pulse (3 On and 2 Off Seconds) for the proper mixing to avoid the clustering of solution. While during preparation, the ice blocks were placed beside the beaker of the solution to decline the temperature inside the probe surrounding due to sonication. The solution of TiO_2-water nanofluid was prepared and keep inside the lab room for 24 hrs. and no clustering of nanoparticles was found, furthermore, the solution was put inside the experimental tank. The TiO_2-water nanofluids were synthesized at 0.025%, 0.05%, 0.075% and 0.1% weight concentrations while the preparation procedures were shown in figure 3.7, before and after the nanoparticle solution.

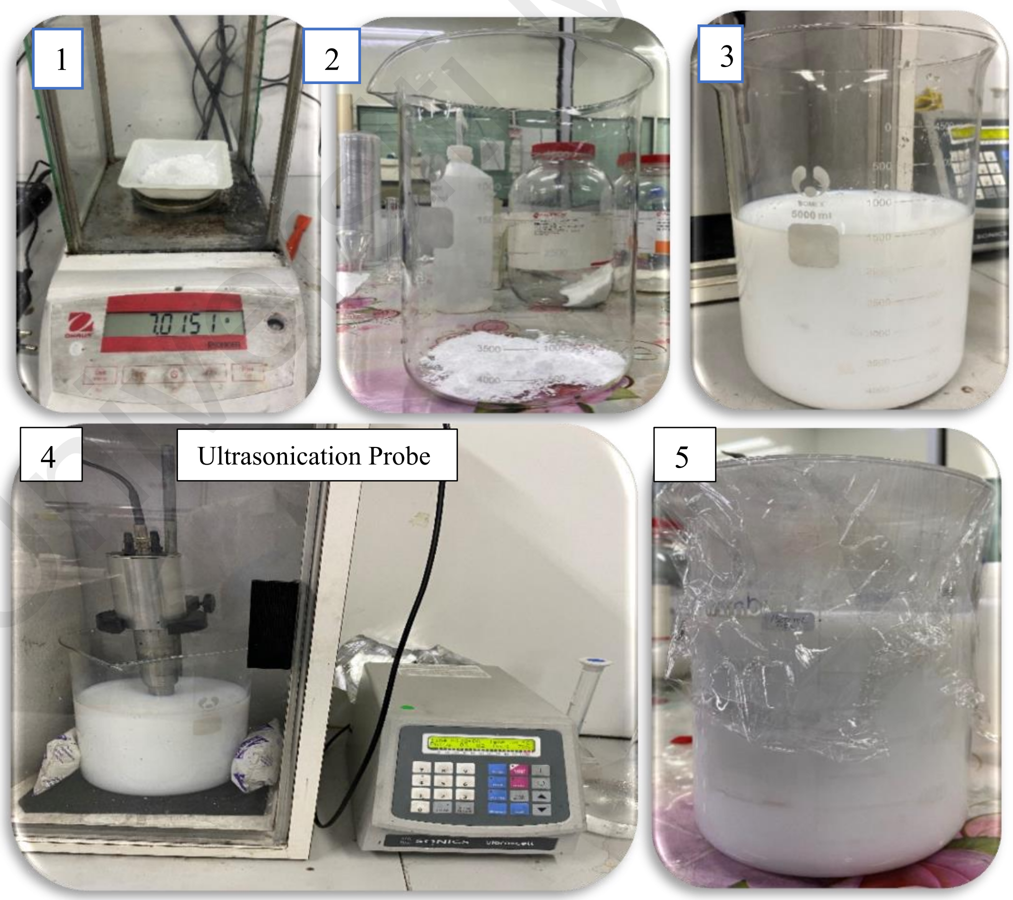

Figure 3. 7: Preparation steps of TiO_2-water nanofluid

3.2.2 Graphene nanoplatelets preparation

The Graphene nanoplatelets (Pristine) have 2μm maximum diameter of particles, purity 99.5% and 750 m^2/g specific surface area were gained from the USA (XG Sciences, Lansing). The eco-friendly method and non-toxic material used to prepare the GNPs and free radical grafting of Gallic-acid against graphene nanoplatelets (GNPs) was accomplished employing H_2O_2 and heat. The synthesizing Gallic-acid treated GNP were prepared after ultra-sonication with probe-sonicator and kept the mixture under heat for several hrs. The sample was kept for dry under the heating condition at 60 ºC inside the oven in the lab.

The synthesized Gallic-acid treated GNPs were put into a weight boat for 0.1% weight concentration and mixed with DI-water into a beaker. The solution was placed for the sonication process and kept the rest of the procedure as TiO_2-water nanofluid methods. The probe-sonicator was used to prepare the nanofluid and surrounding heat was absorbed by placing ice blocks beside the beaker (Figure 3.8). The solubility of GAGNPs-aqueous nano-coolant was higher in water than simple pristine GNP (Sadri, R., Hosseini, M., Kazi, S. N., Bagheri, S., Ahmed, S. M., Ahmadi, G., ... & Dahari, 2017). The prepared GNPs nanofluids were synthesized with 0.025%, 0.05%, 0.075% and 0.1% weight concentrations, respectively.

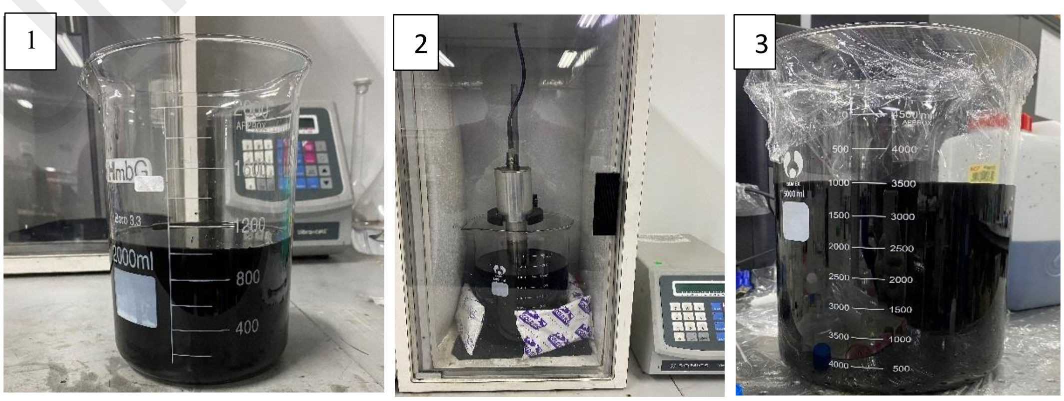

Figure 3. 8: Preparation of Graphene nanoplatelets nanofluid

3.2 Experimental test-rig and operating procedure

The experiment test section was comprised of the following main parts and placed inside the computational fluid dynamics lab at the University of Malaya. The main parts are shown in figure 3.9:

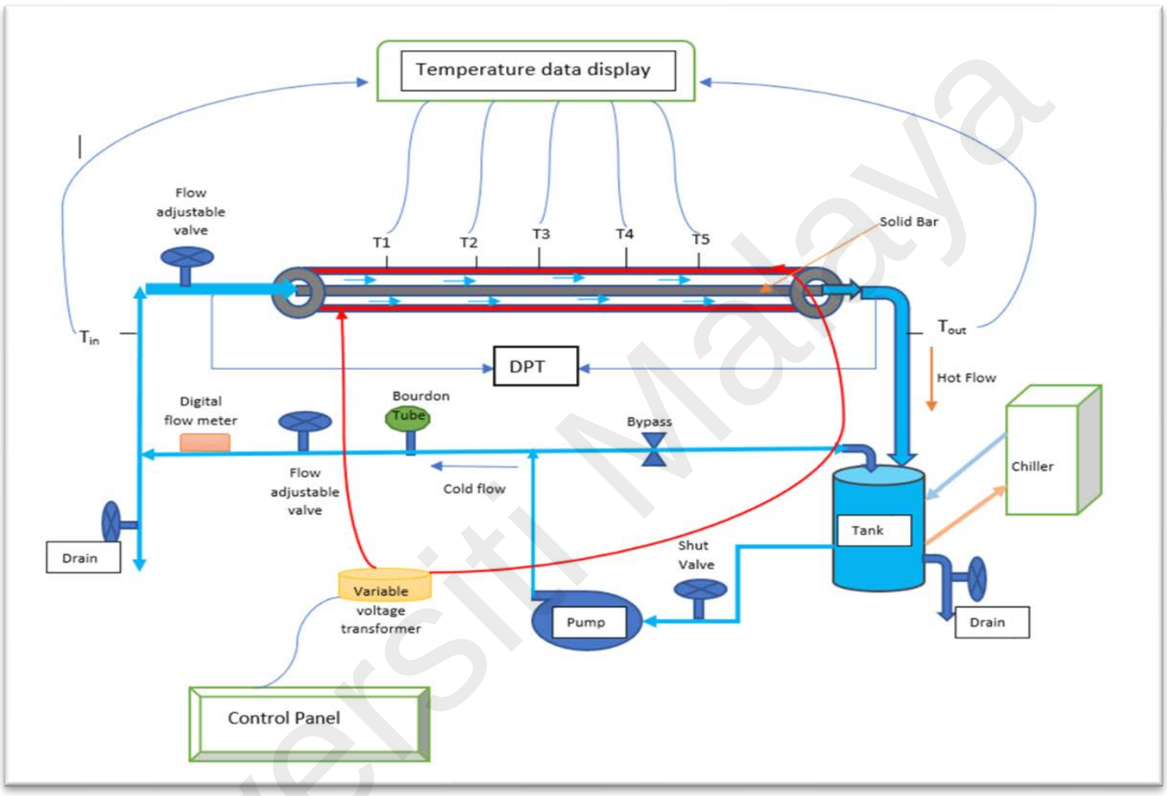

Figure 3. 9: Schematic drawing of experimental test section

- Pump
- Differential Pressure Transmitter
- Storage Tank
- Thermocouples
- Cooling unit (Chiller)
- Adjustable valve and By-pass valve
- Flow meter

- ➢ Temperature Display unit
- ➢ Main control panel

The test section was consumed energy at various stages such as heating the test section, cooling the circulation fluid, and pumping the fluid, however, the actual test section is shown in figure 3.10.

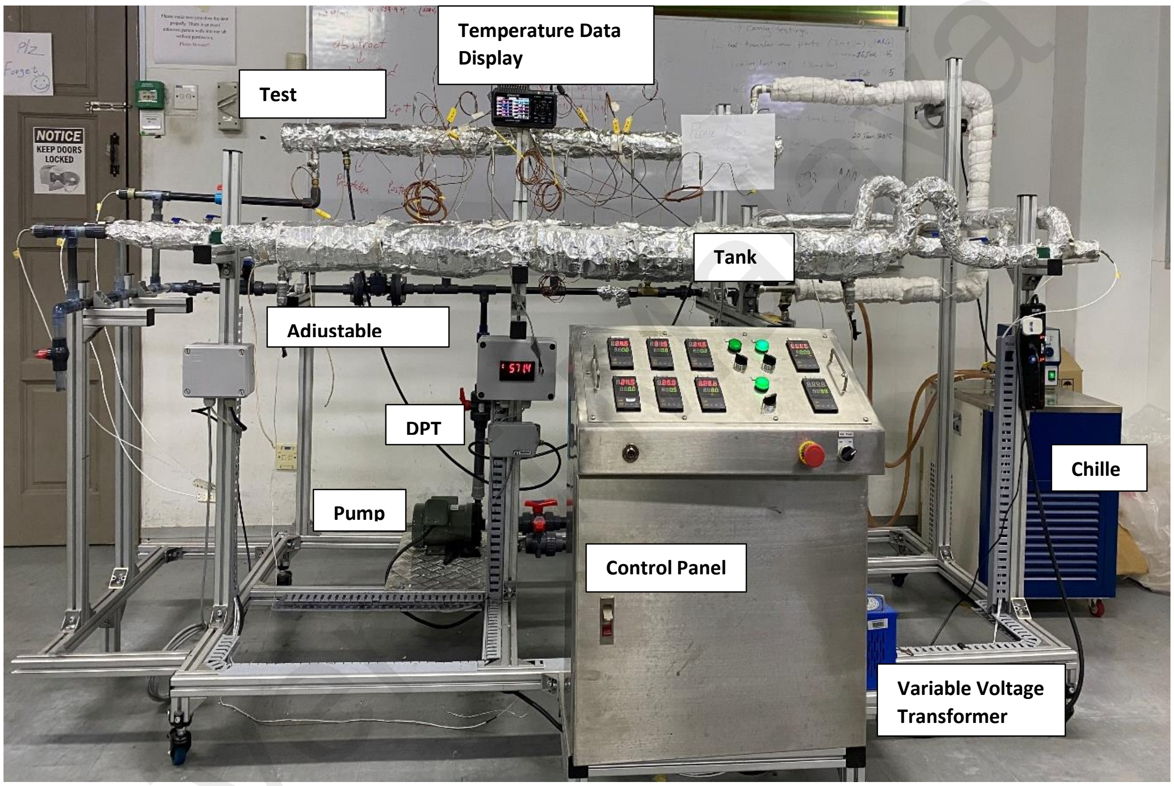

Figure 3. 10: Actual Experimental setup inside the CFD Lab

The cleaning of the test rig was performed before the experiment, while the accuracy and the reliability of the test rig were performed by the DI-water. The valve positions were properly checked as per experiment flow and filled the reservoir tank by using 7 liters of DI-water or nanofluid. The chiller was connected to the reservoir tank to avoid the increasing of temperature of working fluid during operation while it was closed-cycle flow inside the chiller using water. There were five k-type thermocouples were connected with a distance of 0.2 m on the outer surface of pipe and data were displayed at mini data logger, however, the bulk temperature (Inlet & Outlet) were also using K-type thermocouple and displayed the data on the same panel. The constant heat flux method was used to carry out the flow experiment while the (q = 4450 W/m^2) was generated by using two heaters. The heaters were wrapped around the outer surface of the pipe in series connection within 1000 mm of length and power supply were connected to external variable voltage transformer. The Reynold numbers of the flow were kept under the ranges (2300 to 5000) and the study was continued within the low turbulent flow condition. The pump was used to flow the fluid into the test-section and flowrate was manipulated by the manual shut-valve beside the pump exit, however, the flowrate was measured in digital flow meter before the heating section. The overhead stirrer was employed to avoid the sedimentation of nanofluid inside the reservoir tank and chiller was used to maintain the temperature of working fluid. The flowrates were studied in the ranges of 5 L/min, 7 L/min, 9 L/min and 10 L/min respectively, and the temperature readings were noted every (1 hr. :30 min) while it was steady. The cleaning process was continued after flowing the nanofluid and sometimes the nanoparticles were placed with boundary inside test-section then decon90 with DI-water was used to wash.

3.3 Data evaluation method

The experimental data were obtained to calculate the convective heat transfer performance and the hydrodynamic behavior of the annular heat exchanger. The important parameters were applied to govern the effect of the nanofluids on the thermophysical properties of distilled water such as pressure drop (ΔP), convective heat transfer coefficient (h) and Nusselt number (Nu). The heat transfer coefficient was measured from the heat flux, bulk surface and (Inlet & Outlet) temperatures by well-known correlation Newton's law of cooling:

$$h = \frac{q''}{(T_w - T_b)} \tag{3.1}$$

where q″, T_w and T_b denotes the heat flux, average wall temperature and bulk (average inlet and outlet) temperature of the flow, respectively.

The heat flux was calculated by the subsequent equation:

$$q'' = \frac{Q}{A_S} \tag{3.2}$$

In equation (3.2), the A_S denotes surface area and Q denotes the input power. However, the surface area was determined by using ($A_S = \pi D_o L$), where D_o is the outer diameter, L is the specified length) and Q was determined by using (Q=V*I, where V is voltage and I is the current).

The hydraulic diameter (Dh) of annular passage was derived from the following equation:

$$Dh = \frac{4A_C}{P} = \frac{\frac{4\pi\left(D_O^2 - D_i^2\right)}{4}}{\pi(D_o - D_i)} = D_o - D_i \tag{3.3}$$

Here, Do and Di denotes the outer diameter and inner diameter. The Reynold number (Re) is a key parameter for heat transfer flow where the flow type based on this number, the Reynold number is determined by the following equation:

$$Re = \frac{\rho D_h \upsilon}{\mu} \tag{3.4}$$

In Eq: (3.4) where υ, ρ and μ denote the dynamic viscosity, density and velocity of the flowing fluid, correspondingly. The Nusselt number is derived by the following equation:

$$Nu = \frac{D_h * h}{k} \tag{3.5}$$

Eq: (3.5), denote $k = thermal\ conductivity\ and\ h = heat\ tranfer\ coefficient$ of the working fluid, accordingly. Furthermore, the friction factor is always calculated by using the differential pressure across the experiment flow section. The equation (Eq. 3.6):

$$f = \frac{\Delta P}{\left(\frac{L}{D_h}\right) * \left(\frac{\rho \upsilon^2}{2}\right)} \tag{3.6}$$

Here, ΔP denotes the pressure-drop across the flow section, accordingly.

3.4 Nanofluid properties analysis

The dispersion of nanoparticles within base fluid enhances the thermophysical characteristics of the nanofluid due to colloidal suspension. As mentioned in the literature review, many researchers were carried out various methods to enhance the nanofluid properties and improved the heat transfer coefficient.

In this study, the well-known correlation was used to determine the effective thermal conductivity of the nanofluid by using the effect of particle radius, nanolayer thickness, base-fluid, etc., accordingly. The effective thermal conductivity was calculated by using the Yu and Choi (Yu, W., & Choi, 2003) formula as follow:

$$K_{nf} = \left[\frac{k_{np}+2k_{bf}+2(k_{np}-k_{bf})(1+\beta)^3\phi}{k_{np}+2k_{bf}+(k_{np}-k_{bf})(1+\beta)^3\phi}\right] * k_{bf} \tag{3.7}$$

Eq: (3.7), where the consideration of volume concentration (ϕ) and β (ratio of nanolayer thickness to actual particle radius) of the nanofluid, whereas ($\beta = 0.1$) used to determine.

K_{nf} = Thermal conductivity of nanofluid

K_{np} = Thermal conductivity of nanoparticle

K_{bf} = Thermal conductivity of base-fluid

The viscosity of nanofluid properties were followed by using the well-known Einstein's equation (3.8), which was efficiently used to estimate the viscosity of dilute suspension by researchers in the various experiment as follow:

$$\mu_{nf} = (1 + 2.5\phi)\mu_{bf} \tag{3.8}$$

Eq: (3.8), where μ_{nf} and μ_{bf} represents the viscosity of nanofluid and base-fluid with the effect of volume concentration (ϕ), accordingly. The specific heat and density of nanofluid were determined by most applicable correlation the Pak and Choi (Pak, B. C., & Cho, 1998), which is defined as follows in equation (2.9) & (2.10):

$$Cp_{nf} = \phi Cp_{np} + (1 - \phi)Cp_{bf} \quad (2.9)$$

And density

$$\rho_{nf} = \phi \rho_{np} + (1 - \phi)\rho_{bf} \quad (2.10)$$

In Eq: (2.9), where Cp_{nf}, Cp_{bf} and Cp_{np} represent the specific heat of nanofluid, base-fluid and nanoparticles, accordingly. However, Eq: (2.10) ρ_{nf}, ρ_{np} and ρ_{bf} denote the density of the nanofluid, nanoparticles and base-fluid, respectively.

The aforementioned equations were evaluated the nanofluid properties by applying the water as base-fluid and nanoparticles at average room temperature conditions.

The calculated thermophysical properties of nanofluids and base fluid as shown in Table 3.1:

Table 3. 1: Thermo-physical properties of nanofluids with varied concentrations.

Heat Transfer Fluids	**Thermo-physical Properties**		
	k (W/m.K)	**μ (Pa. s)**	**ρ (m^3/kg)**
DI-water	0.607	0.000891	997.1
TiO_2-water nanofluids (% vol.)			
TiO_2 0.025%	0.6075	0.00089156	997.913
TiO_2 0.05%	0.60800	0.00089211	998.726
TiO_2 0.075%	0.60849	0.00089267	999.54
TiO_2 0.1%	0.60899	0.00089323	1000.35
GNPs-water Nanofluids (% vol.)			
GNP 0.025%	0.640	0.000835	995.65
GNP 0.05%	0.663	0.000843	995.78
GNP 0.075%	0.685	0.00085	995.9
GNP 0.1%	0.718	0.00087	996.0

3.5 Numerical Analysis

The numerical study was simulated to justify the reliability and accuracy of the experimental test section using the DI-water as the working fluid. The schematic geometry of the annular tube was drawn to perform the study as shown in the figure (3.11).

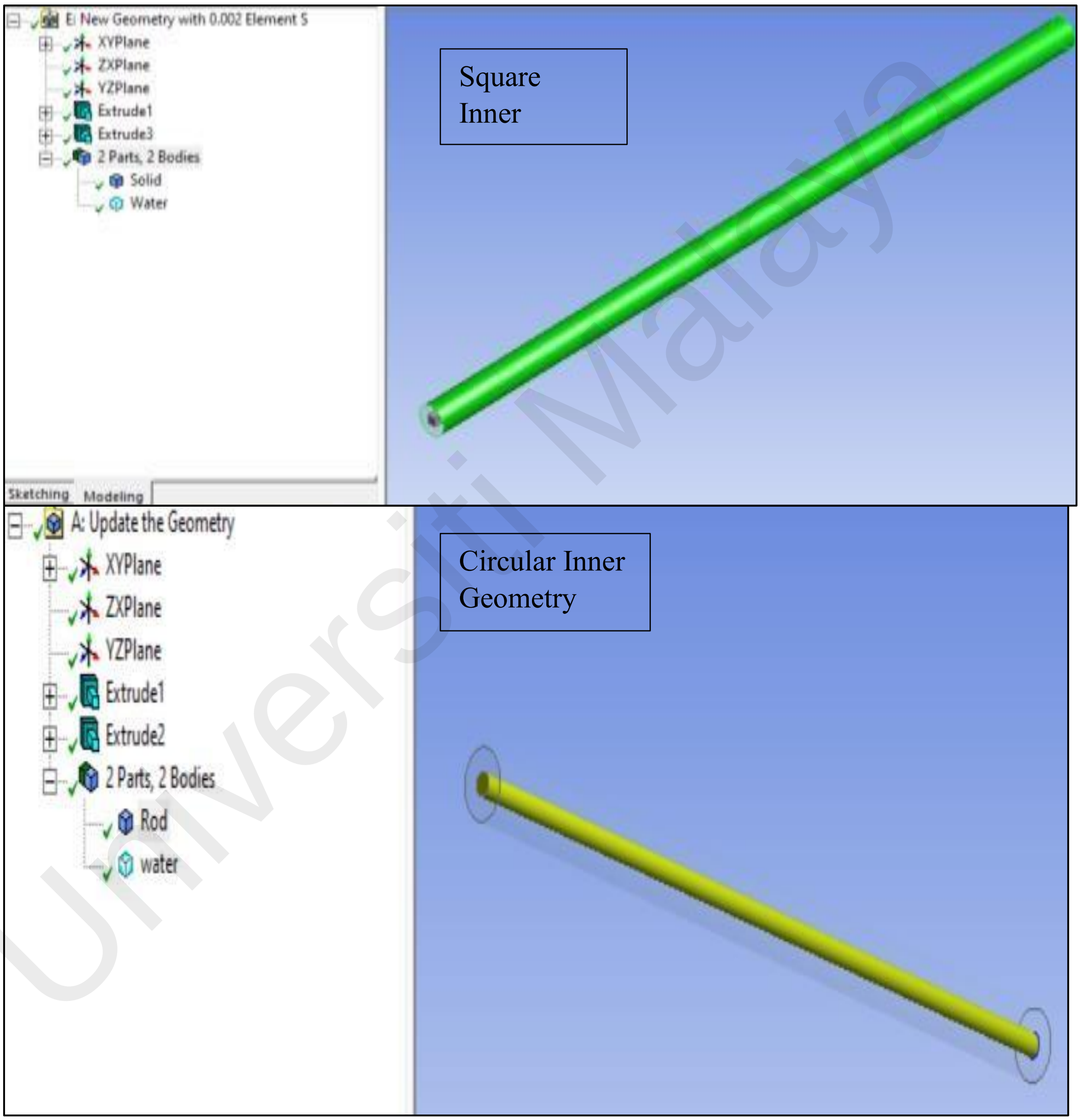

Figure 3. 11: Schematic geometry with varying inner shape (Square & Circular)

A finite volume method-based flow solver of the CFD software (ANSYS Fluent) 18.2 was employed in the study. The geometry was drawn using the Design Modular for the annular tube as well as varied the inner circular bar to square bar while keeping the hydraulic diameter (Dh) constant. The mesh independence study was performed using a fine meshing method to maintain minimum changes for the post-processing result as shown in figure (3.12).

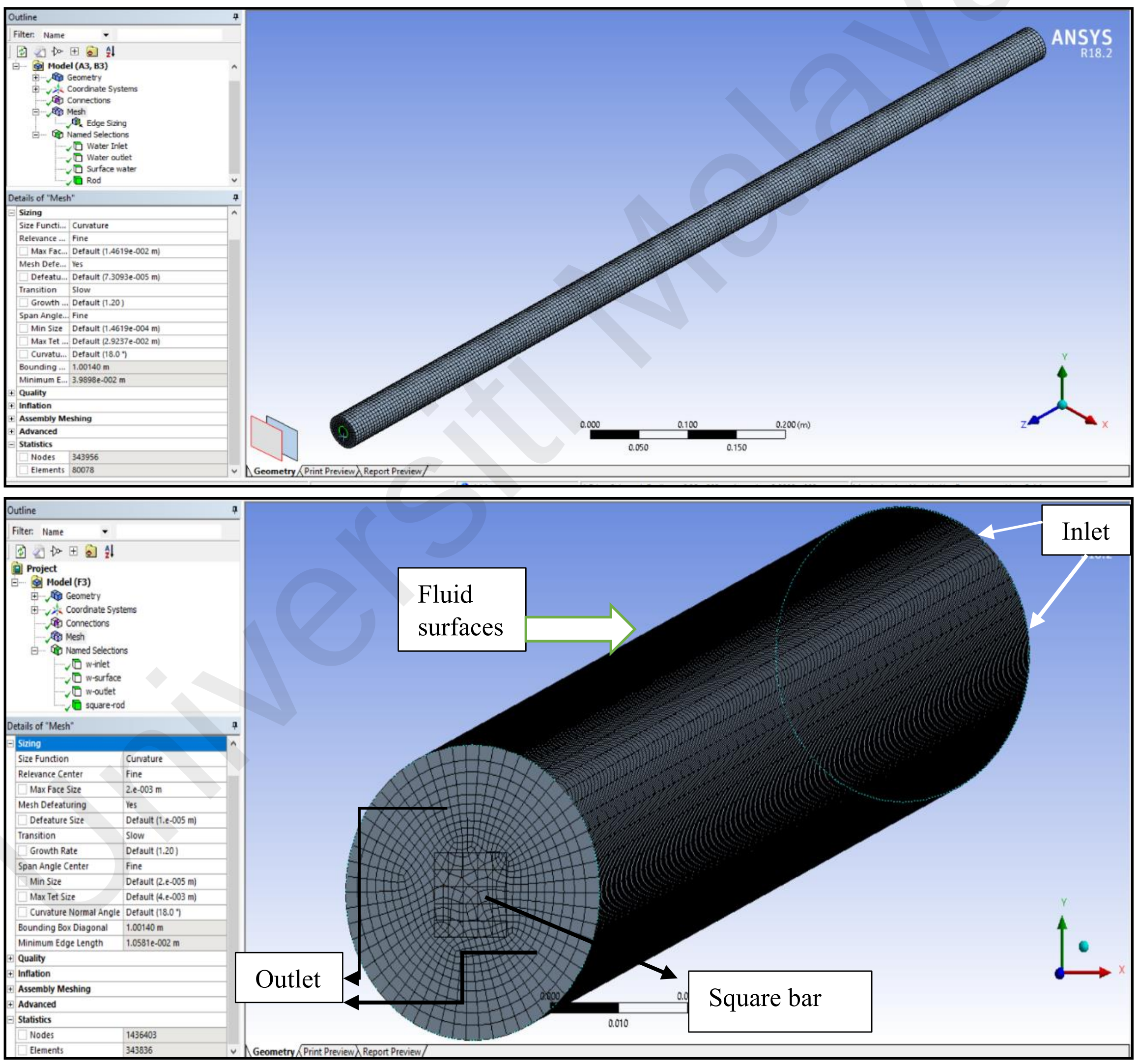

Figure 3. 12: Computational mesh of annular geometry with varying inner shapes

The thermophysical properties of the DI-water were given under room temperature (25 ºC) and kept constant heat flux as a source of heat for the simulation. The boundary terms of the geometry were defined as the velocity of the fluid at inlet, pressure outlet at the outlet and heat flux at the surface of fluid flow at 1 m length, turbulent intensity 5.5% and hydraulic diameter. The 2nd -order pressure-based solver was used in the simulation and standard SST-k-omega viscous model was applied to compute the low Reynold number turbulent flow conditions. This model has also efficient to estimate the better solution in steady-state turbulent flow (C. S. Oon et al., 2012), furthermore, a SIMPLE algorithm were used to iterate the various energy equations and simulated the result as shown in the figure (3.13) and (3.14).

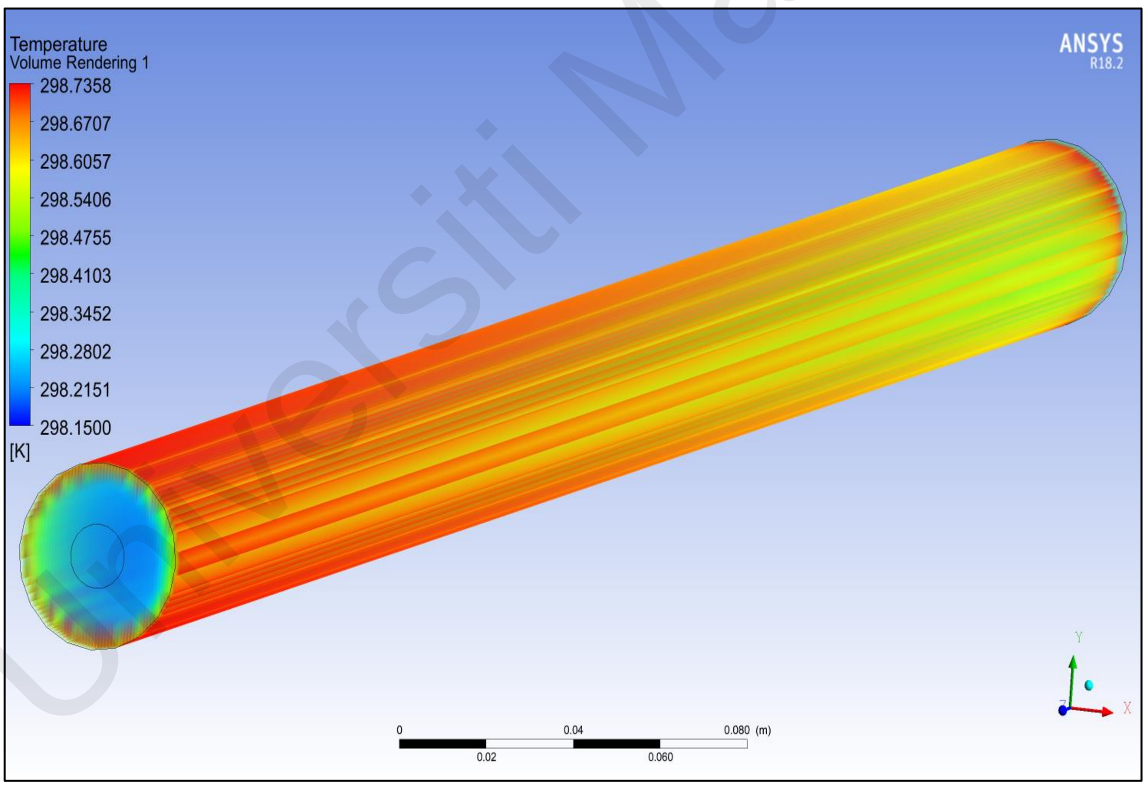

Figure 3. 13: Result simulation of annular heat exchanger with circular bar

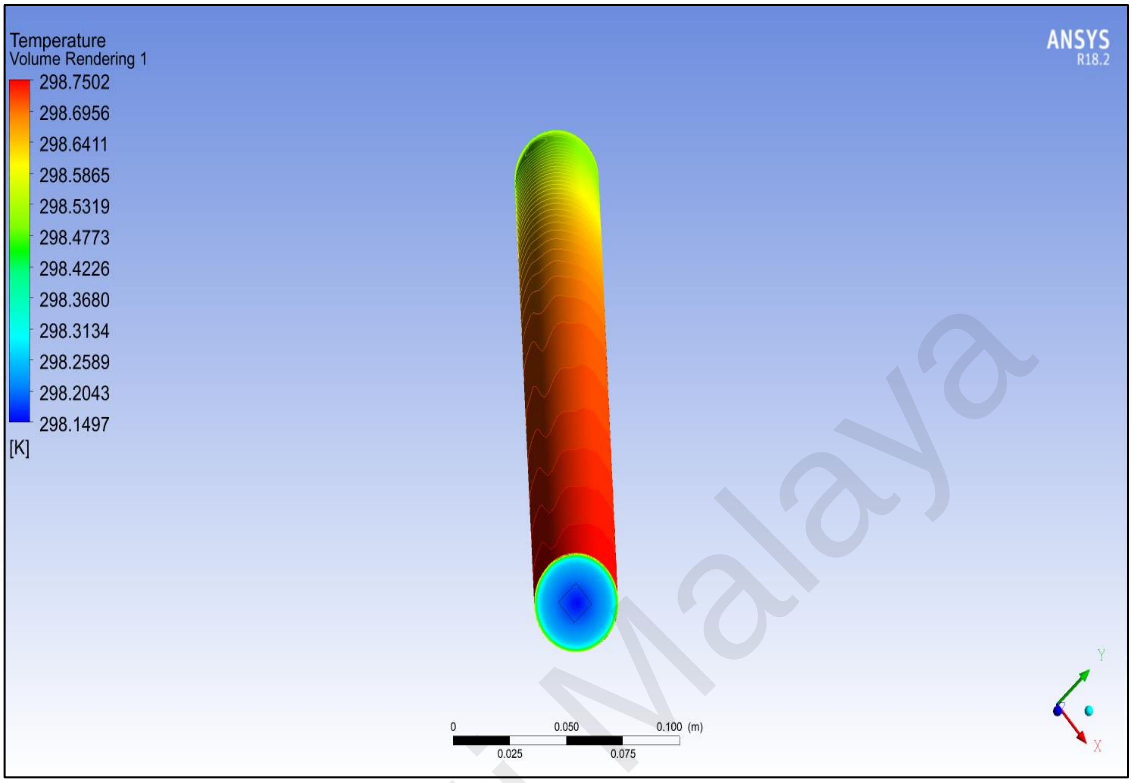

Figure 3. 14: Result simulation of annular heat exchanger with square bar

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Experimental setup results and discussions

In this chapter, the heat transfer coefficient (h), Nusselt number (Nu) and friction factor (f) of nanofluids at different concentrations (TiO_2-water & GNP-water) were compared with the conventional base fluid (DI-water). Although, the validation and accuracy of the test section were performed by DI-water against well-known standard equations, like the Dittus-Boelter and Gnielinski equations for the turbulent conditions. The 0.1 wt.%, 0.075 wt.%, 0.05 wt.% and 0.025 wt.% concentrations of TiO_2-water and GNP-water nanofluids were experimentally studied and results were discussed in this chapter.

4.1.1 Test-section validation

To determine the accuracy and reliability of the experimental test section by using the base-fluid (DI-water) a series of experiments were conducted for the validation at the constant heat flux boundary techniques under turbulent flowsteady state by varying the flow rate. The Nusselt number (Nu), convective heat transfer coefficient (h) and friction factor (f) were evaluated to compare the results with the data from standard equations. The DI-water experimental results were compared with the data from standard equations at the constant heat flux, however, the standard equations such as Dittus-Boelter and Gnielinski equations under turbulent flow conditions (Kayhani, M. H., Soltanzadeh, H., Heyhat, M. M., Nazari, M., & Kowsary, 2012).

The Dittus-Boelter equation is followed in Eq:(4.1).

$$Nu = 0.023 Re^{0.8} Pr^{n} \tag{4.1}$$

Where $n = 0.4$ for the heating function and applied for the range of $Re > 10^4, 0.6 < Pr < 200$.

The Gnielinski relation is followed in Eq: (4.2).

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}\left(Pr^{2/3}-1\right)} \qquad \begin{matrix}(0.5 \le Pr \le 2000)\\(3000 < Re < 5000)\end{matrix} \qquad (4.2)$$

Where f is the friction factor and ranges are given in the Eq: (4.2).

The friction factor varies with the influence of Re number and relative roughness (ε/D_h) for the turbulent flow and is derived by using the Colebrook equation as follows in Eq: (4.3)

$$\frac{1}{\sqrt{f}} = -2.0\ log\left(\frac{\varepsilon/D_h}{3.7} + \frac{2.51}{Re\sqrt{f}}\right) \qquad (4.3)$$

Figure 4.1 exhibits the comparison relation between the empirical equations (4.1 & 4.2) and experimentally evaluated averaged Nusselt number (Nu) by using the DI-water under turbulent flow condition at 25 ºC inlet temperature. With the increase of flow rate (5 LPM to 10 LPM) the Reynold number was enhanced with the augmentation of the Nusselt number of the fluid.

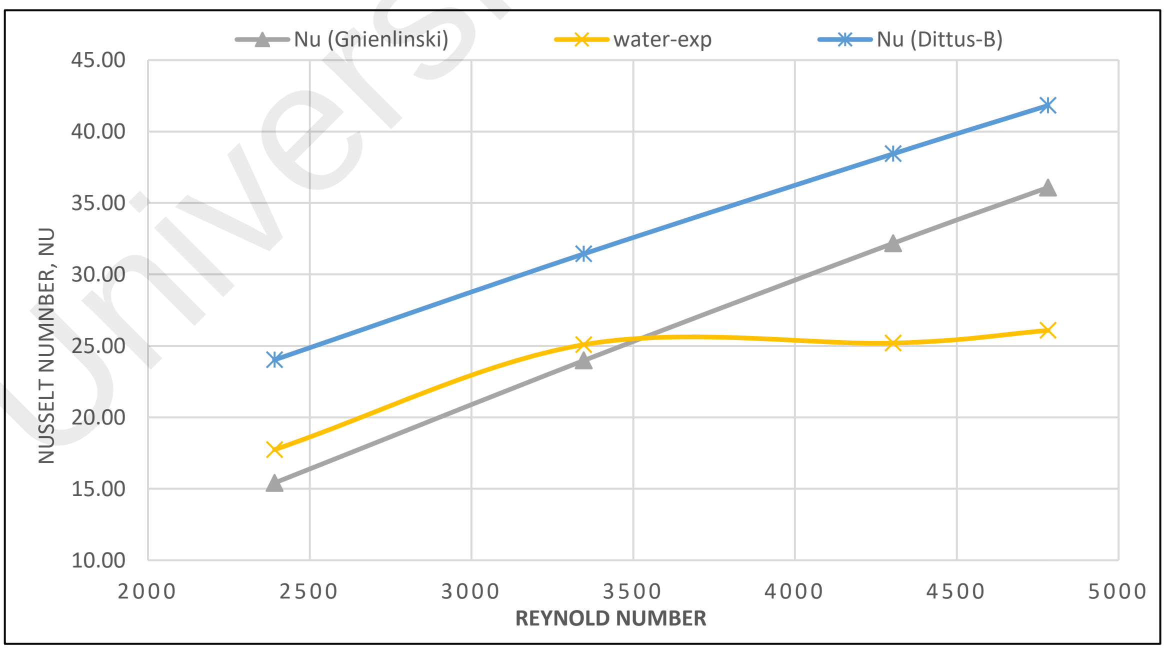

Figure 4. 1: Relation among experimental measured Nu of DI-water with empirical correlations

The experiment results and empirical correlations value gained maximum errors while flow becomes high Reynold numbers, there is good relation obtained with Gnielinski correlation and experimental values under low Reynold numbers conditions. The results performed with experiments are in excellent agreement with the empirical correlations under turbulent flow within the ranges of Reynold numbers ($2300 < Re < 5000$). Therefore, the experimental set-up was validated to evaluate the convective heat transfer performance of the nanofluid concentrations (TiO_2-water & GNP-water) at low turbulent range.

4.1.2 0.1 wt.% of TiO_2-water and GNP-water nanofluid heat transfer properties

The experiment was conducted for the 0.1 wt.% concentration of nanofluids (TiO_2-water & GNP-water) by varying the velocity of flow from 0.088 ± 0.0005 to 0.175 ± 0.0005 to determine the heat transfer coefficient under the turbulent condition. The constant heat flux was kept at ($q = 4450$ W/m^2) as a heat source of the working fluid and heat transfer coefficient determined from Eq: (3.4). The experiment outcomes of the nanofluid 0.1 wt.% concentrations are exhibited in figure 4.2 and the results are compared with DI-water experiment data. The results show that the heat transfer coefficient enhances whereas the velocity is enhanced equally for DI-water as well as nanofluid concentrations. Numerous researches have been investigated that addition of nanoparticles for enhanced concentration can enhance the convective heat transfer coefficient of the nanofluids (Duangthongsuk, W., & Wongwises, 2010; Kazemi, Sajadi, & Kazemi, 2011; Murshed, S. M. S., Leong, K. C., & Yang, 2005; Sadeghinezhad et al., 2015). The graphene and TiO_2 nanofluids have resulted the remarkable enhancement in the heat transfer coefficient due to their high thermal conductivity properties than base-fluid while flowing in the annular tube under turbulent conditions. The present experimental study resulted the remarkable enhancement in the heat transfer coefficient of GNP-water nanofluid by 21.75% with maximum velocity under turbulent condition for the nanoparticle concentration of 0.1 wt.% as compared with DI-water. While, the convective heat transfer coefficient of the TiO_2-water nanofluids enhances by 11.72% with maximum velocity for the 0.1 wt.% of nanoparticle concentration under the turbulent condition as compared with DI-water. Figure 4.3 has shown the result of a remarkable enhancement in the convective heat transfer achieved with a high Reynold number of nanofluids (GNP-water & TiO_2-water) with 0.1 wt.% nanoparticle concentration than the base fluid.

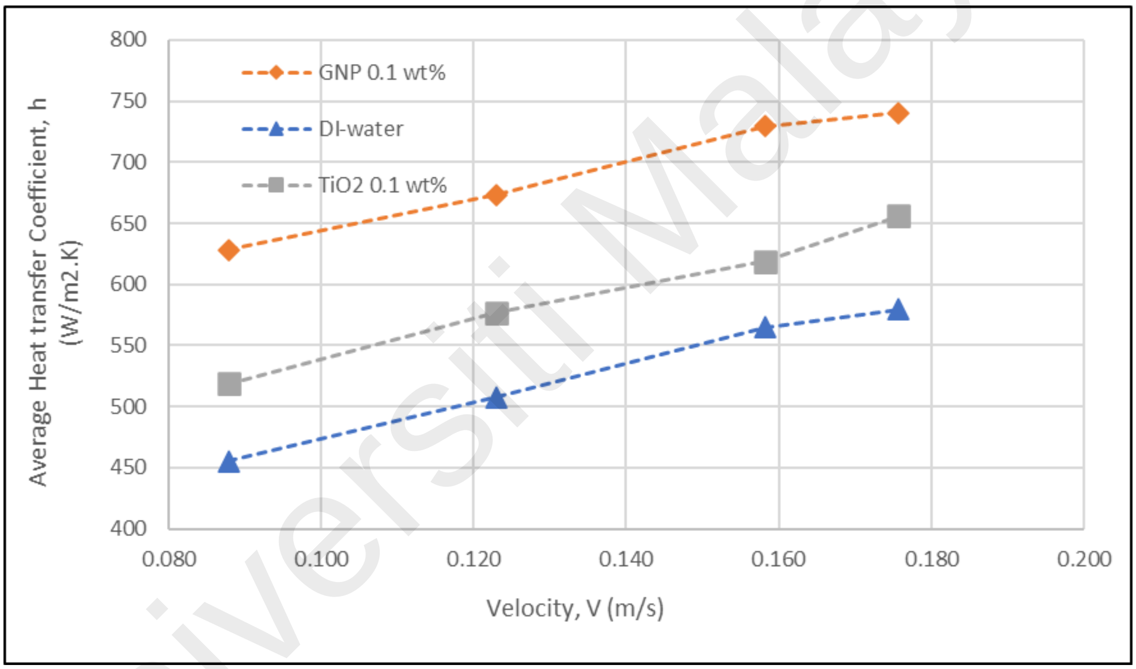

Figure 4. 2: Variation of Heat transfer coefficient for nanofluids of 0.1 wt.% against DI-water versus Velocity

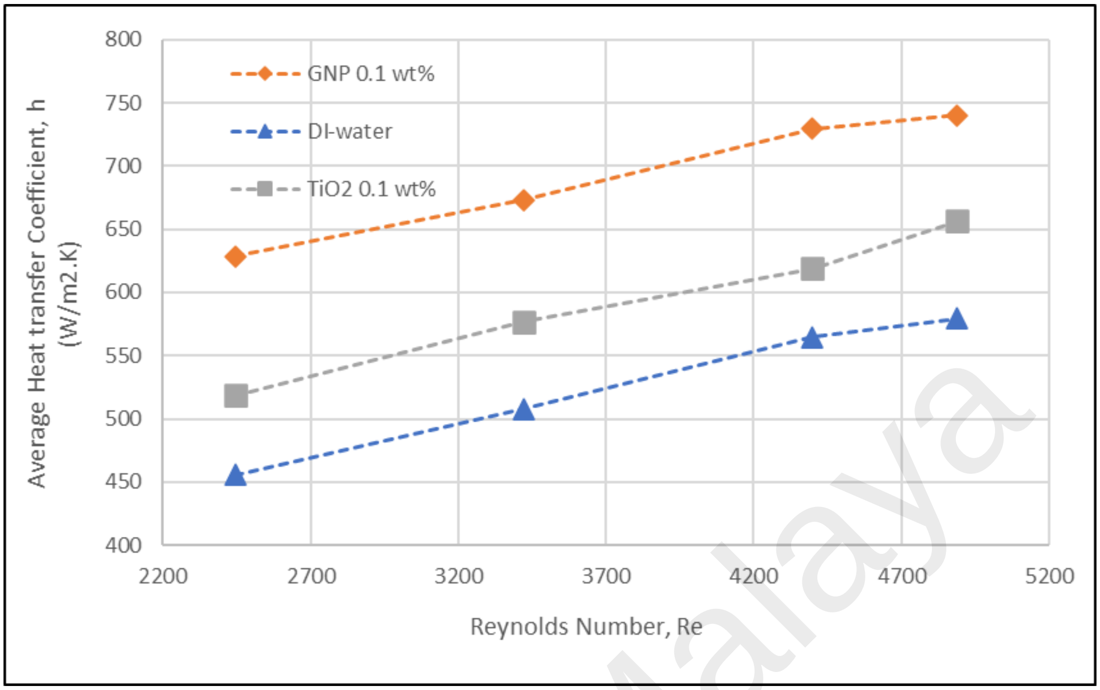

Figure 4. 3: Variation of Heat transfer coefficient for nanofluids of 0.1 wt.% against DI-water versus Reynolds Number

The Nusselt number determined from the Eq: (3.5) and used to calculate the convective heat transfer coefficient. Although, the higher thermal conductivity value can increase the value of the Nusselt number of nanofluid solutions (Arulprakasajothi, Elangovan, HemaChandra Reddy, & Suresh, 2015). The experimental results are exhibited in figure 4.4 and it can be examined that there is a significant increase in the Nusselt number of nanofluids concentration with exceeding of velocity compared to DI-water. The higher Nusselt number for the GNP-water nanofluid has resulted in 14.3% with a minimum velocity of 0.1 wt.% with gradually increase by varying the velocity as relative to DI-water. While, the higher Nusselt number for the TiO_2-water nanofluid has resulted in 12% higher than DI-water with varying of the velocity. In the fully turbulent region, the higher Nusselt number has resulted in TiO_2-water nanofluid than GNP-water nanofluid. Figure 4.5 has shown the result of the maximum increase in the Nusselt number achieved with a high Reynold number of nanofluids (GNP-water & TiO_2-water) with 0.1 wt.% nanoparticle concentration than the base fluid.

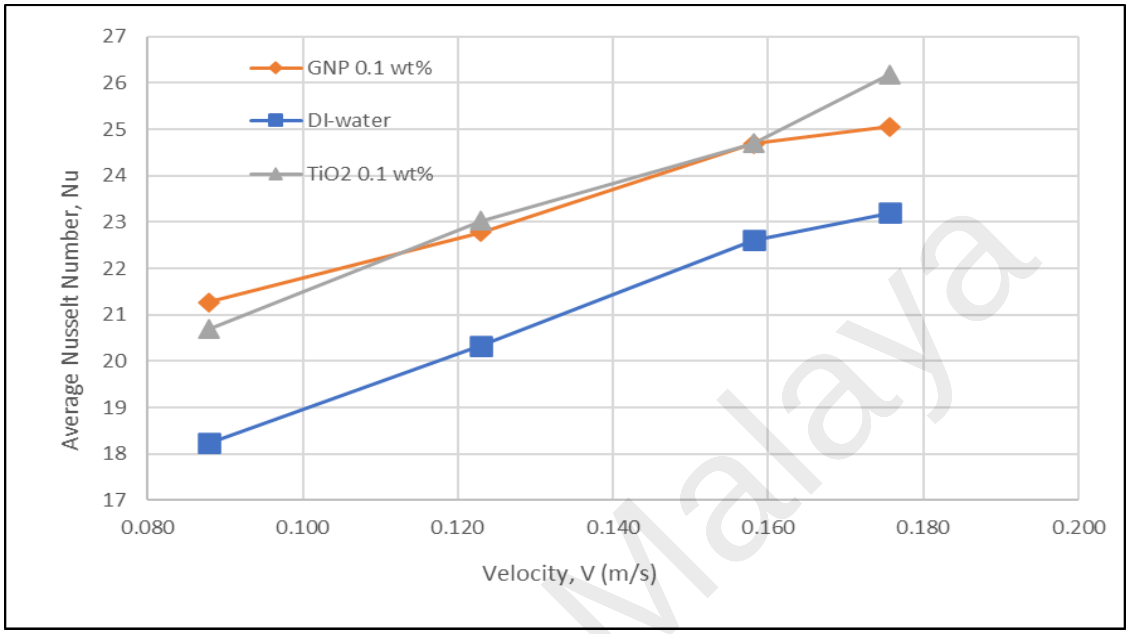

Figure 4. 4: Variation of the averaged Nusselt number for nanofluids of 0.1 wt.% against DI-water versus Velocity

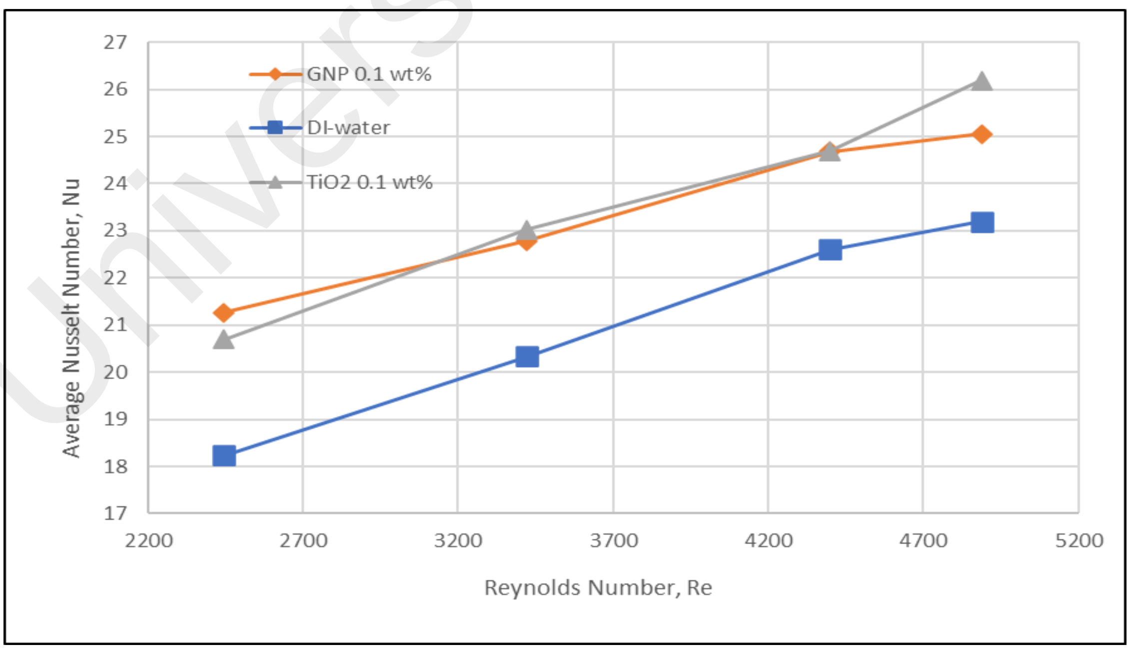

Figure 4. 5: Variation of averaged Nusselt number for nanofluids of 0.1 wt.% against DI-water versus Reynolds Number

The variation of pressure drop of the nanofluid concentrations 0.1 wt.% recorded by varying the velocity range flowing through the experimental test section as displayed in Figure (4.6). The corresponding Darcy friction factor values were obtained by Eq: (3.6) wherein the pressure drop across the test section influenced by the density of the nanofluids with nanoparticle concentrations (Sadeghinezhad et al., 2015). The experimental data resulted that there is a minimum inclination of the friction for the nanofluids than DI-water and varying the velocity brings to minor value with a fully turbulent flow condition. The pressure drop of the flowing fluid increases with exceeding the Reynolds number, however, varying the velocity can be minimized by the friction factor of the nanofluid for the high-velocity regime under fully turbulent condition.

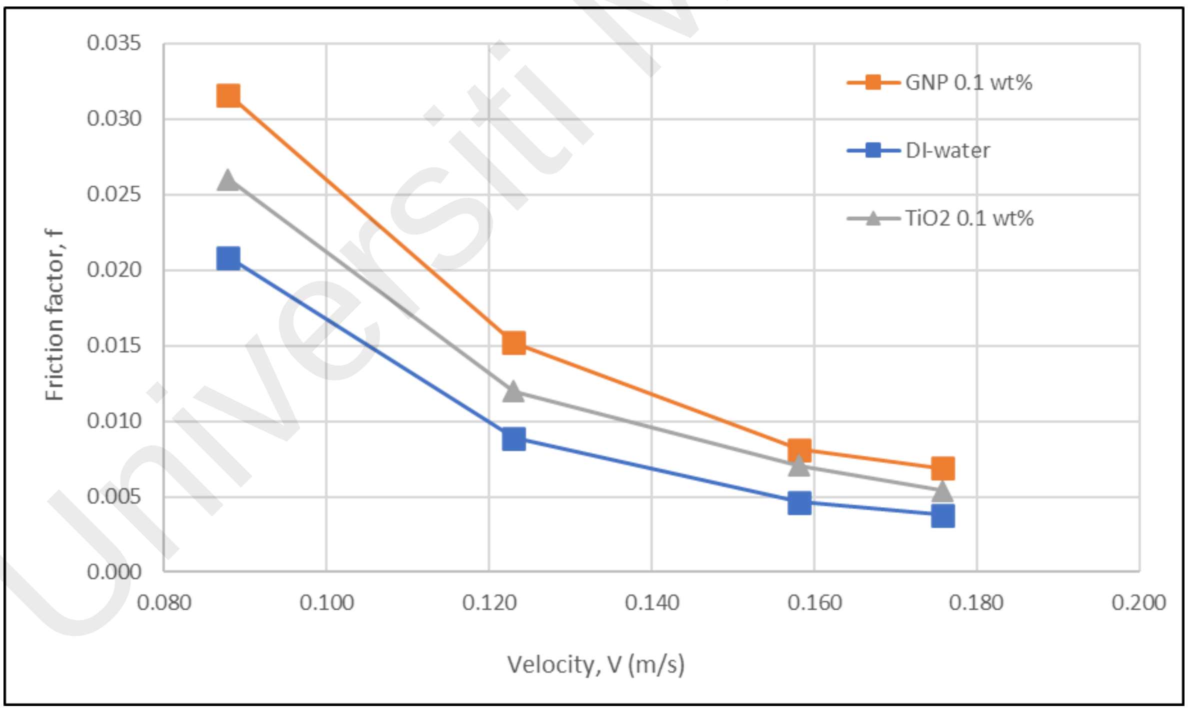

Figure 4. 6: Variation of Darcy friction factor for the nanofluid 0.1 wt.% against DI-water versus velocity

4.1.3 0.075 wt.% of TiO_2-water and GNP-water nanofluid heat transfer properties

The experiment was conducted for the 0.075 wt.% concentration of nanofluids (TiO_2-water & GNP-water) by varying the velocity of flow from 0.088 ± 0.0005 to 0.175 ± 0.0005 in the purpose to determine the heat transfer coefficient under the turbulent condition. The experiment outcomes data of the nanofluid 0.075 wt.% concentrations are exhibited in Figure 4.7 and results are compared with DI-water experiment data. The results show that the heat transfer coefficient enhances whereas the velocity is enhanced equally for DI-water as well as nanofluid concentrations. The present experiment study resulted in the remarkable enhancement in the heat transfer coefficient of GNP-water nanofluid by 17.45% with maximum velocity under fully turbulent conditions for the nanoparticle concentration of 0.075 wt.% as compared with DI-water. While, the convective heat transfer coefficient of the TiO_2-water nanofluids enhances by 7.7% with maximum velocity for the 0.075 wt.% of nanoparticle concentration under the turbulent condition as compared with DI-water. The GNP-water nanofluid has resulted in a remarkable enhancement in the convective heat transfer as compared to TiO_2-water nanofluid with corresponding 0.075 wt.% under turbulent flow at constant heat flux.

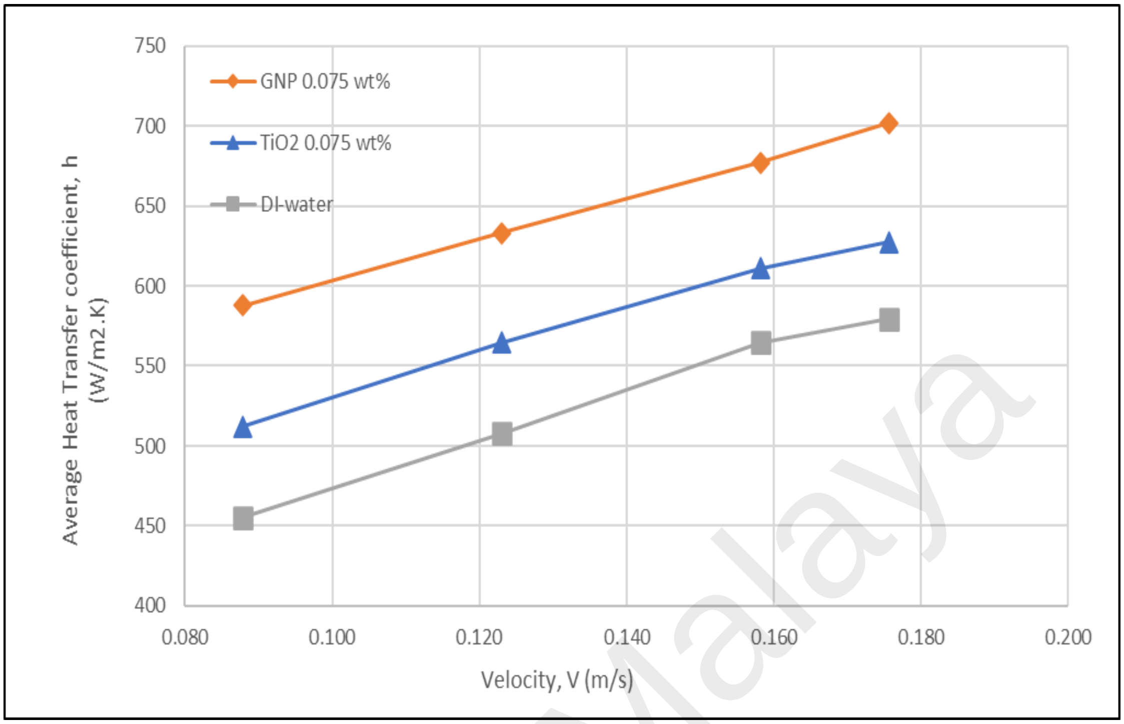

Figure 4. 7: Variation of averaged Heat transfer coefficient for nanofluids of 0.075 wt.% against DI-water versus Velocity

The experimental data are shown in Figure 4.8 and examined that there is a maximum increase in the Nusselt number of nanofluids concentration with exceeding of velocity compared to DI-water under turbulent flow condition. The higher Nusselt number for the GNP-water nanofluid has resulted in 12.6% with a minimum velocity of 0.075 wt.% with gradually increase by varying the velocity as relative to DI-water. While, the higher Nusselt number for the TiO_2-water nanofluid has resulted in 10.84% higher than DI-water with varying of the velocity. In the fully turbulent region, the higher Nusselt has resulted in TiO_2-water nanofluid than GNP-water nanofluid. The influences of the graph caused by both nanofluid concentration of 0.075 wt.% vary under various maximizing the velocity of the working fluid.

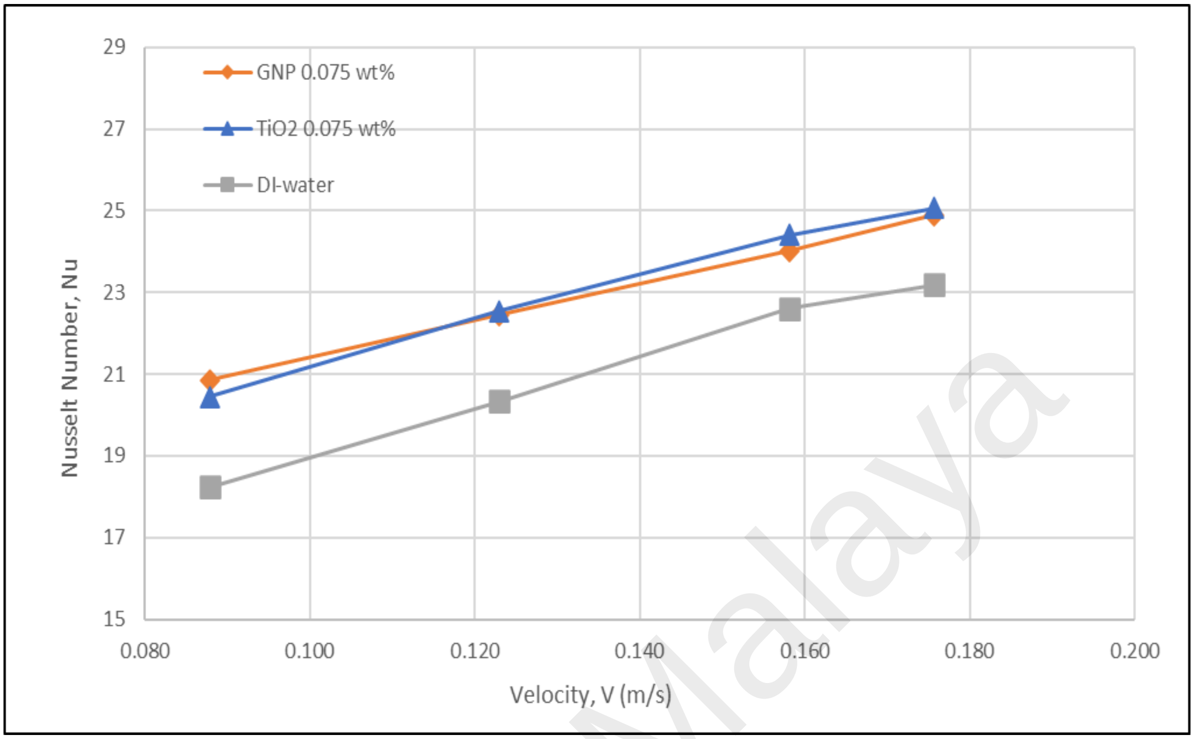

Figure 4. 8: Variation of averaged Nusselt number for nanofluids of 0.075 wt.% against DI-water versus Velocity

4.1.4 0.05 wt.% of TiO_2-water and GNP-water nanofluid heat transfer properties

The experiment was conducted for the 0.05 wt.% concentration of nanofluids (TiO_2-water & GNP-water) by varying the velocity of flow from 0.088 ± 0.0005 to 0.175 ± 0.0005 in the purpose to determine the heat transfer coefficient under the turbulent condition. The experiment resulted in data of the nanofluid 0.05 wt.% concentrations are demonstrated in Figure 4.9 and results are compared with DI-water experimental data. The results demonstrate that the coefficient of heat transfer enhances whereas the velocity is enhanced equally for DI-water as well as nanofluid concentrations. The present experiment study resulted in the remarkable enhancement in the heat transfer coefficient of GNP-water nanofluid by 14.06% with maximum velocity under fully turbulent condition for the nanoparticle concentration 0.05 wt.% as compared with DI-water. While, the convective heat transfer coefficient of the TiO_2-water nanofluids enhances by 7.03% with maximum velocity for the 0.05 wt.% of nanoparticle concentration under the turbulent condition as compared with DI-water. The GNP-water nanofluid has resulted a remarkable enhancement in the convective heat transfer as compared to TiO_2-water nanofluid with corresponding 0.05 wt.% under turbulent flow at constant heat flux.

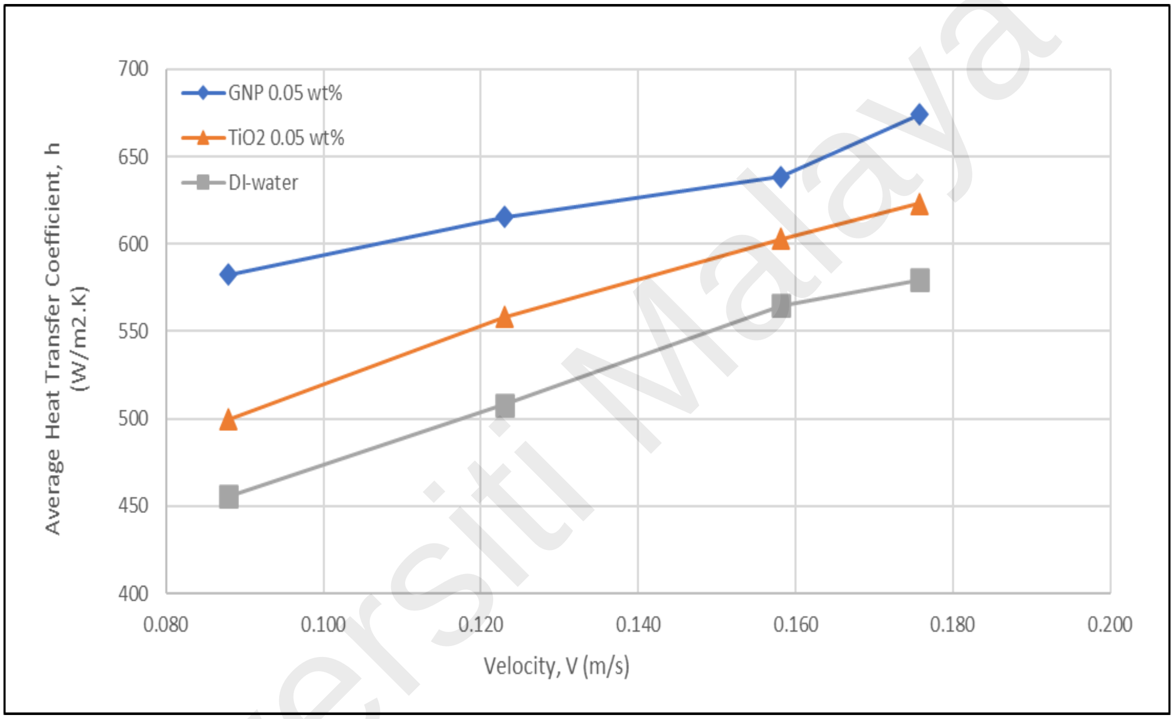

Figure 4. 9:Variance of 0.05 wt.% nanofluids heat transfer coefficient against DI-water versus Velocity

The experimental data are shown in Figure 4.10 and examined that there is a maximum increase in the Nusselt number of nanofluids concentration with exceeding of velocity compare to DI-water under turbulent flow condition. The higher Nusselt number for the GNP-water nanofluid has resulted in 11.6% with a minimum velocity of 0.05 wt.% with gradually increase by varying the velocity as relative to DI-water. While, the higher Nusselt number for the TiO_2-water nanofluid has resulted in 8.87% higher than DI-water with varying of the velocity, respectively. The fully turbulent region, the higher Nusselt has resulted in TiO_2-water nanofluid than GNP-water nanofluid. The influences of the graph caused by both nanofluid concentration of 0.05 wt.% vary under various maximizing the velocity working fluid.

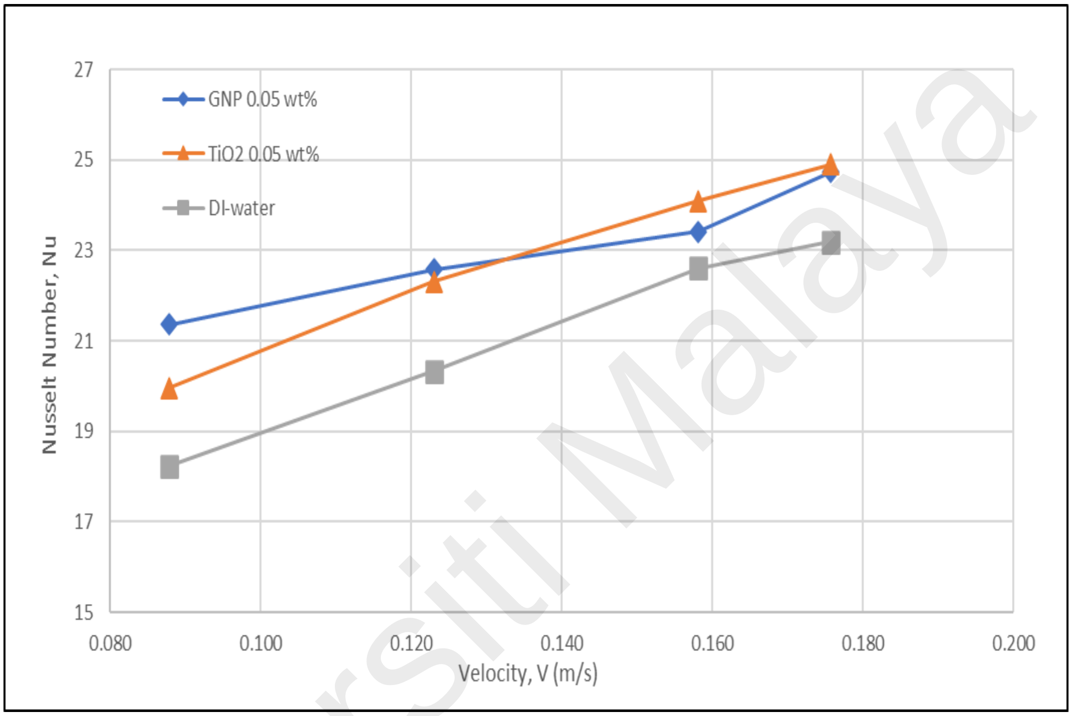

Figure 4. 10: Variation of averaged Nusselt number for nanofluids of 0.05 wt.% against DI-water versus Velocity

4.1.5 0.025 wt.% of TiO_2-water and GNP-water nanofluid heat transfer properties

The experiment was conducted for the 0.025 wt.% concentration of nanofluids (TiO_2-water & GNP-water) by varying the velocity of flow from 0.088 ± 0.0005 to 0.175 ± 0.0005 in the purpose to determine the heat transfer coefficient under the turbulent condition. The experiment resulted in data of the nanofluid 0.025 wt.% concentrations are demonstrated in Figure 4.11 and results are compared with DI-water experiment data. The results demonstrate that the coefficient of heat transfer enhances whereas the velocity is enhanced equally for

DI-water as well as nanofluid concentrations. The present experiment study resulted in the remarkable enhancement in the heat transfer coefficient of GNP-water nanofluid by 5.99% with maximum velocity under fully turbulent conditions for the nanoparticle concentration 0.025 wt.% as compared with DI-water. While, the convective heat transfer coefficient of the TiO_2-water nanofluids enhances by 2.34% with maximum velocity for the 0.025 wt.% of nanoparticle concentration under the turbulent condition as compared with DI-water. The GNP-water nanofluid has resulted in a remarkable enhancement in the convective heat transfer as compared to TiO_2-water nanofluid with the corresponding 0.025wt.% under turbulent flow at constant heat flux. The study gained the remarkable enhancement in convective heat transfer coefficient of GNP-water by 18.32% for the minimum velocity of the flow with 0.025 wt.% concentration as compared to the DI-water under developing turbulent conditions.

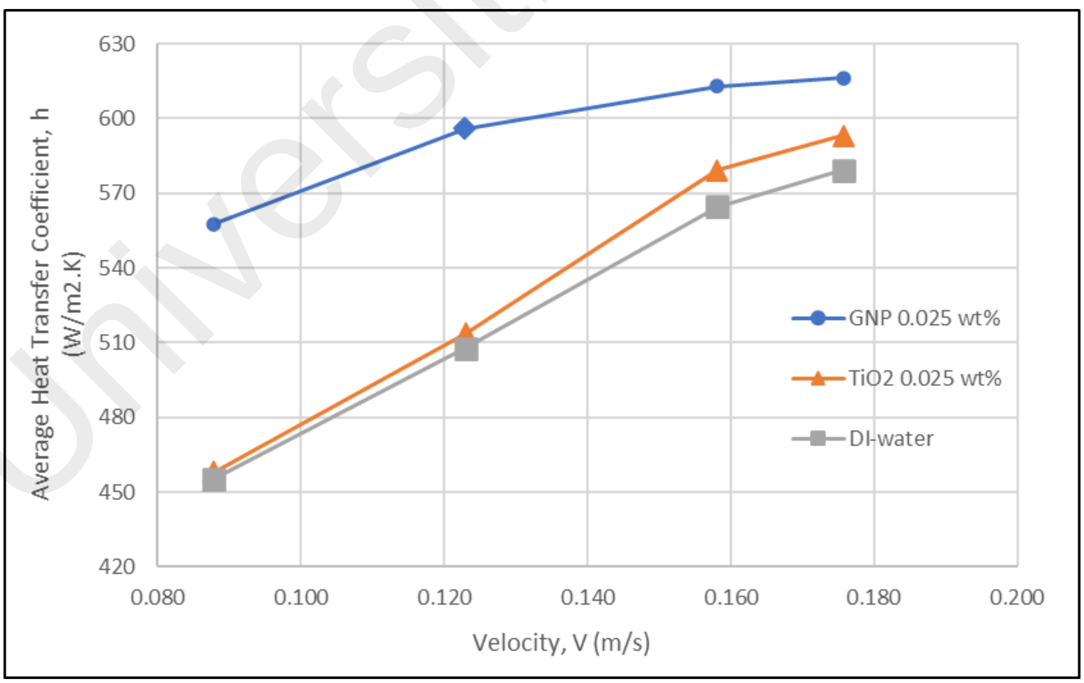

Figure 4. 11: Variation of Heat transfer coefficient for nanofluids of 0.025 wt.% against DI-water versus Velocity

The experimental data are shown in Figure 4.12 and examined that there is a maximum increase in the Nusselt number of nanofluids concentration with exceeding of velocity compare to DI-water under turbulent flow condition. The higher Nusselt number for the GNP-water nanofluid has resulted in 11.2% with a minimum velocity of 0.025 wt.% with gradually increase by varying the velocity as relative to DI-water. While, the higher Nusselt number for the TiO_2-water nanofluid has resulted in 2.46% higher than DI-water with varying of the velocity, respectively. The fully turbulent region, the higher Nusselt has resulted in TiO_2-water nanofluid than GNP-water nanofluid. The influences of the graph caused by both nanofluid concentration of 0.025 wt.% vary under various maximizing the velocity working fluid. There is a significant increment in the Nusselt number for the minimum velocity with GNP-water fluid than TiO_2-water and DI-water as demonstrated in the graph, while the maximum velocity of the flow correspondingly equalized the Nusselt number enhancement with a minimum difference, respectively.

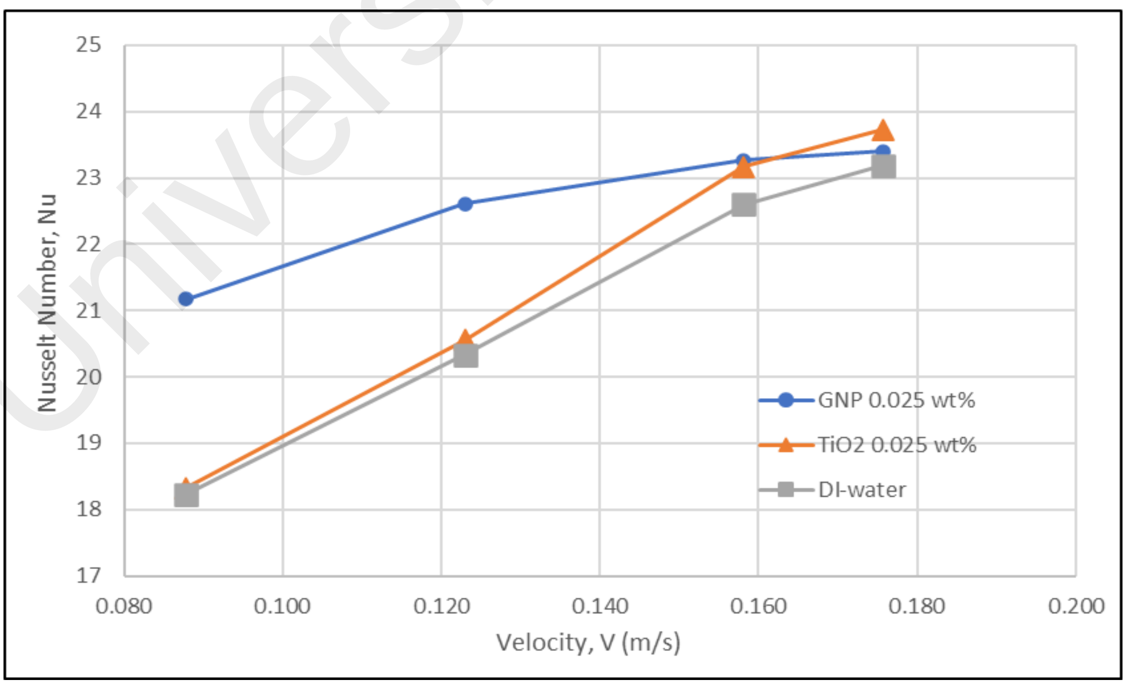

Figure 4. 12: Variation of averaged Nusselt number for nanofluids of 0.025 wt.% against DI-water versus Velocity

4.2 Comparison of Nanofluid concentrations heat transfer properties against the volumetric flow

The forced convective heat transfer for the turbulent flow regime is chosen and employed in heat transfer applications. The experimental setup was performed for the GNP-water and TiO_2-water nanofluids of different nanoparticle concentrations (0.1, 0.075, 0.05 and 0.025 wt.%) by varying the volumetric flow ($\dot{V}$) and the experimental results were compared with the DI-water result.

4.2.1 GNPs-water nanofluid concentrations heat transfer properties against DI-water

From systematic experiments, the number of investigations were observed for the GNP-water (nanoparticles weight concentration: 0.025, 0.05, 0.075 and 0.1 wt.%) nanofluids by varying the volumetric flowrate 5, 7, 9 and 10 lit/min under turbulent flow regime. The experiment results exhibited that increasing of the nanoparticle wt.% concentration enhanced the convective heat transfer coefficient (Keklikcioglu, Dagdevir, & Ozceyhan, 2019; Sadeghinezhad et al., 2016, 2015) related to the conventional fluid. Figure 4.13 demonstrated the experimental outcomes, the maximum nanofluids heat transfer coefficient enhance by 5.99, 14.06, 17.45 and 21.75% for the nanoparticle weight concentrations of 0.025, 0.05, 0.075 and 0.1 wt.% as compared to DI-water, respectively. The maximum heat transfer coefficient achieves by maximum volumetric flowrate for the nanoparticle concentration of 0.1 wt.% among others nanofluid concentration and DI-water, accordingly.

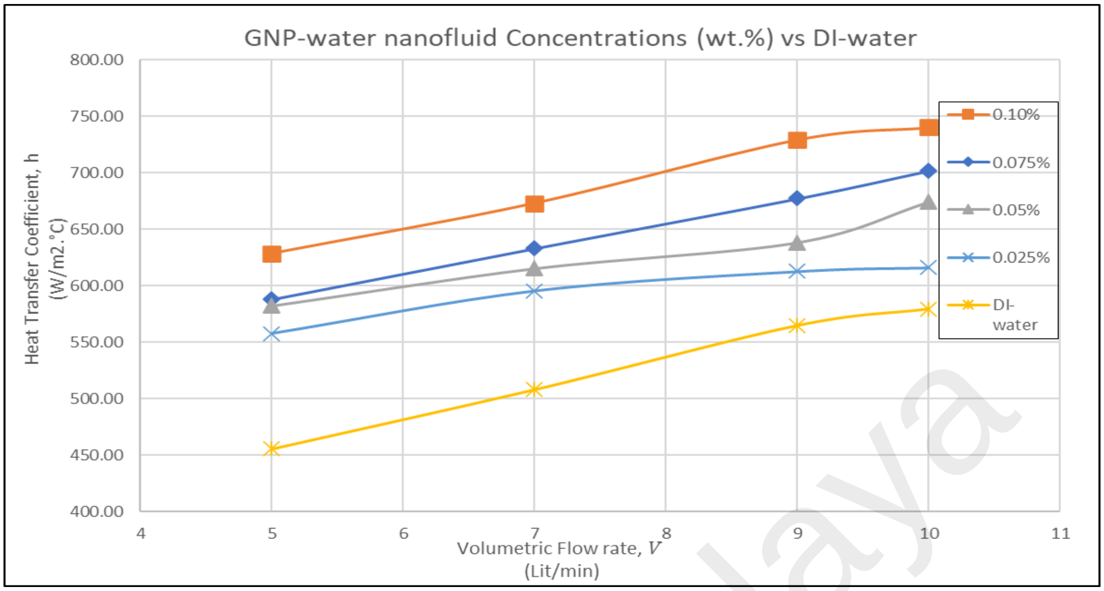

Figure 4. 13: Variation of convective heat transfer coefficient of GNP-water nanofluid concentrations as a function of Volumetric flowrate with DI-water

The experiment was performed to evaluate the Nusselt number of the GNP-water nanofluid (nanoparticle weight concentrations: 0.025, 0.05, 0.075 and 0.1 wt.%) by varying the volumetric flowrate 5, 7, 9 and 10 lit/min under the turbulent flow condition. The significant enhancement of Nusselt number can be achieved by maximizing the volumetric flowrate (means increasing the Reynolds number) of the working fluid as obtained numerous researchers (Cheen Sean Oon et al., 2015; Wang, Y., Al-Saaidi, H. A. I., Kong, M., & Alvarado, 2019; Wen & Ding, 2005). Figure 4.14 demonstrated the experimental outcomes of the study that the highest Nusselt number of the nanofluids enhanced by 11.2, 11.6, 12.6 and 14.3% for the nanoparticle weight concentrations of 0.025, 0.05, 0.075 and 0.1 wt.% respectively as compared to DI-water. The significant enhancement of Nusselt number was achieved by the minimum volumetric flowrate for the nanoparticle concentration of 0.1 wt.% among others nanofluid concentration and DI-water.

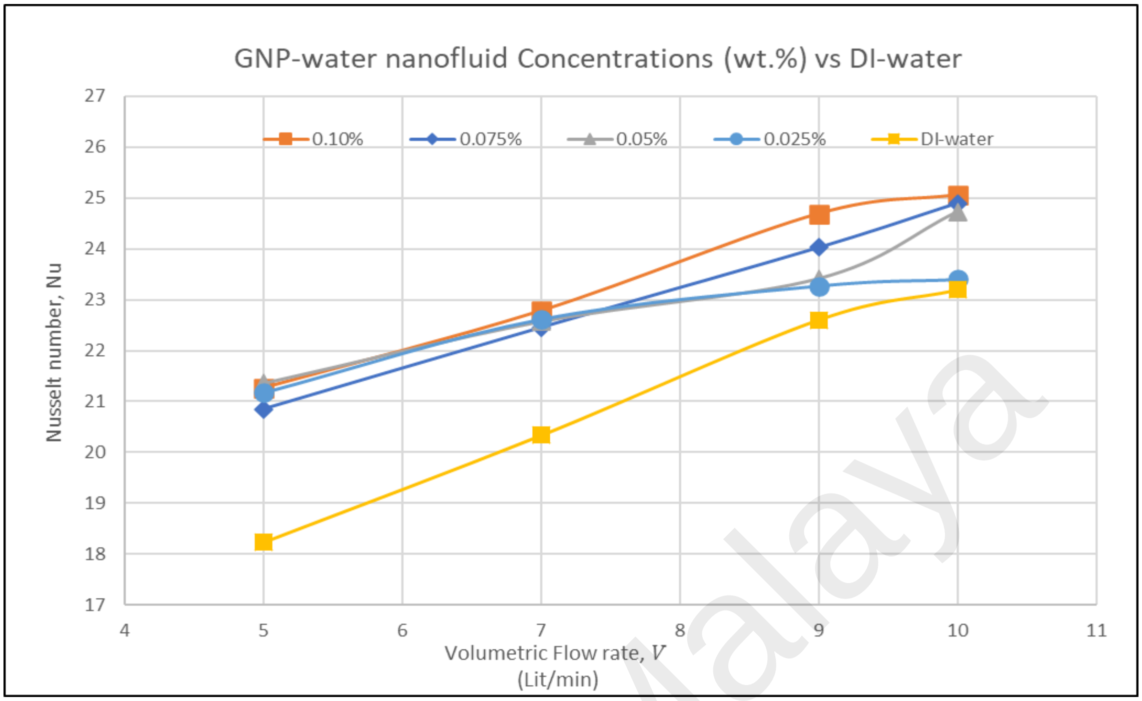

Figure 4. 14: Variation of Nusselt number of GNP-water nanofluid concentrations as a function of Volumetric flowrate with DI-water

The friction factor of the GNP-water nanofluid (nanoparticle weight concentrations: 0.025, 0.05, 0.075 and 0.1 wt.%) studied in the experiment of the annular test section and compared the results with DI-water friction factor data under turbulent flow regime. The friction factor achieved at the differential pressure across the experimental test section. Figure 4.15 exhibits that the friction factor was determined and found a minor variation effect than DI-water, while the friction factor has shown no changes for the corresponding nanoparticle wt.% concentration. As reported by the researchers that friction factor might not be affected by the nanoparticle dispersion, while some reported that the influence of nanoparticle concentrations can affect the friction factor under the various regime of flow (Javed et al., 2019).

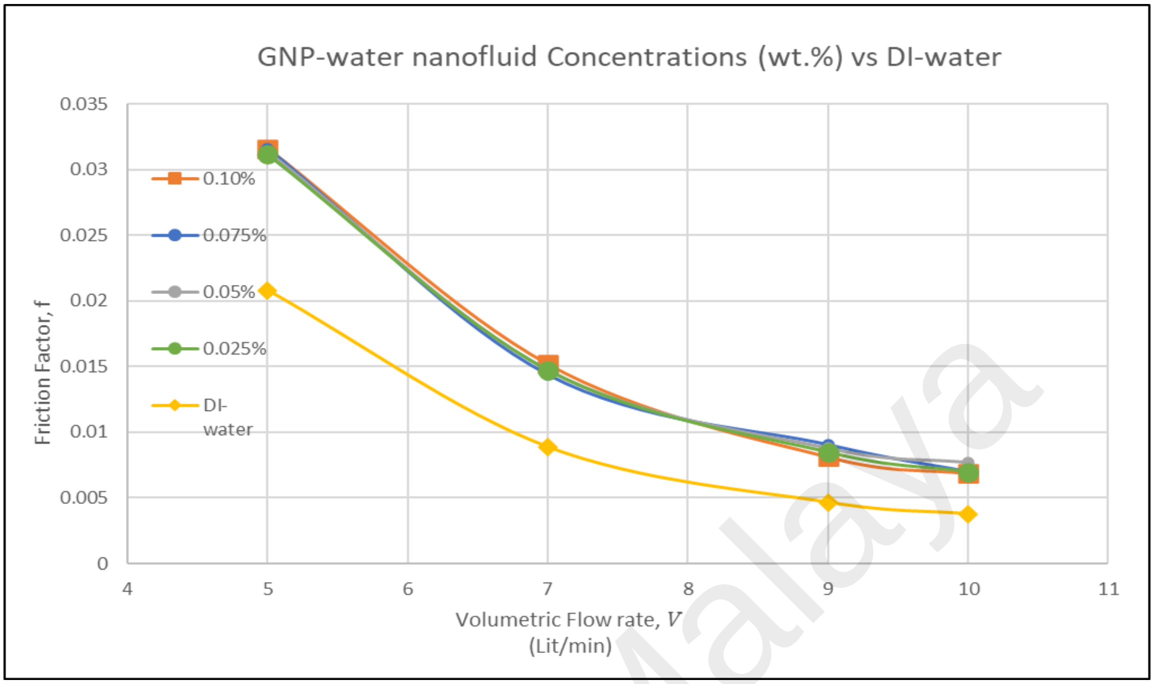

Figure 4. 15: Variation of friction factor of GNP-water nanofluid concentrations as a function of Volumetric flowrate with DI-water

4.2.2 TiO_2-water nanofluid concentrations heat transfer properties against DI-water

From systematic experiments, the number of investigations were observed for the TiO_2-water (nanoparticles weight concentration: 0.025, 0.05, 0.075 and 0.1 wt.%) nanofluids by varying the volumetric flowrate 5, 7, 9 and 10 lit/min under turbulent flow regime. The experimental data exhibited that addition of the nanoparticle wt.% concentration enhanced the heat transfer coefficient (Azmi, Sharma, Sarma, Mamat, & Najafi, 2014; Duangthongsuk & Wongwises, 2009; Cheen Sean Oon et al., 2015) as compared to the conventional base fluid. Figure 4.16 demonstrated the experimental results that the highest heat transfer coefficient of the nanofluids enhanced by 2.34, 7.03, 7.14 and 11.72% for the nanoparticle weight concentrations of 0.025, 0.05, 0.075 and 0.1 wt.% respective as compared to the data from DI-water. The maximum heat transfer coefficient was achieved at the maximum volumetric flowrate for the nanoparticle concentration of 0.1 wt.% among others nanofluid concentration and DI-water.

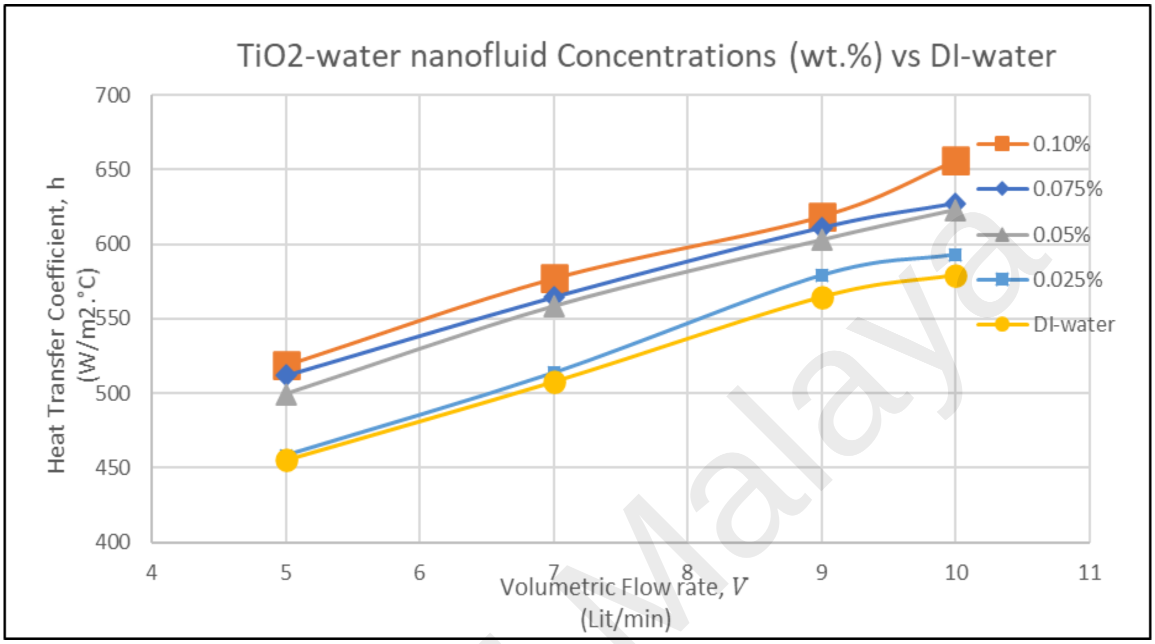

Figure 4. 16:Variation of heat transfer coefficient of TiO_2-water nanofluid concentrations as a function of Volumetric flowrate with DI-water

The experiment was conducted to evaluate the Nusselt number of the TiO_2-water nanofluid (nanoparticle weight concentrations: 0.025, 0.05, 0.075 and 0.1 wt.%) by varying the volumetric flowrate of 5, 7, 9 and 10 lit/min under the turbulent flow condition while keeping the heat flux constant. The significant enhancement of Nusselt number can be achieved by maximizing the volumetric flowrate (means increasing the Reynolds number) of the working fluid as resulted by the numerous researchers (Arulprakasajothi, M., Elangovan, K., Reddy, K. H., & Suresh, 2015; Duangthongsuk, W., & Wongwises, 2010; Cheen Sean Oon et al., 2015). Figure 4.17 showed the experimental results of the study that the maximum Nusselt number of the nanofluids were achieve by 2.46, 8.87, 10.84 and 12% for the nanoparticle concentrations of 0.025, 0.05, 0.075 and 0.1 wt.% respectively as compared to DI-water. The significant enhancement of Nusselt number achieved by the minimum volumetric flowrate for the nanoparticle higher concentrations.

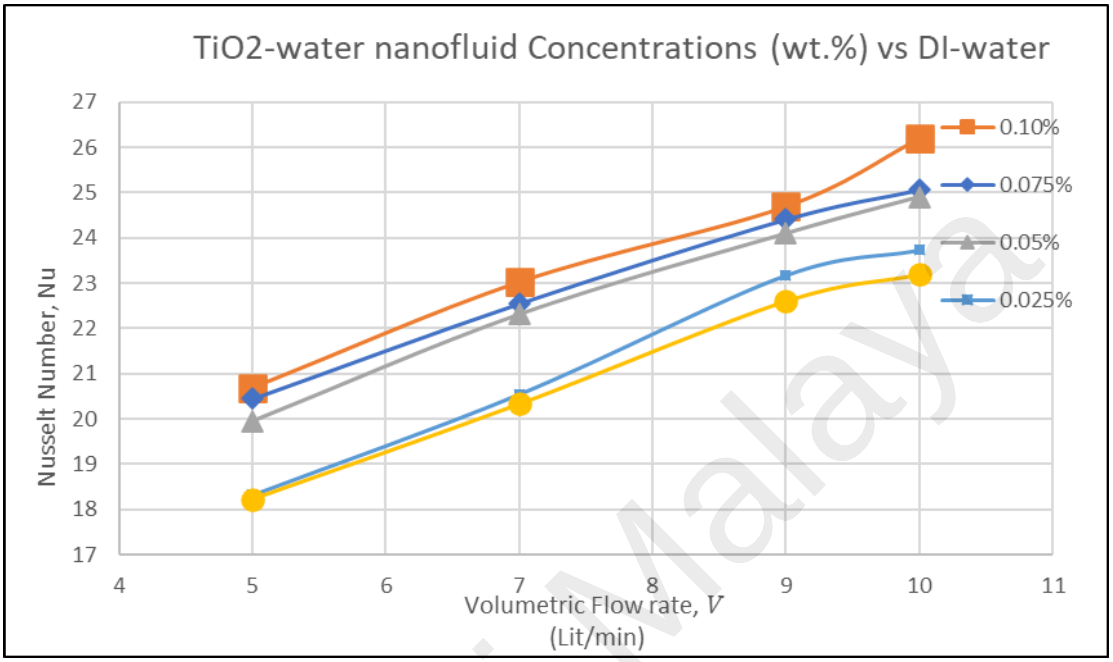

Figure 4. 17:Variation of Nusselt number of TiO_2-water nanofluid concentrations as a function of Volumetric flowrate with DI-water

The friction factor of the TiO_2-water nanofluid (nanoparticle weight concentrations: 0.025, 0.05, 0.075 and 0.1 wt.%) studied in the annular test section and compared the results with DI-water friction data under turbulent flow regime. The friction factor achieved by the differential pressure across the experimental test section. Figure 4.18 exhibits the friction factor as the function of velocity and revealed minor enhancement incomparison to the data from DI-water, while the friction factor has shown no changes for the corresponding nanoparticle wt.% concentrations. As reported by the researchers that the friction factor might not be affected by the nanoparticle dispersion, while some reported that the influence of nanoparticle concentrations can affect the friction factor under the various regime of flow (Kaya, H., Ekiciler, R., & Arslan, 2019; Cheen Sean Oon et al., 2015).

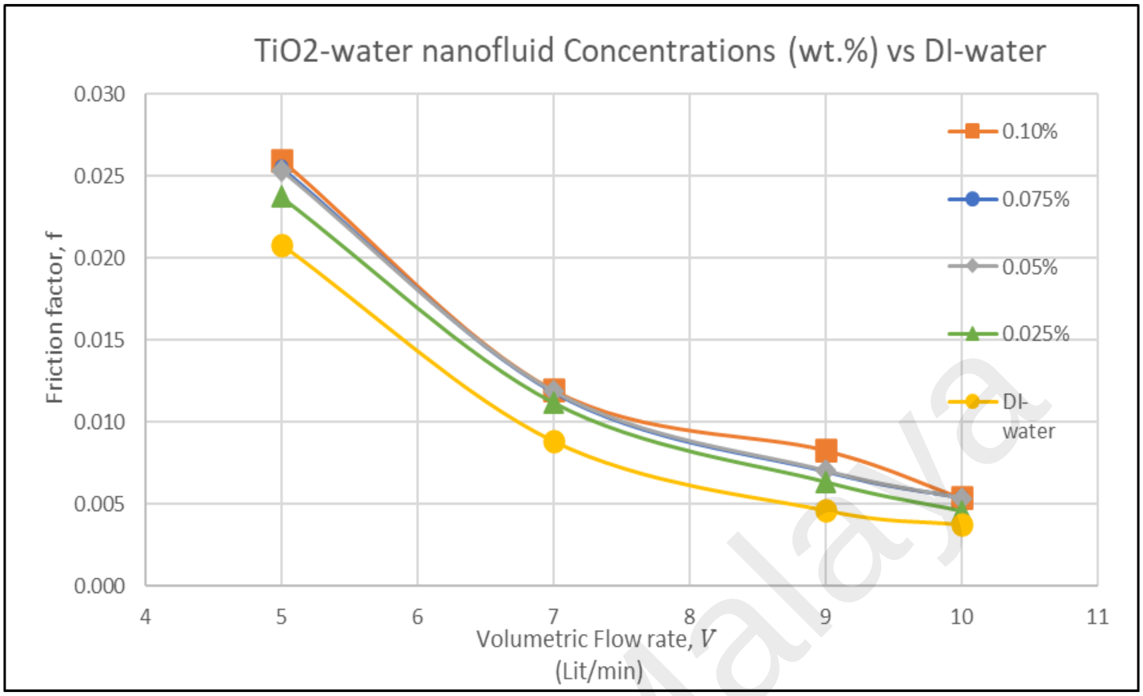

Figure 4. 18:Variation of friction factor of GNP-water nanofluid concentrations as a function of Volumetric flowrate with DI-water

4.3 Numerical study of DI-water by varying the inner shape of the experimental test section

The simulation of the experimentalal test section was carried out for the DI-water by ANSYS fluent software. The comparison of the two different inner shapes (Circular and Square bar) to evaluate the temperature distribution inside the annular heat exchanger and kept constant hydraulic diameter (Dh) for both the designs. Figure 4.19 exhibits the distribution of the inner wall temperature of the annular heat exchanger under the fully turbulent regime for the constant heat flux. The simulated results show that the inner temperature distribution of the DI-water gradually increased for both the geometries, while the inner square geometry demonstrated an insignificant increment for the temperature than the circular configuration.

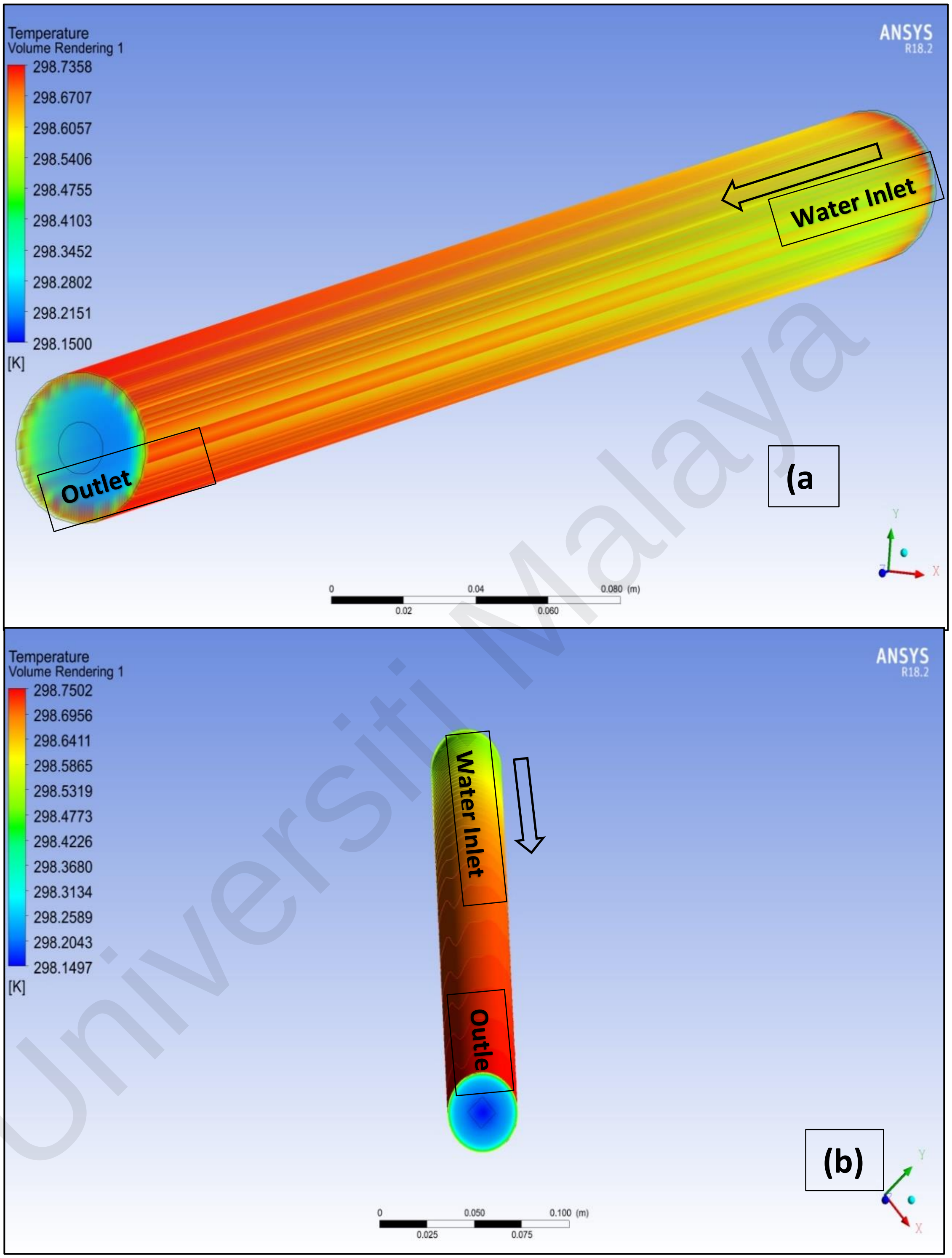

Figure 4. 19: DI-water surface of inner wall temperature distribution for the annular heat ex-changer with (a) inner circular bar (b) inner square bar

Figure 4.20 demonstrated the distribution of inner wall temperature of DI-water corresponding to wall distance for the annular heat ex-changer with different inner geometry (circular bar and square bar). The circular inner geometry resulted in sudden high temperature and then gradually became stable with the distance while in the square inner geometry it steadily increased with the wall distance and resulted in an insignificant increment for the wall temperature under fully turbulent flow.

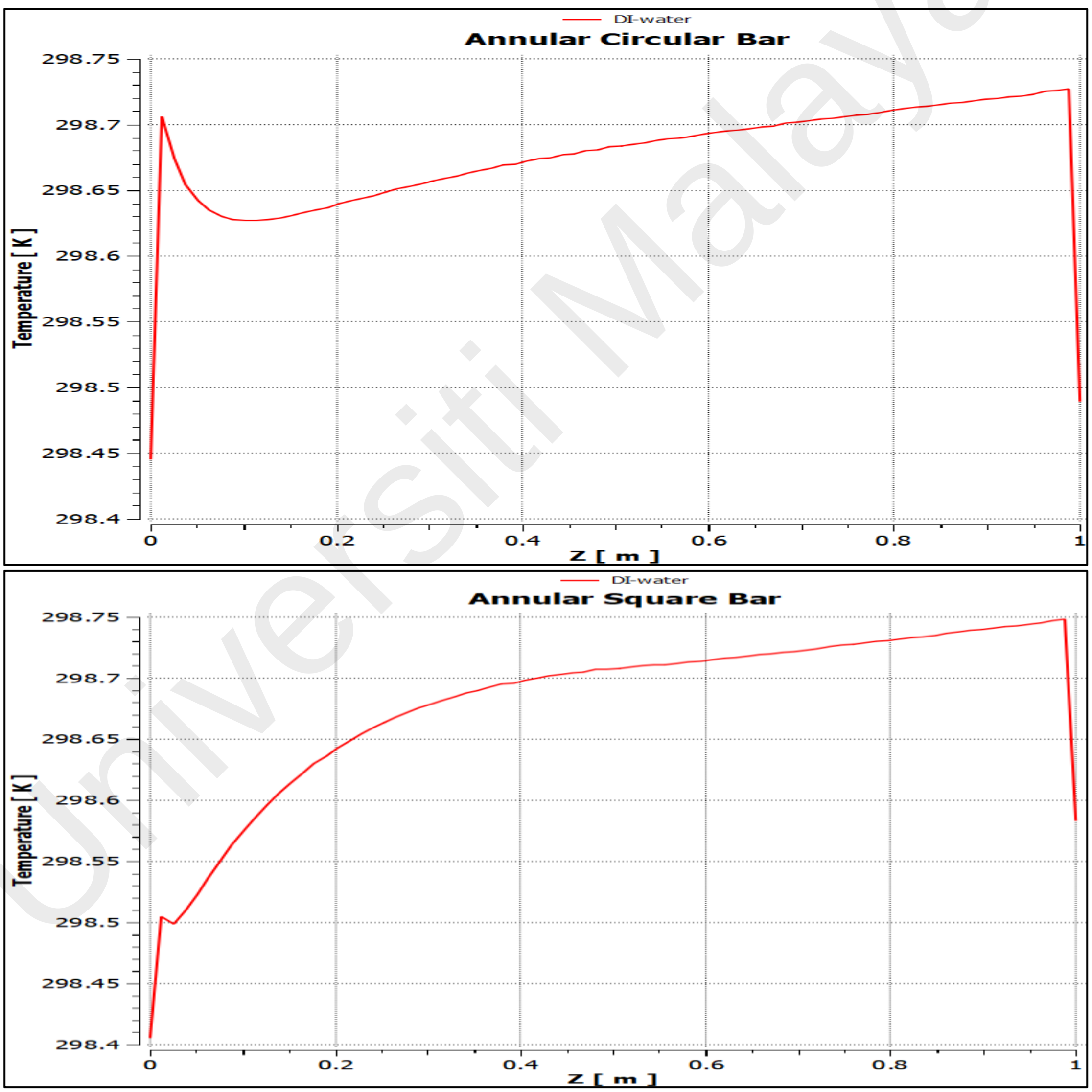

Figure 4. 20: The Graph of DI-water surface of inner wall temperature distribution along with wall distance for the annular heat ex-changer with varying inner geometry

This might be noted that the distribution of the inner wall temperature of DI-water insignificantly increased when the DI-water simulated for the square inner geometry. This is determined by the high heat transfer coefficient for the circular inner geometry.

Figure 4.21 demonstrates the DI-water velocity contours of the annular heat exchanger with circular and square inner geometry. This might be noticed from the simulation result that the higher velocity achieved by simulating the DI-water through the square inner geometry while keeping the flowrate constant. The maximum velocity reported along with the inner geometry for both the designs of simulation.

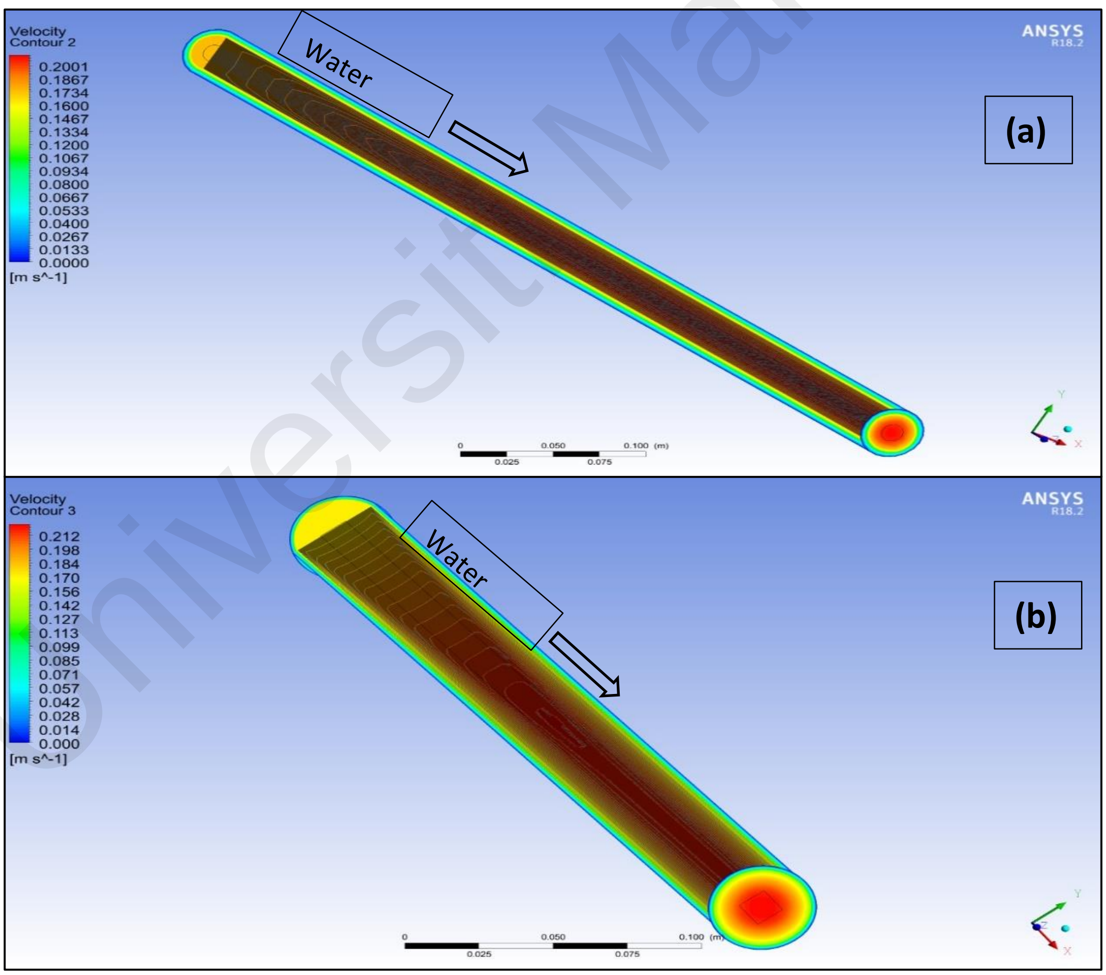

Figure 4. 21: DI-water velocity distribution for the annular heat ex-changer with (a) inner circular bar (b) inner square bar

The simulation result shows in Figure 4.22 that the inner wall temperature distribution of 0.1 wt.% GNP-water and TiO_2-water nanofluids have lower than DI-water under maximum volumetric flowrate. The minimum temperature distribution observed for the 0.1 wt.% GNP-water nanofluid and this lower temperature distribution have resulted in the high heat transfer improvement than DI-water, accordingly.

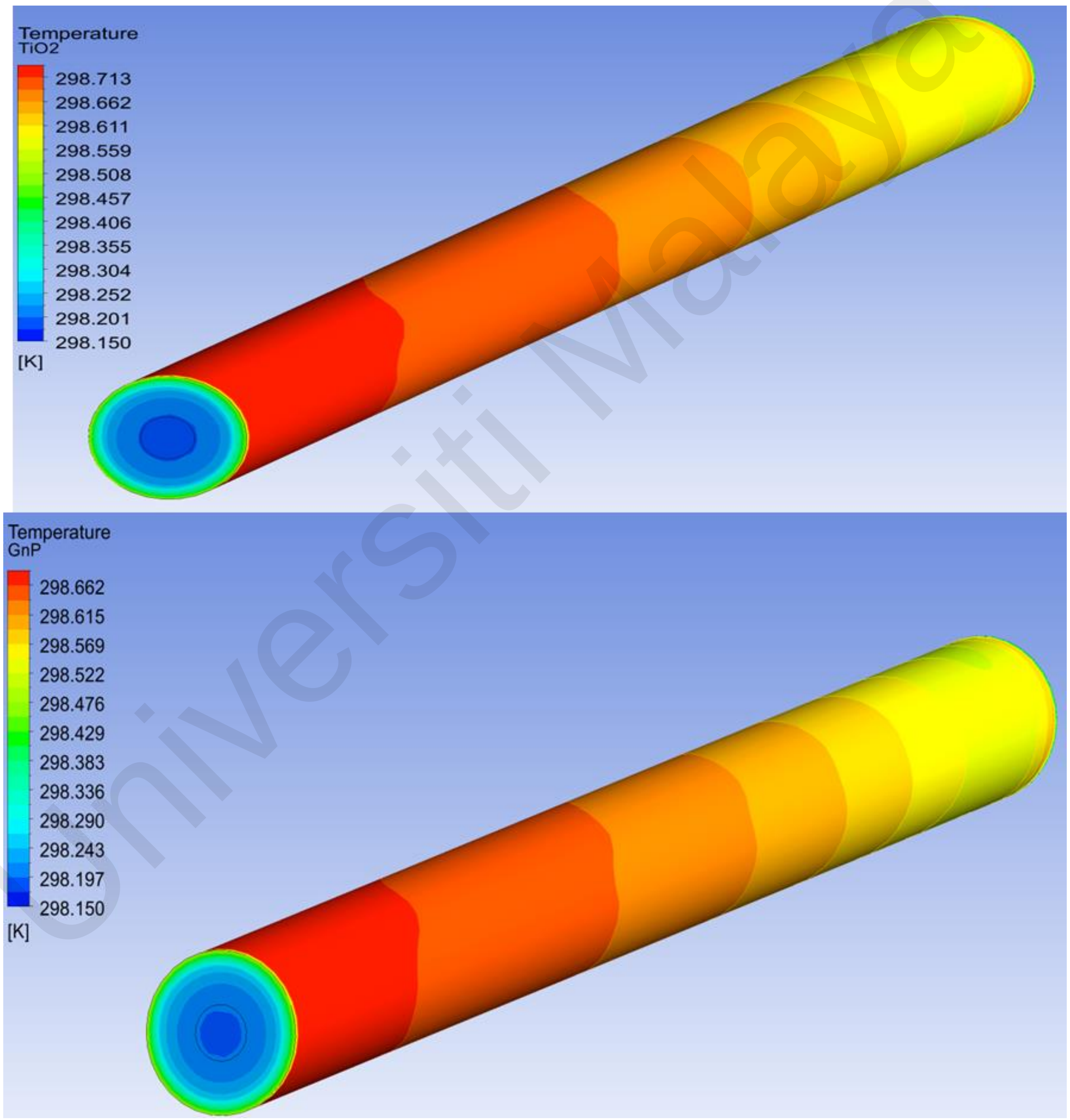

Figure 4. 22: 0.1 wt.% nanofluids concentration surface of inner wall temperature distribution for the annular heat ex-changer

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The heat exchangers are widely used in petrochemical industries, power generation plants, automobiles, etc. to transport energy. Efficient energy transportation required significant cooling and heating attributes to save energy and protect the climate change.

Present research outcomes revealed eco-friendly nanofluids and cost-effective annular heat exchanger design. The simplest two-step preparation techniques used to disperse the TiO_2 and GNPs nanoparticles into the base fluid (DI-water) for the preparation of nanofluids. Ecofriendly functionalization process applied successfully implemented in the current research with positive output. The performance of the modeled techniques in enhancing the forced convective heat transfer in small heat exchanger incomparison to the basefluid (DI-water) has successfully achieved.

The nanoparticle weight concentrations of 0.1, 0.075, 0.05 and 0.025 wt.% of TiO_2-water and GNPs-water nanofluids studied during the experimental work and results compared with the DI-water results. The higher thermal conductivity property resulted with the addition of nanoparticles and enhanced with the weight concentrations incomparison to the data from DI-water.

Additionally, The CFD commercial package ANSYS Fluent 18.2 software has been used to simulate the flow of DI-water heat transport energy in the annular geometry. The CFD analysis used the finite volume method, uniform heat flux boundary conditions and low turbulent SST- k-ω model for the solver. The simulation results demonstrated the distribution of inner wall temperature enhanced while the insignificant increment resulted in the square inner geometry than the circular inner geometry under high Reynolds number incomparison to the DI-water results. The lower inner wall temperature resulted high heat transfer coefficient in annular heat exchanger with circular inner shape.

The experimental results of nanofluids concentration are based on the heat transfer coefficient (h) and Nusselt number (Nu) under turbulent flow regime by keeping the heat flux constant. The maximum enhancement of heat transfer resulted in 21.75% by the 0.1 wt.% GNP-water nanofluid than DI-water, while the 0.1 wt.% of TiO_2-water nanofluids resulted in 11.72% than DI-water. The higher Nusselt number resulted in the addition of nanoparticle weight concentration into the base fluid while insignificant friction factor reported with the nanofluid concentrations than DI-water data.

5.2 Recommendation

The present study focused on the enhancement of the eco-friendly nanofluids concentrations and cost-effective annular heat exchanger for the heat transfer application at constant heat flux boundry condition. The future recommendation works could be varying the constant heat flux for the high Reynolds number and modify the inner shape of the annular heat exchanger to different geometric shapes under turblent flow and investigate the heat transfer and frictional pressure losses of the fluid.

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LIST OF PUBLICATION AND PAPERS PRESENTED

Paper abstract of the research have presented online on dated: 1st May 2020 at "**The 5th RSU National and International Research Conference on Science and Technology, Social Science, and Humanities 2020 (RSUSSH 2020)**, **Thailand**".