STUDY OF HEAT TRANSFER AND FRICTION LOSS OF NANO FLUID SUSPENSION FLOW IN CIRCULAR PIPE HEAT EXCHANGER

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DEPARTMENT OF MECHANICAL ENGINEERING
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DEPARTMENT OF MECHANICAL ENGINEERING
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ORIGINAL LITERARY WORK DECLARATION

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Tittle of Research Report: Study of heat transfer and friction loss of nanofluid suspension flow in circular pipe heat exchanger

Field of Study: Fluid mechanics & Heat transfer

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STUDY OF HEAT TRANSFER AND FRICTION LOSS OF NANO FLUID SUSPENSION FLOW IN CIRCULAR PIPE HEAT EXCHANGER

ABSTRACT

This stated experiment focused on the study of convective heat transfer and friction loss in a circular flow passage for Graphene oxide-based nanofluids which are consist of Graphene Oxide/Distilled water with their different wt. % concentrations. These GO/DW based nanofluids where been prepared by using a facile two-step method, while the GO particles were synthesized by a modified hummer method. Four different (0.025, 0.05, 0.075, and 0.1 wt. %) were produced by dispersing graphene particles in distilled water under high probe sonication. The GO/DW based nanofluids flowing in a horizontal shell and tube heat exchanger counter flow under turbulent flow conditions where been investigated for heat transfer, Nusselt numbers, pressure drop, and friction loss studies. The constant heat flux and varying flow rate conditions have been used to analyse the heat transfer improvement in a circular heat exchanger. The results show the convective heat transfer coefficient of the nanofluids is slightly higher than the base fluid at the same flow rate and the same inlet temperature. The heat transfer coefficient of the nanofluids increases with the increase of flow rate, also the heat transfer coefficient increases with the increase of the concentration of the nanofluids, however, an increase in the concentration causes the increase in the viscosity of the fluid leading to a slight increase in the friction loss. As for further analysis, distilled water where been compared with graphene oxide (GO/DW) base nanofluids to compare their heat transfer, Nusselt numbers, and pressure drop variations.

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ABSTRAK

Laporan eksperimen ini, mengkaji mengenai pengalihan haba konvektif dan faktor geseran pada bendalir nano berasaskan karbon yang terdiri daripada air dan grafena oksida (Graphene Oxide) (GO) yang mempunyai kepekatan berbeza. Nanopartikel GO / DW berdiameter kira-kira 25µm digunakan dalam eksperimen ini, bendalir nano GO / DW pada kepekatan 0.025, 0.05, 0.075, dan 0.1% kepekatan. dihasilkan dengan kaedah "advance/modified hummer". Bendalir nano yang mengalir di cangkang mendatar dan aliran kaunter penukar haba tiub dalam keadaan aliran bergelora disiasat. Tiub akan dipanaskan dengan haba yang berterusan pada sepanjang ujian. Hasil kajian menunjukkan pemindahan haba menggunakan penghubung nanofluids sedikit lebih tinggi daripada bendalir asas pada kadar aliran dan suhu "inlet" yang sama. Koefisien pemindahan haba nanofluids naik dengan peningkatan kadar aliran. Selain itu, peningkatan pekali pemindahan haba dengan peningkatan kepekatan nanofluids, peningkatan kepekatan menyebabkan peningkatan pada kelikatan bendalir menyebabkan sedikit peningkatan dalam faktor geseran. Untuk analisis lebih lanjut, air suling dibandingkan dengan GO/DW untuk mengkaji perbezaan pemindahan haba, penurunan tekanan dan faktor geseran bendalir nano.

ACKNOWLEDGEMENTS

There have been countless moments of struggle and founder in the path of completing this research project. Hence, it is not only a bunch of papers that reflect the endless ideas obtainable in science but also parallel to the values that I have in me which was discovered in the course of finishing this research project. To my surprise, I persevered in this journey of many hurdles and managed to complete the research project. As the saying goes “Rome wasn’t built in a day” there were many sleepless nights in front of my laptop and countless hours spent in the lab. However, I would need to acknowledge that this was not a solo voyage and many people acted as a catalyst for me to keep moving forward.

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Moving on, to my family and especially my parents Mr. Ramadas and Mrs.Vasantha. I will forever be indebted to you for the lessons of life that go beyond classroom learning. A simple thank you will never be enough for all the encouragement, love, and emotional support that I have received from both of you. I hope to continue making you all proud.

Last but not the least, a special mention to my friends who have not only eased up difficult moments but have also made me enjoy my time as a student. All the light and funny moments of my master’s studies will forever be close to my heart, and when times were difficult, we always had each other’s back.

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LIST OF SYMBOLS AND ABBREVIATIONS

GO	:	Graphene Oxide
GO/DW		Graphene Oxide with distilled water as base fluid
Al_20_3	:	Aluminium Oxide
Al_20_3/DW		Aluminium Oxide with distilled water as base fluid
CuO	:	Copper Oxide
K	:	Kelvin
nm	:	Nanometer
µm	:	Micrometer
wt.%	:	Weight percentage
Cp	:	Specific transfer coefficient based on average temperature (J/Kg.K)
h	:	Heat transfer coefficient (W/m^{2}K)
Nu	:	Nusselt number (h.D/K)
P	:	Static pressure (N/m^2)
Re	:	Reynolds number
q	:	Heat flux (W/m^2)
T	:	Temperature (°C)
v	:	Velocity (m/s)
ρ	:	Density (Kg/m3)
D	:	Tube diameter
V	:	Voltage
I	:	Current
P	:	Power
f	:	Friction factor

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Research Background

The cooling system is one of the most significant encounters facing in many engineering sectors. A heat exchanger is used to transferring heat from one medium to another medium with the help of a fluid. For example, a swimming pool uses a boiler or solar-heated water to heat the swimming pool with the help of a heat exchanger. Heat is transferred by conduction through the exchanger materials which separate the mediums being used. A shell and tube heat exchanger pass fluids through and over tubes, whereas an air-cooled heat exchanger passes cool air through a core of fins to cool a liquid. Water, ethylene glycol, etc. is used as a conventional heat exchanger fluid. Although various research and development are focusing on industrial heat transfer requirements, major improvements in cooling abilities have been lacking because of conventional heat transfer fluids have poor heat transfer properties (Sankar, Rao , & Rao, 2012).

Researchers are trying out ways to improvise highly efficient fluid for the heat exchanger to be used in the future with better performance from the current fluids. Researchers have come out with metal oxide and carbon structured base nanofluids as a substitution fluid for heat transfer but the problem with metal oxide and carbon structured base Nanofluids was the sedimentation of particles in most of the cases (K. Kouloulias, K. Kouloulias, & Y. Hardalupas, 2016). The metal oxide and carbon structured base nanofluids failed to stabilize with base fluid for a long-term run. To overcome this problem surfactants and non-covalent functionalization methods are used to stable and homogeneous states.

Table 1.1 : Physical properties of graphene

Physical Properties	Graphene
Melting point (K)	3800
Thermal conductivity (10^3W/mK)	3 - 5
Current density (A/cm^2)	> 10^8
Electron mobility (cm^2/ (V.s))	> 10,000
Mean free path (nm)	1 x 10^3

Nowadays, many researchers around the world testing on the surfactants and non-covalent functionalization method to produce graphene oxide. Graphene has an excellent property as in Table 1.1. Thermal, mechanical strength, electrical properties and other properties that make graphene one of the useful materials for a wide range of applications (Kausar, 2018). Graphene is characterized as a carbon nanomaterial group, which means the main structure is made of carbon and difference based on the layer and shape of the material. Layers of graphene are arranged on top of each other to form graphite. The main idea of this research project will focus on the new preparation methods of nanofluids and stability mechanisms, especially the new application trends for Nanofluids in addition to the heat transfer properties of nanofluids. An attempt to find some challenging issues that need to be solved for future research based on the review on these aspects of nanofluids.

1.2 Problem Statement

A heat exchanger is used widely in most of the industrial sectors globally. However, the capability in terms of dissipation and stability in most of the common fluid used in the heat exchanger is one of their biggest drawbacks. Nanofluids have been researched for a long time by researchers which mostly focused on metal oxide with surfactant. But in this research, the approach is by using an advanced hummer method to produce nanofluids as a heat exchanger fluid. This will improve the performance of the heat exchanger.

1.3 The Objective of This Research

The objective of this study is to improve the stability and properties of nanofluids and study their potential in different types of heat-based applications. In this research, the following objectives will be achieved:

1. Preparation of graphene oxide through advance/modified hummer method.
2. Preparation of GO/DW based nanofluids with varying wt. % concentrations by using a two-step technique.
3. Evaluate heat transfer properties and friction loss of the graphene oxide at different concentrations with different flow rates on the circular pipe.

1.4 Outline of This Research Project

This report is on heat transfer and friction loss of GO suspension flow in a circular pipe heat exchanger. The research project is outlined as follows.

Chapter 1: Provides a basic introduction to the research. It gives an overview of the current boundaries regarding the graphene oxide nanofluids. This chapter also will present the problem statements and the objectives to be achieved at the end of this research.

Chapter 2: Reviews from other journals and research on graphene oxide and their properties. This chapter also will highlight the contributions of graphene oxide in different types of fields.

Chapter 3: Detailing on the methodology for the advanced hummer method of graphene oxide nanofluids is clarified. This chapter also contains some techniques to conduct convection heat transfer. Furthermore, the procedures related to the experimental setup for convection heat transfer are described in detail.

Chapter 4: Results and discussion for each flow rate and concentration test on the heat transfer coefficient, Nusselt number, friction loss and pressure drop discussed in this chapter.

Chapter 5: Provide results in this research that are discussed in the earlier chapters are brief as a conclusion. The potentials and recommendations for upcoming works are also presented in this chapter.

CHAPTER 2: LITERATURE REVIEW

The background literature which is relevant to the study in this research project is reviewed in this particular chapter. Degrees, where linked examination needs are distinguished after, make the need for this research project.

The ideas tended to in the literature review are expansively held as follows; heat transfer in circular tube heat exchangers, nanofluids and its properties, Al_2O_3, and GO.

2.1 Heat Transfer in Heat Exchangers

A phenomenon that deals with temperature, heat energy flow and its associations to other forms of energy through radiation, conduction and convection exercising thermodynamics are heat exchangers. Heat exchangers are devices employed for heat transfer mechanisms.

Heat exchangers differ from its heat transfer mechanism, whereby mediums that do not undergo phase change during heat transfer is "single-phase heat exchangers" and "two-phase heat exchangers" are those vice versa.

Furthermore, the flow configuration in a heat exchanger also determines its characterization. These flow arrangements are the direction of movement of the medium within the heat exchanger. The common flow configurations in heat exchangers are shown in Figure 2.1.

There are few sorts of components that can be utilized in heat exchangers, just as a wide scope of materials used to build them. The components and materials utilized rely upon the heat exchanger type and its planned usage. To narrow down, this research project focuses on the tube component of heat exchangers where the heat transfer occurs in the system.

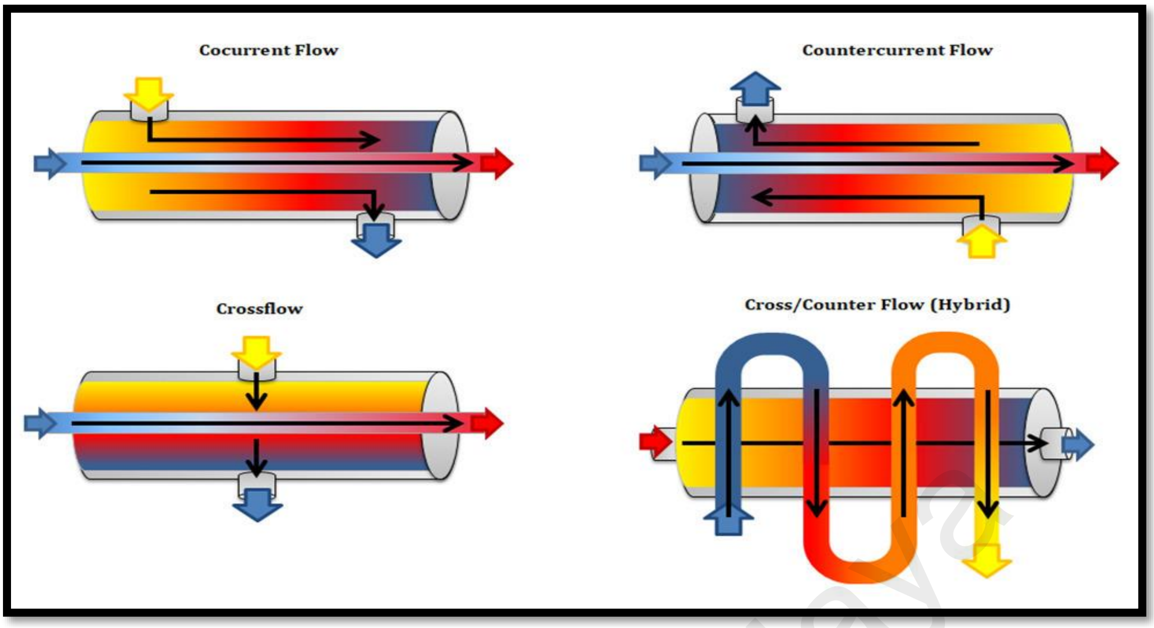


Figure 2.1 : Heat exchanger flow configurations

2.1.1 Tubular Exchangers

The heat transfer improvement empowers the size of the heat exchanger to be decreased, upgrading the performance of the heat exchanger. The flow of genuine fluid exhibits viscous impacts inflow under turbulent flow conditions. The average heat transfer coefficient is an important factor evaluating convective heat loss or gains in thermodynamics, applied in figuring convection heat transfer among moving fluid and solid.

To enhance the heat transfer coefficient on the internal surface and to obtain a large heat transfer area per unit volume, circular tube heat exchangers are usually utilized. (Priyanka Bisht, Manish Joshi, & Anirudh Gupta, 2014) Approached in precisely forecasting the Nusselt number under completely developed flows and built a comparison on uniform wall temperature condition between circular and non-circular duct.

An opting system that assuming steady and turbulent water flowing through a circular and rectangular channel, they made several hypotheses in this numerical research whereby physical properties of water are constant, the inlet velocity profile is uniform, flow assumed to be steady and the radiation heat transfer is negligible

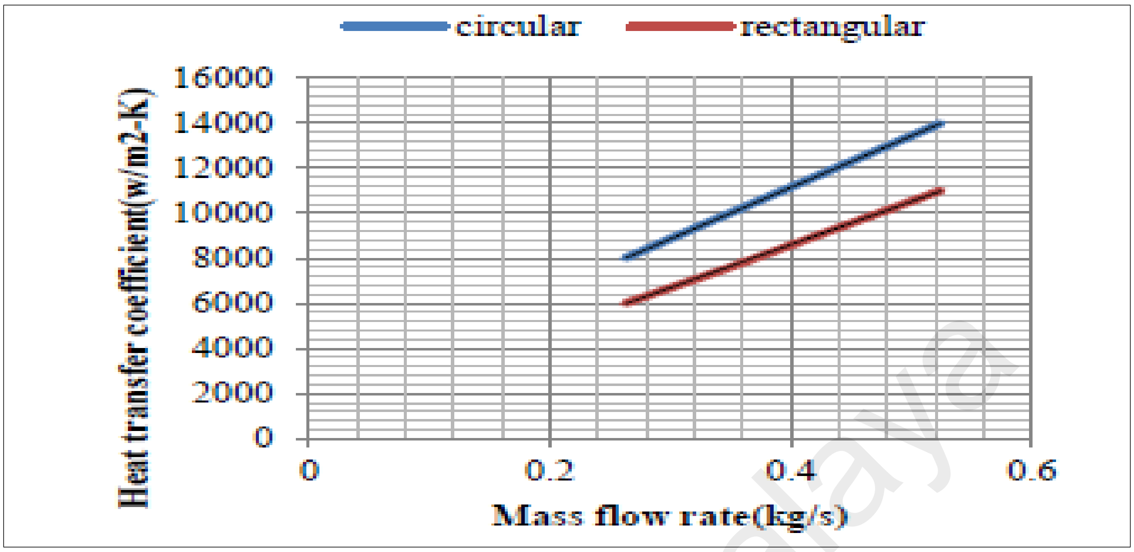


Figure 2.3 : Heat Transfer Coefficient vs Flow Rate

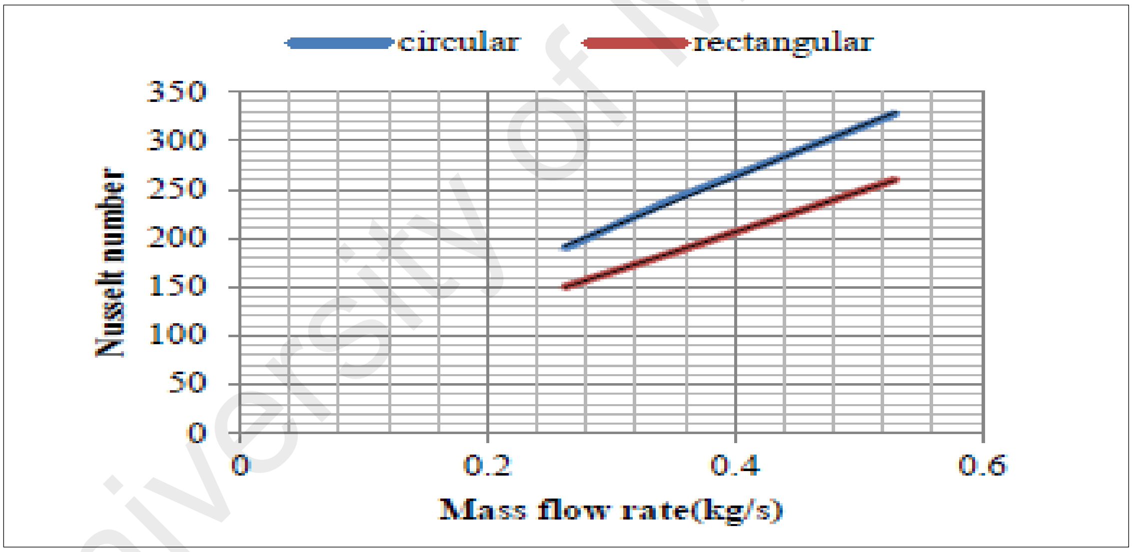


Figure 2.2 : Nusselt number vs Flow Rate

CFD analysis was carried out and results are compared and validated with the close agreement between CFD predicted and correlation results used by various researches. Results were obtained as per Figure 2.2 that circular pipe heat exchangers with a 2.5% increase in heat transfer rate compared to the rectangular tube. Figure 2.3 shows the Nusselt number for the circular tubes also shows a trend of 8.5% increase over the rectangular tube.

Similar research was carried out with a two-dimensional numerical CFD model to appraise characteristics of heat transfer and fluid flow with circular and non-circular shaped heat exchangers (NajlaElGharbi, AbdelhamidKheiri, MomammedElGanaoui, & RyanBlanchard, 2015). The study finds circular tubes cause severe parting and huge wakes which indirectly leads to high-pressure drop, whereas non-circular tubes of rationalized shapes gave fairly lesser pressure drop. Due respect to curtailing entropy generation, results portray that there is no best geometric shape effective across all flow conditions.

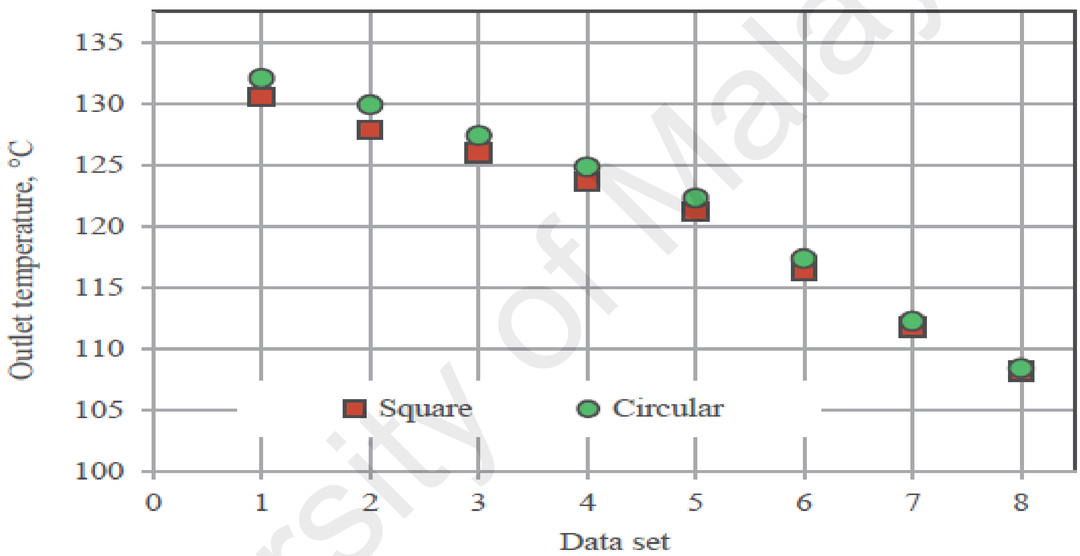


Figure 2.4 : Effects of cross-section on heat transfer enhancement

The Figure 2.4 above shows the performance comparison of circular and square cross-sectioned Helical Coil Heat Exchangers (HCHE) studied by another literature using experimental and CFD analysis (İbrahim Halil Yılmaz, Taha Tuna Goksu, Mustafa Kilic, & Mehmet Sait Söylemez, 2017). Two different cross-sectioned HCHE's exposed to boiling were examined, with circular one was modeled first and validated results with experimental results. Afterward, square cross-sectioned HCHE was modeled, made a comparison with the circular one on thermal performance criteria. Referring to the outlet temperatures of both HCHE's came close to each other as inlet temperature decreases, due to reduced differential temperature. Yet, square HCHE still offers better thermal performance. It is concluded that at given conditions, square cross-sectioned HCHE boosts heat transfer up to 1.6% comparative to a circular one.

2.2 Nanofluids

Engineering applications such as refrigeration, automotive, power production, environmental engineering, waste management, food, chemical and many more industries extensively use heat exchangers. The thirst to improve energy efficiency requires more exertions in enhancing the heat transfer rate at the minimal time in heat exchangers.

Conventional fluids such as oil, ethylene glycol and also water have limited room in development as an energy-efficient medium of heat transfer as it is a low thermal conductivity source. With the aggressive progression of thermal engineering, the need to develop or identify a decisive heat transferring medium with optimal thermal conductivity for a better performance of heat transfer is crucial in recent years. (Yanjiao Li, Jing'en Zhou, Simon Tung, Eric Schneider, & Shengqi Xi, A review on development of nanofluid preparation and characterization, 2009) (Valan Arasu Amirtham & Dhinesh Kumar Devendiran, 2016)

Solid nanoparticles (<100 nm) with high thermal conductivity dispersed into base fluids, called nanofluids, boosts thermal performance in a heat transfer system. The key reasons for the significant improvement are that the dispersed nanoparticles increase the heat capacity and surface area of the fluid, indirectly rises the thermal conductivity of the fluid. Due to the contact and impact among particles, fluid and flow passage surface intensifies, it flattens the temperature gradient of the fluid, escalating the mixing flux and turbulence of the fluid. (Yimin Xuan & Qiang Li, 2000)

Physical methods such as mechanical grinding, inert-gas-condensation technique and chemical synthesis process are implied to make out nanoparticles used in nanofluids. (C. G. Granqvist & R. A. Buhrman, 1976)

(K.B. Anoop, T. Sundararajan, & Sarit K. Das, Effect of particle size on the convective heat transfer in nanofluid, 2009) Investigated convective heat transfer in developing region of pipe flow using alumina-water nanofluids concluded smaller nanoparticles show a higher heat transfer coefficient, increasing relative to increased particle concentration and flow rate. The heat transfer coefficient is the most important aspect in forced convection heating-cooling processes and it solely depends on variations such as particle size, particle shape, particle material, particle volume concentration, base fluid material temperature and additives. (Anchasa Pramuanjaroenkij & Sadik Kakac, Review of convective heat transfer enhancement with nanofluids, 2009)

Customary hypotheses flop bounteously when utilized for nanofluids in examination between forecast rising out of the connections projected for the dimensionless thermal conductivity and dynamic viscosity. (Massimo Corcione, 2011).

2.2.1 Preparation Method

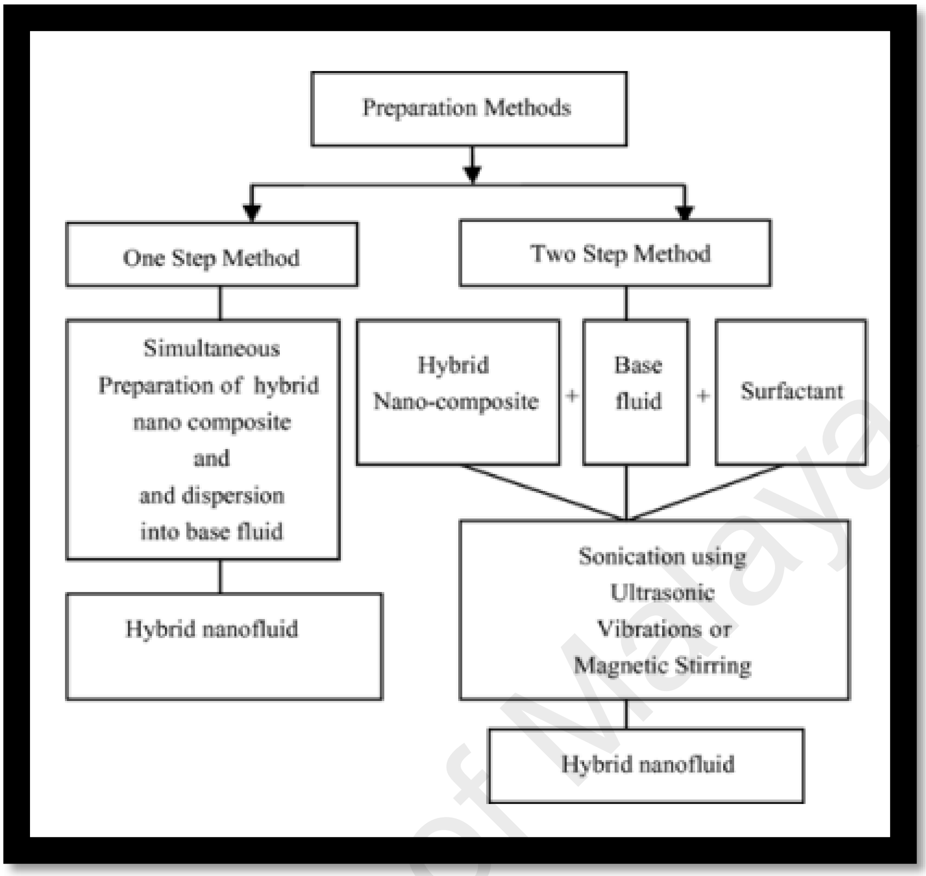


Figure 2.5 : Preparation method of nanofluid

Preparing a stable nanofluid is an involved task with appropriate methods of employment. Generally, dispersing nanoparticles (nanometer-scale solid particles) into base liquids are nanofluids. There are two methods to produce nanofluids, there is a single-step method and two-step method as per Figure 2.5. (Yanjiao Li, Jing'en Zhou, Simon Tung, Eric Schneider, & Shengqi Xi, A review on development of nanofluid preparation and characterization, 2009) (Devendiran & Amirtham, 2016).

The single-step method combines the making of nanoparticles and dispersion of nanoparticles in the base fluid in just one step. But there are several techniques employed in making the of the nanoparticles part, such as direct evaporation technique, physical vapor deposition (PVD) technique, laser ablation technique and chemical synthesis technique.

Direct evaporation single-step method is a common method whereby nanofluids are produced by solidification of the nanoparticles, which are initially in gaseous state inside the base fluid. The single-step method avoids drying, storage, transportation and dispersal of nanoparticles, hence sedimentation of nanoparticles during synthesis is reduced and nanofluids stability increases. The constraint of this method is that it is only in harmony with low vapor pressure fluids.

The two-step method meanwhile separates the process of making nanoparticles as one and then dispersing nano-sized powder into the base fluid as the second step. Techniques such as inert gas condensation, mechanical alloying, chemical vapor deposition, or other available techniques are used to produce nanoparticles, nanofibers or nanotubes into dry powder. Isolating preparation of nanoparticles results in the agglomeration and a decrease in thermal conductivity. Due to the availability of nanopowder synthesis techniques commercially, latent economic advantages in using this method rise relying on the use of such powders.

Homogeneous and long-term stable nanofluids with negligible sedimentation without affecting the thermal conductivity properties are still a challenge even with available preparation methods. Available literature anticipated several methods used to stabilize the suspension (Devendiran & Amirtham, 2016) (Nor Azwadi Che Sidik, H.A. Mohammed, Omer A. Alawi, & S. Samion, 2014), such as using ultrasonic vibrations, using surfactants and also pH value control.

These approaches can change the surface properties of the suspended particle and can be utilized to defeat the agglomeration to attain stable suspensions. These approaches depend on the type of nanofluids application. Targeting at changing the nanofluids thermo-physical, some investigators prepared their nanofluids without the usage of the approaches.

(K.B. Anoop, T. Sundararajan, & Sarit K. Das, 2009) Prepared their alumina-water nanofluids using commercially purchased nano-powders produced by laser evaporated physical methods. Employing a top-down approach to suspend the nanoparticles into water (base fluid), they reconfirmed the particle average size of 45nm as specified by the manufacturer. To break down the particle cluster formed in the air; the particles were dispersed further in the suspension using ultra-sonification. Keeping the pH value away from the zero-zeta potential, the stability of the nanofluids is achieved. Approximate of 2.5 ℓ of each concentration prepared is further observed as the suspensions were stable for several weeks.

2.2.1.1 Hummer Method

As is well known, GO is synthesized dominantly via chemical oxidation of natural graphite even though there are a few reports on alternative electrochemical oxidation. Back to 1859, Brodie first synthesized graphite oxide by adding potassium chlorate to the slurry of graphite in fuming nitric acid. After about 40 years, Staudenmaier improved this method by replacing about two thirds of fuming HNO_3 with concentrated H_2SO_4 and feeding the chlorate in batches. Based on these works, Hummers and Offeman developed an alternate oxidation method in 1958, often called Hummers method, in which $NaNO_3$ and $KMnO_4$ dissolved in concentrated H_2SO_4 was used to oxidize graphite into graphite oxide within a few hours. Thanks to the ease and short time of execution, Hummers method was widely adopted to afford GO but it still suffers from several flaws, including toxic gas generation (NO_2, N_2O_4), residual nitrate and low yield etc. To address these problems, various modification on Hummers' method have been made in the past 20 years, and the main strategies can be summarized as follows: first removing $NaNO_3$ directly from Hummers method with an improved workup; second by adding a step of peroxidation before $KMnO_4$ oxidation (in the absence of $NaNO_3$), third by increasing the amount of $KMnO_4$ instead of $NaNO_3$, fourth by replacing $KMnO_4$ with K_2FeO_4 while

$NaNO_3$ was removed. For example, in the report of (Nina I. Kovtyukhova, et al., 1999), graphite was protoxidized by K_2S2O_8 and P_2O_5 before Hummers' procedure was implemented. This work resulted in highly oxidized GO, but the whole process which contains solution transfer and material drying is rather time-consuming. By increasing the amount of both $KMnO_4$ and concentrated H_2SO_4 (containing 1/9 H_3PO_4) instead of $NaNO_3$, (Daniela C. Marcano, et al., 2010)found that the improved Hummers method leads to higher yield and the temperature can be easily controlled. Recently, Gao et al.25,26 reported a K_2FeO_4-based oxidation approach instead of $KMnO_4$, and obtained single-layer GO at room temperature. Despite the above progresses, two problems remain in various modified versions of Hummers method: (1) high consumption of the oxidants and intercalating agents was inevitable, (2) most of the synthesis routines proceed for a long time, both of which result in high cost and poor scalability in practical applications. Therefore, there is a strong demand to develop an economical and efficient method for the synthesis of GO.

2.2.2 Heat Transfer Mechanism

For nanofluids utilized in the design of heat exchanger equipment, improving the heat transfer coefficient is better compared to thermal conductivity enhancement. The heat transfer coefficient of nanofluids is better than that of its base fluid mutually in natural and forced convection heat transfer, proven in many experimental and theoretical observations in recent years. This is due to the dispersion of nanoparticles greatly improve heat transfer.

General observations of theoretical and experimental were reviewed and summarized (Devendiran & Amirtham, 2016) in nanofluids characterization studies as below;

Theoretical Observations; -

- Increasing the aspect ratio at the peak of heat transferred across the enclosure and increasing the nanoparticle volume fraction up to an optimal particle loading results in an increase in heat transfer enhancement.
- All parameters due respect to volume fraction enhances the heat transfer coefficient of nanofluids.
- Nanofluids have a better heat transfer coefficient and more stable than conventional fluids.

Experimental Observations; -

- The heat transfer rate of nanofluids increasingly disintegrated with the volume fraction of the nanoparticles.
- Particle shape plays an important part in rising convective heat transfer enhancement compared to thermal conductivity.
- As nanoparticle concentrations increase, nanofluids decrease the natural convective heat transfer.
- Escalating particle concentration for an agreed Rayleigh number is a systematic deprivation of natural convective heat transfer.
- For the entire array of Rayleigh number, mean Nusselt number upsurges with volume fraction.

2.2.3 Stability of Nanofluids

Investigations on stability are also crucial in understanding nanofluids properties for future applications. Due to its high surface-activity, nanoparticles lean towards to amassed with time elapsed. The accumulation of nanoparticles consequences not only the settlement and congestion of microchannels but also the falling of thermal conductivity in nanofluids.

Periodically over time many methods have been derived and employed to assess the stability of nanofluids. The sedimentation method is considered the easiest and consistent method deployed. Special apparatus is being used to attain the variation of concentration or particle size of a supernatant particle with sediment time. As the concentration of supernatant particles constant over time, the nanofluids are considered stable. The setback in this method is a long period for observation (Yanjiao Li, Jing'en Zhou, Simon Tung, Eric Schneider, & Shengqi Xi, 2009).

Meanwhile, with the limitation of nanofluid viscosity and concentration, Zeta Potential Analysis is another method of evaluating nanofluid stability by identifying potential variance between base fluid and charged hybrid nanoparticles. It identifies the repulsion rate between charged particles, whereby suspends with high zeta potential (negative or positive) are stable and suspends with low zeta results to lump.

Two main methods for perceiving particle aggregation is by measurement of particle size spreading by microscopy and light scattering techniques. Electron micrographs are utilized to capture the digital image of nanoparticles by using a very high-resolution microscope such as TEM and SEM (Nor Azwadi Che Sidik, Muhammad Mahmud Jamil, & Wan Mohd Arif Aziz Japar, 2017).

2.2.4 Test Method for Nano-fluid

Although nanofluid behavior considers as a fluid it can’t be ignored that a nanofluid is a mixture of solid material with a base fluid. Hence nanofluids have a possibility of reducing the effect of heat transfer for long-term usage. Researchers have come out with few methods to test the nanofluid's performance, to evaluate in the nanofluid stability.

2.2.4.1 Sedimentation Method

The sedimentation method is one of the ways that has been used by researchers to evaluate nanofluid stability. To determine stable nanofluids, particle size and the concentration of nanofluids remain the same for a long time of period. By using this sedimentation method nanofluids samples will be kept in the test tube, the stability observation is taken from the photograph over some time to be compared and come to a conclusion on the stability of the nanofluids. The sedimentation test has been taken by a researcher on AL_2O_3 nanofluids at 3wt. % for 30days as shown in Figure 2.6. (Munkhbayar Batmunkh, 2012)

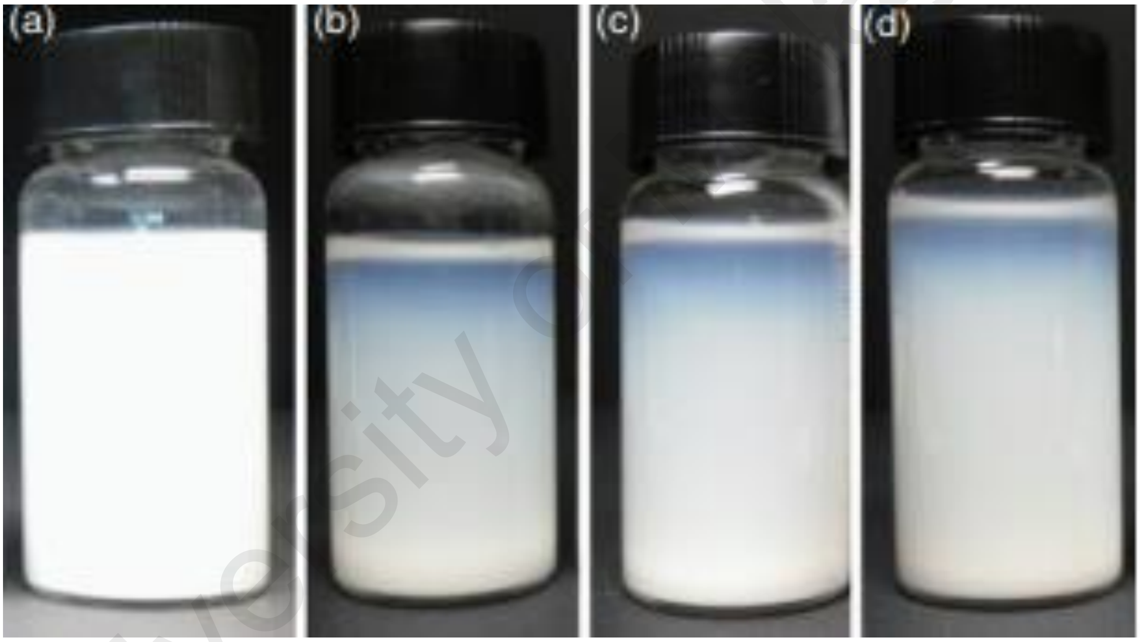


Figure 2.6 : Sedimentation test on Al2O3 at 3 wt% after 30 days

2.2.4.2 Zeta Potential Analysis

Another way to identify the stability of the nanofluids by Zeta potential analysis. The potential difference among the stationary layer and dispersion medium of the nanofluids attached to the particles as Figure 2.7. Zeta potential value from 40-60 mV, understood to have good stability of nanofluids. A lot of researchers have tried out this method to find out the stability, (Ho Jin Kim, In Cheol Bang, & Jun Onoe, 2009) tested this method to find the stability of Au nanofluids.

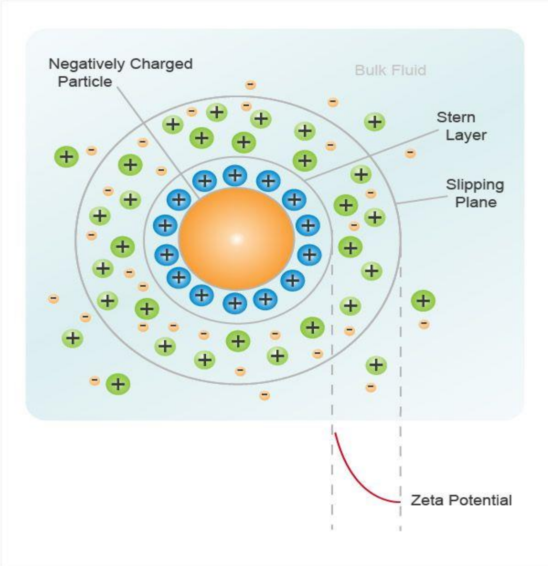


Figure 2.7 : Zeta Potential Diagram

(Nurettin Sezer , Muataz A. Atieh, & Muammer Koç, 2019)

2.2.4.3 Centrifugation Method

Another method has been used by the researcher to find the stability of nanofluids by Centrifugation method. The reason this method was developed because the sedimentation method consumes a longer time of period to observe the changes happen in nanofluids. (Ashok K. Singh & Vijay S. Raykar , 2008) Uses the centrifugation method on silver nanofluids by decreasing $AgNO_3$ and selecting polyvinylpyrrolidone (PVP) as a stabilizer.

2.2.4.4 Spectral Analysis Method

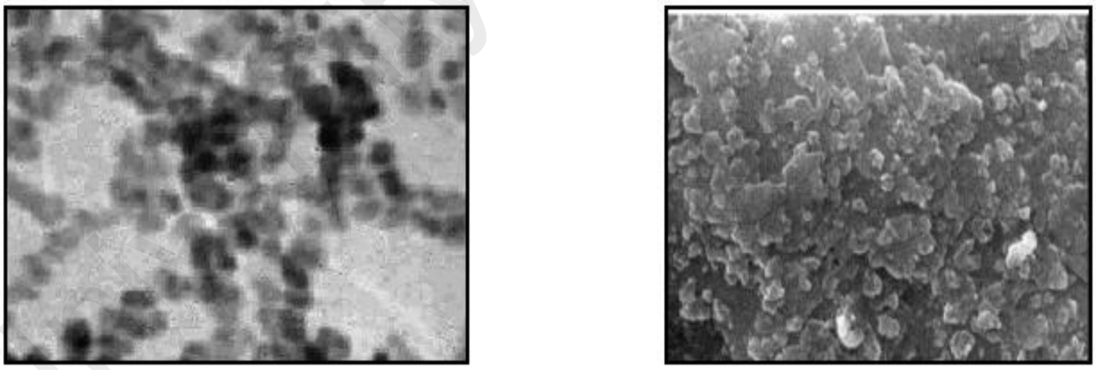
UV- vis spectrophotometer is an alternative method to estimate the stability of nanofluids. The improvement compares with other methods that UV-vis spectroscopy gives measurable outcomes respectively to the concentration of nanofluids. (Y.Hwang, et al., 2007) From Korea identify the stability of multi-walled carbon nanotube (MWCNT) nanofluids using the UV-vis absorption at different sediment time.

2.2.4.5 3ωMethod

Considering the thermal heat conductivity development by nanoparticle sedimentation in a larger volume fraction range, nanoparticle stability can be evaluated. (Dong-Wook Oh, Ankur Jain, John K. Eaton, Kenneth E. Goodson, & Joon Sik Lee, 2008) Tested this method to detect sedimentation of aluminum oxide nanofluids

2.2.4.6 Electron Microscopy and Light Scattering Methods

Microscopy and light scattering method are normally used to measure the particle size distribution and observing particle aggregation. TEM and SEM are a very high-resolution microscope been used to capture the digital image of nanoparticles. Photographs using TEM and SEM are shown in Figure 2.8 below for CuO nanoparticles respectively (Haitao Zhu, Dongxiao Han, Zhaoguo Meng, Daxiong Wu, & Canying Zhang, 2011) (Pooyan Razi, M.A. Akhavan-Behabadi, & M. Saeedinia, 2011). To study the complex nanosuspension light scattering method can be used.



a b

Figure 2.8 : (a). TEM of CuO nanoparticles. (b) SEM of CuO nanoparticles

2.2.5 Thermal Conductivity of Nanofluids

Research has been continuously carried out to compare analytical models with experimental data to evaluate how much increase of thermal conductivity in nanofluids. The ratio of thermal conductivity of nanofluids to the thermal conductivity of the base fluid is defined as the thermal conductivity enhancement ratio.

Studies had been made by proposing and examining two empirical equations anticipating the effective thermal conductivity and dynamic viscosity of nanofluids dependent on literature investigational information. Given the base fluid and nanoparticle substantial is determined, an increase in nanoparticle volume fraction and temperature, decrease in nanoparticle diameter, results in an increase in the thermal conductivity ratio of the nanofluids to the pure base liquid. (Massimo Corcione, 2011)

(Maxwell, 1904) published effective thermal conductivity for a two-phase mixture comprising continuous and discontinuous phase assuming it to be in spherical and nanofluids be subject to the thermal conductivity of spherical particles, particle volume fraction and base fluid.

(R.L.Hamilton & O.K.Crosser, 1962) Presented shape factor determined experimentally in various materials to cover none spherical particles from Maxwell work. Ignoring the size effects of nanoparticles, their model is valid in predicting thermal conductivity as long as the conductivity of particles is larger to the conductivity of continuous phase by a factor of 100.

Another model developed assuming that base fluid molecules close to nanoparticles solid surface form solid-like layer structure, works as a thermal bridge enhancing effective thermal conductivity. (W. Yu & S.U.S. Choi, 2003) This phenomenon named nanolayers is depicted in Figure 2.9.

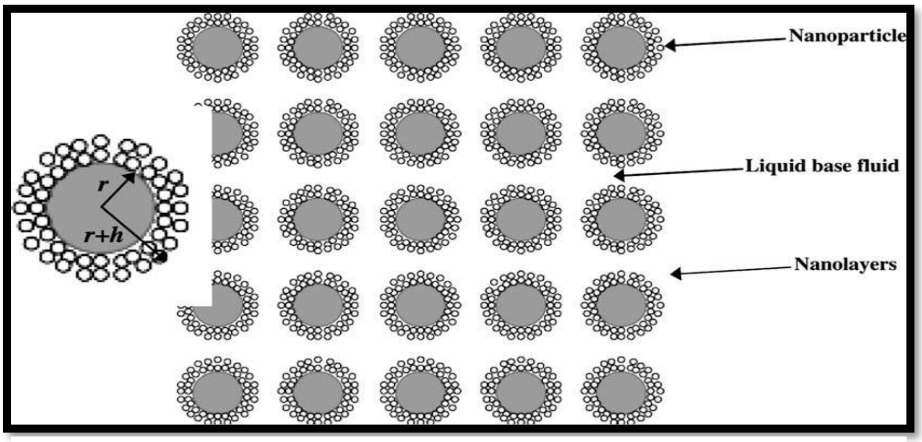


Figure 2.9 : Schematic cross section of nanofluids structure (W. Yu & S.U.S. Choi, 2003)

Assuming the nanolayers and nanoparticles radius, a linear relationship is present in all three models comparatively. The discrepancy of these models is further discussed in a later section.

2.2.5.1 Influence of Nanoparticles

Because of fluid mechanics, nanoparticles are considered as the additives in nanofluids. It has a major role in varying thermal conveyance properties. Effects due to their volume fraction, thermal conductivity, Brownian movement, morphology and several more aspects are the key point delivering into new researches.

Theoretically higher improvement of thermal conductivity in nanofluids is achieved with nanoparticles with high thermal conductivities and most researchers conclude thermal conductivity of nanofluids rises subsequently with an increase of nanoparticles volume fraction.

(S. Choi, 2001) Drew an argument that enhanced thermal conductivity of oil-based nanofluids comprising nanotubes is due to the nature of heat conduction in nanotube suspension, whereby measured the nanofluids thermal conductivity is greater than theoretical predictions and nonlinearly increasing manner with the rise in nanotube loadings.

Meanwhile, a study based on convective heat transfer with alumina-water nanofluids focusing on the effect of particle size in developing region, nanofluids disclosed higher heat transfer characteristics than its base fluids regardless of the particle size. (K.B. Anoop, T. Sundararajan, & Sarit K. Das, 2009)

As discussed, regards to thermal conductivity earlier, (W. Yu & S.U.S. Choi, 2003) have compared their model with and (R.L.Hamilton & O.K.Crosser, 1962) by adopting aluminum oxide nanoparticles. These Al_2O_3/water nanofluids models foresee an increase in thermal conductivity linearly in an increase of particle volume fraction. Figure 2.10 below shows Al_2O_3/water nanofluids thermal conductivity ratio against particle volume fraction.

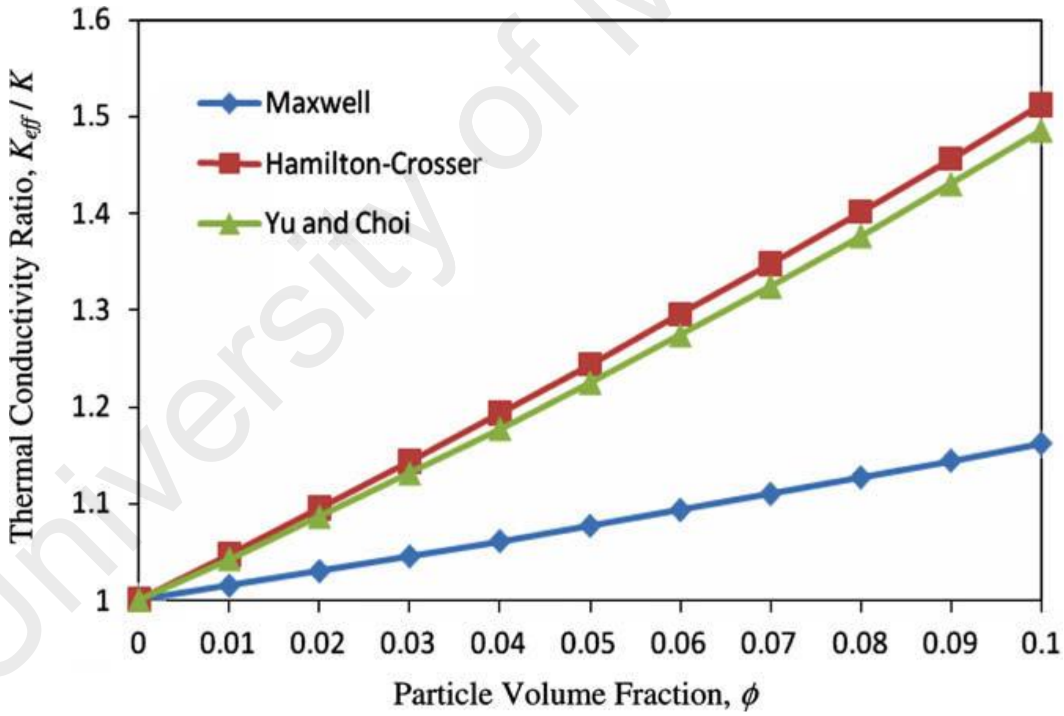


Figure 2.10 : Variation of thermal conductivity ratio against particle volume fraction for Al2O3/water nanofluids

(Anchasa Pramuanjaroenkij & Sadik Kakac, 2009)

2.2.5.2 Influence of Base Fluids

Even research on the effect of base fluids on the enhancement of thermal conductivity in nanofluids is comparatively less investigated, temperature and thermal conductivity of base fluids do affect thermal conductivity in nanofluids.

(CalvinH. Li & G.P. Peterson, 2006) Studied steady-state effective thermal conductivity of CuO and Al_2O_3 nanoparticles suspension by variating the temperature and volume fraction. The experimental conclusion obtained that all nanoparticle material, volume fraction, diameter and temperature does affect the thermal conductivity of those suspensions significantly. Moreover, the thermal conductivity of nanofluids increases significantly with the increase of temperature.

Meanwhile, studies on improving thermal conductivity through temperature necessity in nanofluids containing Bi_2Te_3 nanorods, suggested by (B. Yang & Z.H. Han, 2006). Witnessing different trends, thermal conductivity enhancement decreased with a rise in temperature, concluded that particle aspect ratio difference causing major effects in diffusive heat conduction and Brownian motion.

As for the thermal conductivity of the base fluid, an increase in its results reduced the enhanced thermal conductivity ratio, regardless of the type of nanoparticles used in the nanofluids. This is reported in studies conducted (H. Xie, J.Wang, T. Xi, Y. Liu, & F. Ai, 2002), (Huaqing Xie, Hohyun Lee, Wonjin Youn, & Mansoo Choi, 2003) and Hwang (Y. Hwang, H.S. Park, J.K. Lee, & W.H. Jung, 2006)

2.2.6 Viscosity of Nanofluids

Viscosity is a strong element of thermal conductivity in engineering systems, making it an important property of nanofluids in the heat transfer behavior and nanofluids stability over the years. About fluid viscosity, nanofluids are anticipated to display an increase in thermal conductivity without a rise in pressure drop. Factors manipulating viscosity in nanofluids such as temperature of nanofluids, size of nanoparticles, model for predicting viscosity and shear rate, are limelight alarm to previous studies made by over the years. (Yanjiao Li, Jing'en Zhou, Simon Tung, Eric Schneider, & Shengqi Xi, 2009)

Studies had been made by proposing and examining two empirical equations anticipating the effective thermal conductivity and dynamic viscosity of nanofluids dependent on literature investigational information. Independent of temperature, increase in nanoparticle volume fraction and decrease in nanoparticle diameter, increases the ratio between dynamic viscosities of the nanofluids and the base liquid. Furthermore, no apparent impact on the rheological behavior of nanofluids due to solid-liquid combination. (Corcione, 2011)

2.2.7 Nanofluids Applications in Heat Transfer

In various thermal exchange systems, nanofluids have proved higher energy efficiency and better heat conveyance properties theoretically and experimentally. These findings shall be adopted in different industrial applications such as mechanical applications, transportation, electronic and other energy storage applications. Some of the applications are further briefed below (Lee S, S. U.-S. Choi, S. Li, & J. A. Eastman , 1999).

Reducing friction and wear is the greatest aim in the study of interacting surfaces undergoing relative motion under dry or lubricated conditions. Advanced lubricants can expand yield through the energy-saving and trustworthiness of engineered systems. Due to their exceptional friction-reducing capacity, load carrying properties and good extreme pressure, nanofluids have override research and market interest worldwide over the years. Studies suggest Cu nanoparticles are better than zinc di-triphosphate as an oil improver, during high applied load.

Magnetic sealing offers a better profitable solution to ecofriendly and risky gas sealing compared to mechanical sealing. This delivers high reliability, extended life span, high-speed competence and low friction influence losses for a wide variety of industrial rotation equipment. Steady colloidal deferrals of the magnetic particles are magnetic fluids categorized as special nanofluids. Modifying the size of the magnetic nanoparticles and adapting their external layer to encounter the colloidal constancy of magnetic nanofluids with non-polar and polar transporting liquids.

In efforts to improve exhaust cooling system or reduce the size of vehicle engine cooling systems, adding nanoparticles and nanotubes to standard engine coolants and lubricants to form nanofluids can increase their thermal conductivity, indirectly gives the potential to enhance heat exchange rates and fuel efficiency. CuO and aluminum-oxide based brake nanofluids have improved properties yielding higher boiling point, viscosity and conductivity will diminish the rate of vapor-lock and offer improved safety while driving.

Further studies suggest high enrichment of heat transfer in nanofluids could be useful in strengthening the process of chemical reactors through the incorporation of the functionalities of reaction. Research on nanofluids built on benign TiO_2 particles suspended in ethylene glycol in an integrated reactor-heat exchanger was conducted by (Xiaolei Fan & Haisheng Chen, 2008) sees overall heat transfer coefficient rise to 35% under stable state continuous experiments.

2.2.8 Cost Impact on Nano Fluid Application

Anyway, the heat transfer development potential identified by many researchers, there are plentiful limitations to extensive implementation in engineering situations. Most of the nanoparticles mostly depend on availability in the market. They were not cheaply priced and there is a limited amount for these particles as of now (for example, 100g of the alumina or copper oxide nanoparticles charge $492.00 and $80.00 US dollars respectively) (Nanostructured & Amorphous Materials, Inc., 2002). Moreover, discussing the industrialist, it seems that the particles of nanoparticles differ which keep to the uncertainty of physical property data. Adding to that, roughly some of the nanomaterials are venomous which lead to protective actions needed in preparation, one of the reason the cost of the production increase. (Mahian, O, Kianifar, A., , Kalogirou, S.A., , Pop, I., , & Wongwises, S, February 2013) Enlightened that experience different problems. For example, the significant price of nanoparticles, unsteadiness and agglomeration, pumping power and pressure drop, corrosion of components make nanofluid monetarily unappealing. The expensive production cost of nanofluids is one reason that may discourage the nanofluids in industrialization. Unconventional ways and sophisticated equipment are required to prepare nanofluids for both a one-step two and step method. (Lee J & Mudawar I, 2007) Stressed that the expensive price of nanofluids is the weakness of the use of the nanofluids.

(Lv, et al., April 2018) said that even with the proper operation production of nanoparticles have restriction issues, the high cost of nanofluids application is continuously becoming one of the most imperative details that may hamper the function of the nanofluids. The cost of a nanofluid is structured by base fluid and the nanoparticles. Price is expensive when the nanoparticles were more difficult to develop to produce the stable colloidal suspension is much more confusing. Price of some common nanofluid with water as a base fluid shown in Figure 2.11.

Type of Nanoparticle	Thermal Conductivity of Particle W/(m-K)	Size of Particle in Solution*	Amount of Solution*	Price of Unit (USD)**
Alumina (Al_2O_3)	30	30-60nm	100.0 mL	$183.50
Copper Oxide (CuO)	401	<50 nm	25.0 g***	$73.10
Gold (Au)	310	10 nm	25.0 mL	$338.00-$362.00
Gold (Au) with Silica Coating	N/A	10 nm	5.0 mL	$318.50
Iron Oxide (Fe_2O3)	0.58	30 nm	5.0 mL	$240.00
Silver (Ag)	429	20 nm	25 mL	$114.50
Titanium Oxide (TiO_2)	22	21 nm	100.0 g	199.50

**All solutions included in table above are in a base fluid of water (H_2O).*
***Prices are from Sigma Aldrich (www.sigmaaldrich.com).*
****Copper oxide nanoparticles are only available in nanopowder form, rather than dispersed in a solution.*

Figure 2.11 : Estimation price of common nanoparticles

(Azizian, 2017)

However, they settled that the overall applications of nanofluids are still in its early levels. Therefore, upcoming researches will increase the potential applications of the nanofluids.

2.3 Aluminum Oxide (Al_2O_3)

Being widely used in ceramics engineering family, alumina is the most cost-effective material. Similarly, aluminum oxide-based nanofluids is in limelight over recent years and various researches have been conducted by many authors on the thermo-physical properties of aluminum oxide-based nanofluids.

(Ningbo Zhao, Jialong Yang, Hui Li, Ziyin Zhang, & Shuying Li, 2016) Conducted three-dimensional numerical investigations of laminar heat transfer and flow performance in a flat tube using Al_2O_3-water nanofluids. New correlation models for thermal conductivity and viscosity considering few thermo-physical properties are developed for Al_2O_3-water nanofluids. The result from the experiment shows Al_2O_3-water nanofluids have higher heat transfer coefficient and pressure drop compare to the base fluid. The result was enhanced by increasing the concentration of nanoparticle volume and reducing nanoparticle size. Relative thermal-hydraulic performance between flat tubes and circular tubes is affected by nanoparticle volume concentration.

Similar results were produced in an experimental study of forced convective heat transfer of different volume concentration Al_2O_3-water nanofluids in horizontal shell & tube heat exchanger, investigated under turbulent counterflow conditions (Jaafar Albadr, Satinder Tayal, & Mushtaq Alasadi, 2013). Nanofluid producing 57% overall heat transfer coefficient greater than of distilled water, incurring slight drawback in pressure drop.

Further results were produced in a research project by University Malaya Undergrade student on convective heat transfer of different volume concentration Al_2O_3-water nanofluids in horizontal shell & tube heat exchanger, investigated under turbulent counterflow conditions. Result is been discussed below.

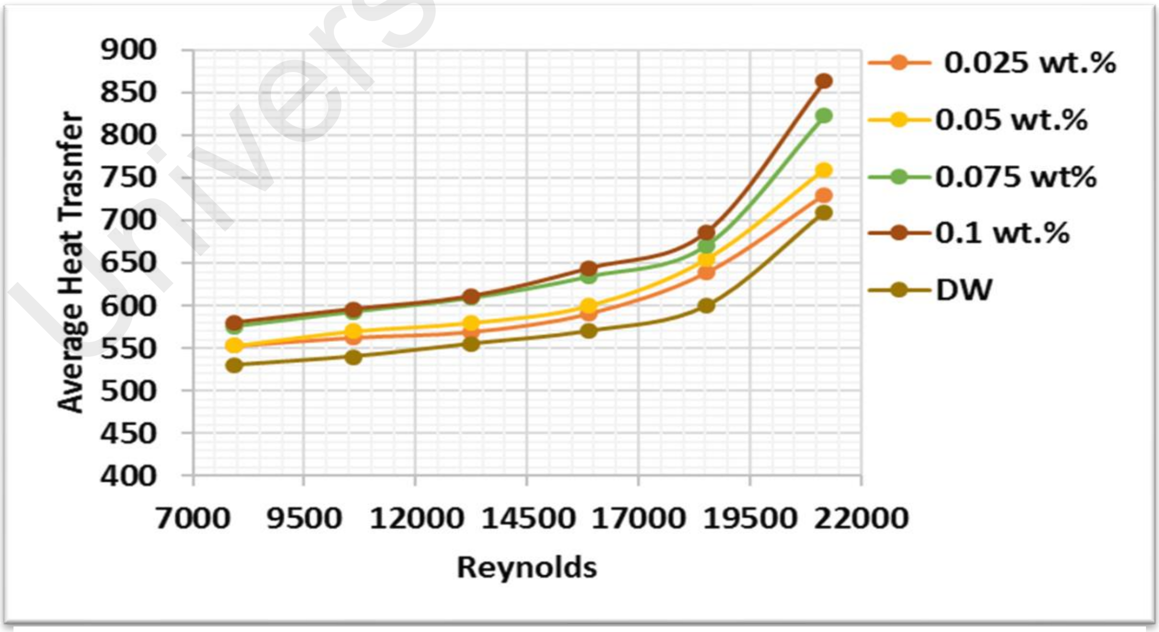


Figure 2.12 : Average Heat Transfer vs Reynolds No

Al_2O_3/DW nanofluids that were already prepared by undergraduate students in University Malaya. Based on the graph in Figure 2.12 Al_2O_3/DW heat transfer coefficient for nanofluids perform better than distilled water. With the higher flow rate of Al_2O_3/DW nanofluids into the test section the higher the heat transfer occurs. Maximum heat transfer occurs when the concentration of nanoparticles is high in weigh percentage. With a low flow rate for concentration 0.025 and 0.05 perform the same heat transfer, the same goes to the concentration of 0.075 and 0.1.

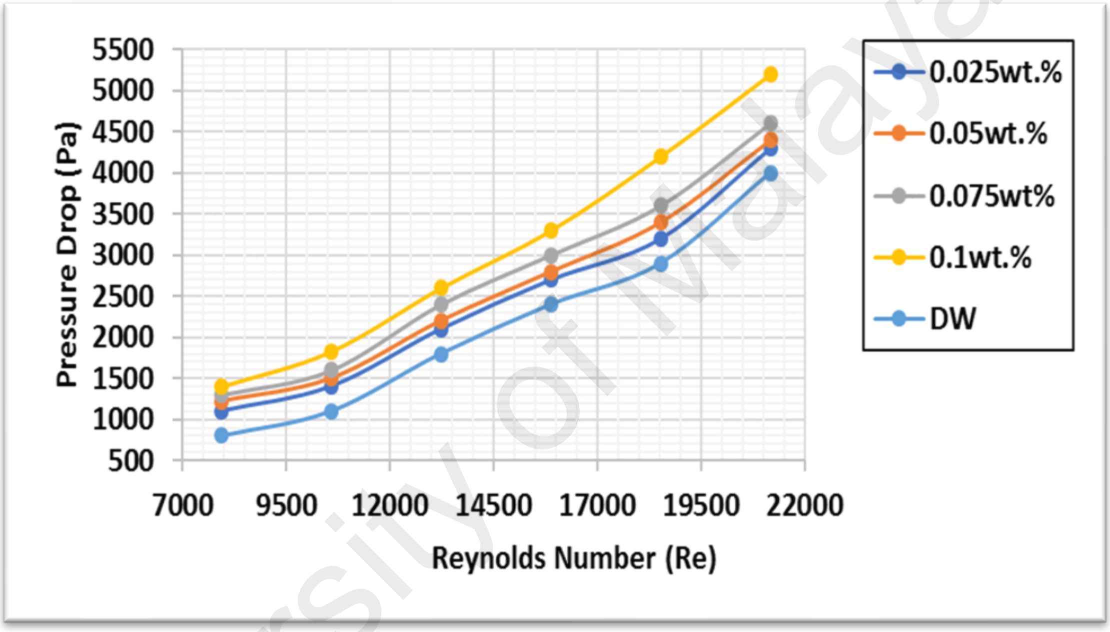


Figure 2.13 : Pressure Drop vs Reynolds No

Based on the graph Figure 2.13 plotted on pressure drop versus Reynolds number, when the flow rate increases the pressure in the test section of circular increase gradually. When comparing the Al_2O_3/DW nanofluids with the base fluid distilled water, Al_2O_3/DW have higher pressure in the test section. The increase of the pressure due to the viscosity and density of the fluid is slightly higher than the base fluid.

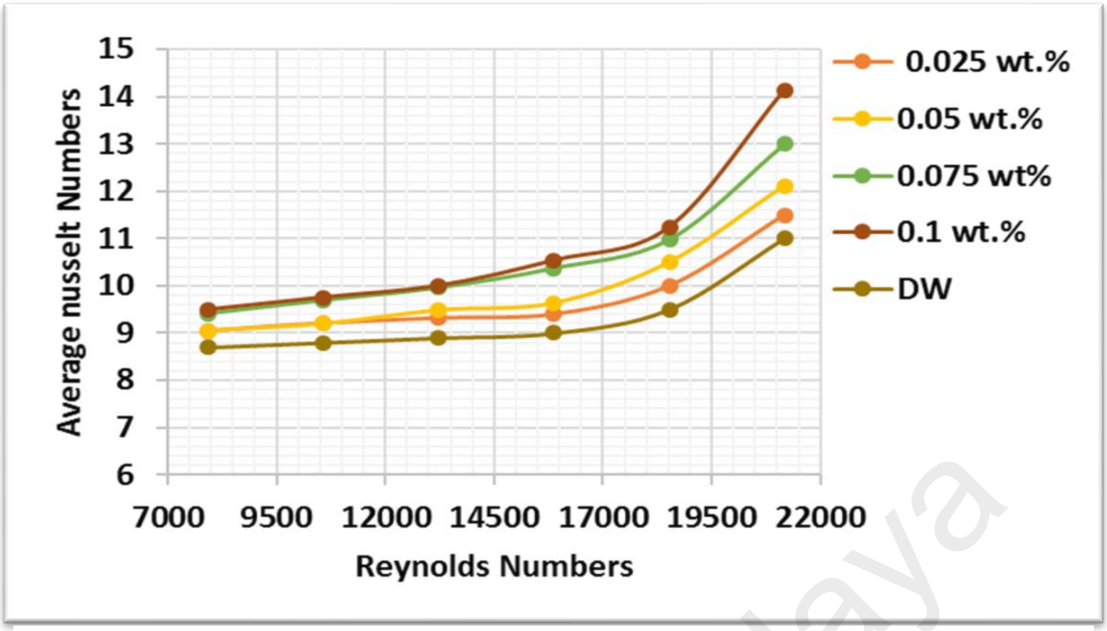


Figure 2.14 : Nusslet No vs Reynolds No

Figure 2.14 represents the result for average Nusselt number vs. Reynolds number. Nusselt number by increasing the Reynolds number increases.

2.4 Graphene Oxide (GO)

Graphene oxide is one of the substances in the resource's world with high heat transfer potential. Utilization of high heat transfer potential particles in nanofluids had concerned various researchers in the improvisation of nanofluids over the recent years.

(Ramin Ranjbarzadeh, Arash Karimipour, Masoud Afrand, Amir Homayoon Meghdadi Isfahani, & Alireza Shirneshan, 2017) Has researched the effect of using water/graphene oxide nanofluid flow on heat transfer and friction loss in a circular isothermal copper tube. The circular copper tube is set up to embrace turbulent flow in experimental development. Results attained show 28% and 36.5% rise, in thermal conductivity and friction coefficient respectively, compared to its base fluids. The desired stability retains for a long period is attained at a pH value of 9, from zeta potential test. Maximum augmentation of convective heat transfer coefficient ratio transpires at a low Reynolds number.

Meanwhile, mild state of alkaline treatment to functionalize Graphene only by utilizing short time sonification without any additives, dispersed in water to obtain alkaline functionalized Graphene (AFG) nanofluid, to investigate effective thermal conductivity versus time and temperature at different concentrations, were done by (Ahmad Ghozatloo, Mojtaba Shariaty-Niasar, & Ali Morad Rashidi, 2013). The pre-eminent result indicates a 17% enhancement in thermal conductivity by sample with 0.05 wt. % of AFG, compared to 50°C water.

Similarly, (Rad Sadri, et al., 2018) experimented graphene nanoplatelet (GNP) synthesized covalently functionalized with clove buds using a one-pot technique, dispersing the clove-treated GNPs (CGNPs) with particle concentration variance into distilled water. Tested the CGNP-water nanofluids in a horizontal tube heat exchanger, attaining 22.92% of maximum thermal conductivity enhancement for the sample with 0.1 wt. % of CGNP's at the fluid temperature of 45°C.

Stimulating its potential in thermal transfer system with insignificant augmentation, in friction loss and pressure drop for base fluid, is the key finding on investigating turbulent heat transfer performance of Reduced Graphene Oxide (RGO) as an additive in close conduit. Using tannic acid as a reducing agent, a hybridization approach was engaged between RGO and various carbon allotropes, to obtain knowledge comparatively with individual RGO on possible heat transfer improvement. 63% and 144% increment recorded in heat transfer coefficient and Nusselt number, at the thermally developed region and further upstream heated section, respectively (Mohd Nashrul Mohd Zubir, et al., 2015).

CHAPTER 3: METHODOLOGY

This chapter will be a discussion on the way of preparation, characterization and properties of the graphene oxide. Will be discussing the procedure of conventional heat transfer measurement test carried out.

3.1 Preparation of Graphene Oxide by Advance Hummer Method

In this research, development of GO with increased stability of nanofluid will be prepared by using hummer method. In this method, the main material used is graphite powder, sulphuric acid, sodium nitrite, sodium hydroxide, hydrogen peroxide, potassium permanganate and hydrochloric acid. To carry out this method have two stages will explain in detail below.

3.1.1 Advance/Modified Hummer Method

Initially add 1.7g of Graphite powder and 0.7g of sodium nitrite powder ($NaNO_3$) into a 1000ml beaker. Mix both compounds. Add 90ml of sulphuric acid (H_2SO_4) into the mixture and kept the beaker under at ice bath (<30°) with continuous constant stirring for 30 minutes. The next step is to add 1.7 grams of potassium permanganate ($KMnO_4$) was added to the solution very slowly while keeping the temperature less than 30°C to avoid overheating and explosion. The solution has been stirred for 8 hours at a controlled temperature of 30°C. The solution needs to been diluted with very slow by adding 100 ml water and kept under stirring for 2 hours at 30°C. Finally, the solution is treated with 40% of hydrogen peroxide (H_2O_2) and continue stirring for 2 hours until the solution colour changes to bright yellow. The solution is washed with 10% of aqueous hydrochloric acid, distilled water and ethanol respectively a few times until forms like a gel substance (pH should be neutral). The gel substance vacuumed and heated in the oven up to 60°C for 6 hours. GO flakes will be obtained. Figure 3.1 shows the flow chart of the method used to obtain GO flakes.

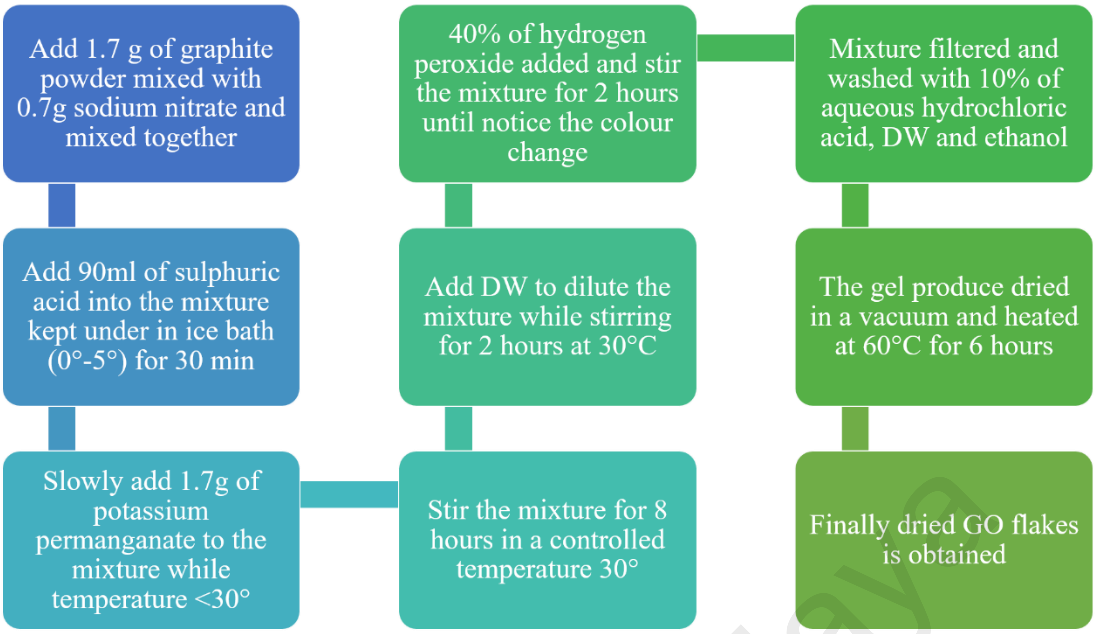


Figure 3.1 : Advance/Modified hummer method glow chart

3.1.2 Preparation of GO/DW Nanofluids

From the earlier method, have to produce GO flakes with advanced hummer method. Figure 3.1 above represents the way to produce GO nanofluids, here are the simple steps that need to be done with the GO flakes produced. For this research there is a need for 8 liters of GO/DW. Nanofluids for each concentration of 0.025 wt. %, 0.05 wt. %, 0.075 wt. % and 0.1 w.t%. Mixing of GO Nanofluids refer to the Table 3.1.

Table 3.1 : Ratio of GO and DW mixing

Concentration wt.%	GO flakes (g)	Distilled water (ml)
0.025	2.0 g	8000
0.05	4.0 g	8000
0.075	6.0 g	8000
0.1	8.0 g	8000

Based on the Table 3.1 amount of GO flakes added to distilled water and ultra-sonication process has been done for 2 hours to disperse and obtain the GO nanofluids as per needed concentration. Figure 3.2 shows the GO/DW nanofluids been obtained by following this process.

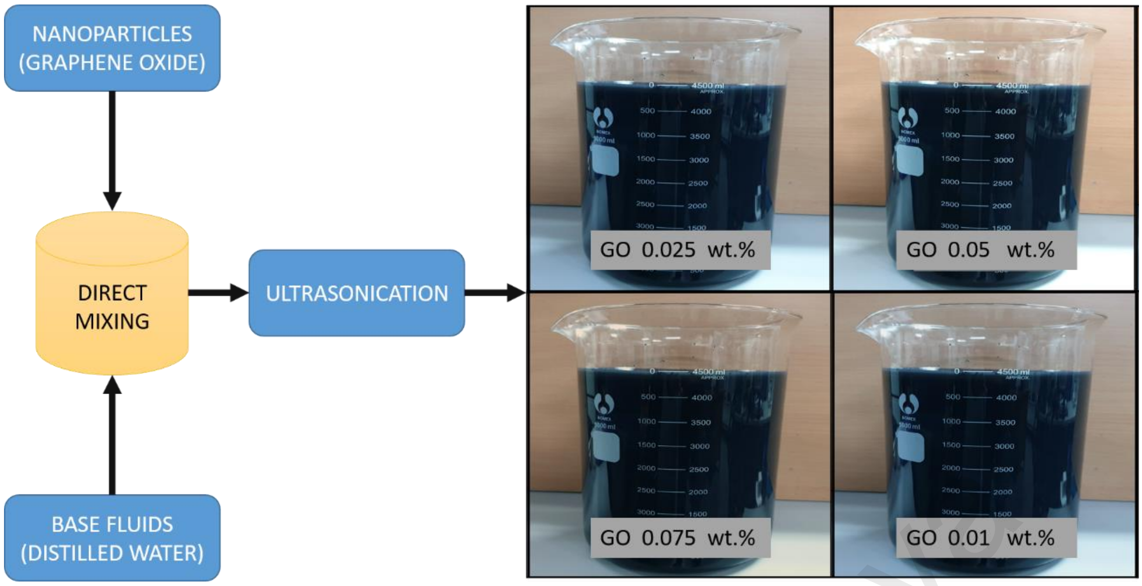


Figure 3.2 : Two-step preparation process of nanofluids (Mukherjee & Paria, 2013)

3.2 Experiment Process

To evaluate the performance of heat transfer, the weight for each sample of nanofluids is mixed at 0.1 wt. %, 0.075 wt. %, 0.05 wt. % and 0.025 wt. %. The experimental test rig that is in the setup at the advanced CFD laboratory at the University of Malaya has been used to investigate hydrodynamic and convective heat exchange properties of GO in a circular test section. The rig parts as illustrated in Figure 3.3 below.

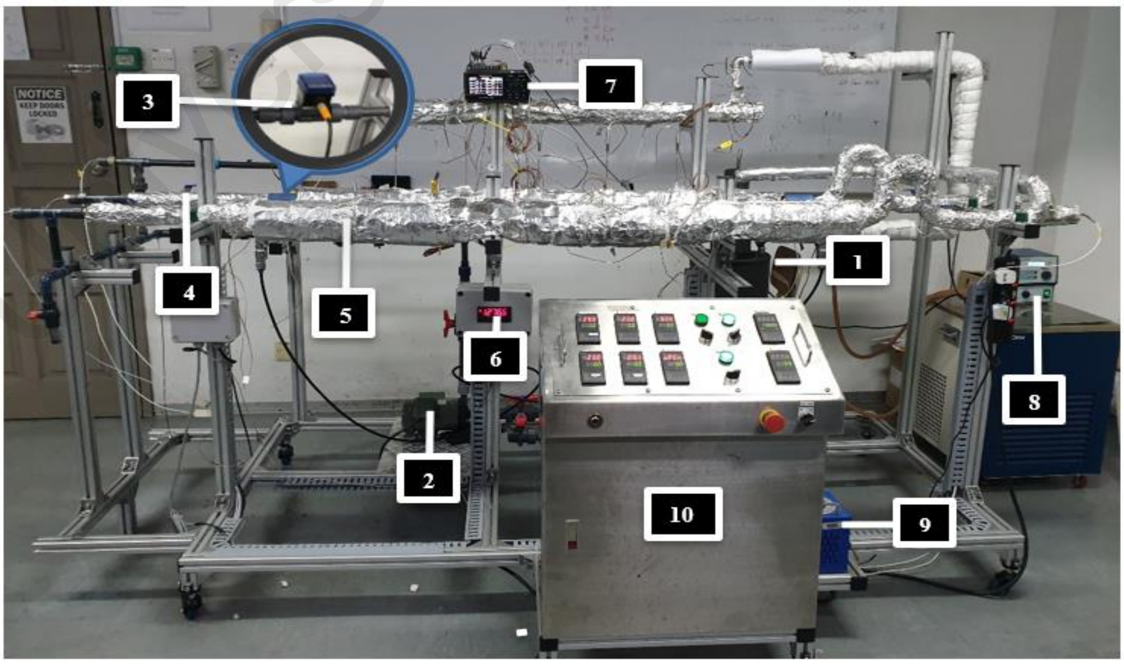


Figure 3.3 : Rig used for convective heat transfer measurement

Table 3.2 : Test rig parts function

No	Description	Function
1	Storage tank	To store the nanofluid as when in process
2	Pump	To pump the test fluid to test section
3	Flow meter	To identify the rate of the fluid flow
4	Stop valve	To control the fluid flow rate
5	Test section	Place where the test fluid temperature reading taken and heat transfer happens
6	DP transmitter	To measure pressure diffrnce in test section
7	Data logger	To observe the reading of thermocouple at test section
8	Cooling unit	To cool down the test fluid at storage tank
9	Transformer	Provide a voltage-adjustable source of alternating current (AC) electricity
10	Power DB	Supply power to all the equipment

Beforehand starting the experiment in the rig, relevant valves, thermocouples, flow meter and differential pressure transmitter were checked and calibrated. The surface temperature of the pipe measured at the depth of the wall thickness is transferred to the internal surface temperature of the test pipe by utilizing the Wilson plot. (Sieres J, Fernández-Seara J , Campo AJ, & Uhía FJ, 2007). Thermophysical properties of DW and GO nanofluids that have been measured will be used to calculate the pressure drop (Pa m^{-1}), Nusselt number (Nu), heat transfer coefficient (h) and friction loss (f). Reynolds (Re) number of distilled water and Nanofluids with different concentrations and flow can be considered. The experiment was conducted on the horizontal circular cross-section on the straight circular tube Figure 3.4. The test section was made of a stainless-steel tube with a length of 1.20 m and the width of the tube is 10 mm internal diameter and 12mm of an external diameter that was wrapped with glass wool to create the insulation layer. The test section is wrapped by a flat wire heating element, where the variable transformer controls the power of the heating element. In the inlet and outlet of the test section thermocouple was installed to measure the temperature at each point, respectively. At the surface of the tube, five K-type of thermocouples (accuracy ± 0.1°C) were installed at 0.3 m from the entering of the nanofluids sample and the distance in between each thermocouple is 0.2 m. The tube was wrapped uniformly by two thick thermal insulation layers (glass wool) to ensure the readings taken are valid and the heat loss from the tube line is reduced.

The magnetic pump will pump the fluid to the test section. Before the fluid goes to the test section flow meter is a place to measure the flow of the fluid. Valves were installed to circulate and adjust the flow rate of the samples during the test. Also, the pressure drop of the fluids at the test section will be measured by a differential pressure transducer (accuracy ± 0.75%). The specification of the cross-section and flow condition of the test rig as in Table 3.3 below.

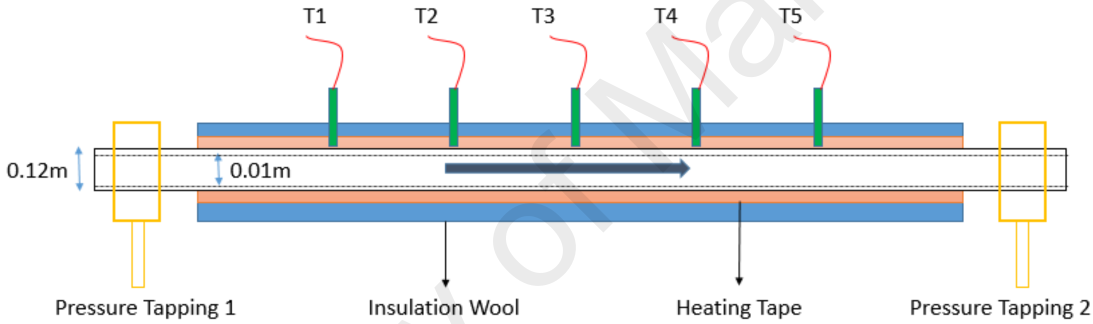


Figure 3.4 : Sectional view of experimental test section

Table 3.3 : Dimension of the test section and flow conditions of the test rig

The dimension of circular heat exchanger pipe	
Length of circular pipe	1.2 m
Cross-section of circular pipe	0.01 m
Shape of pipe	Circular
No. of thermocouples on the pipe	5
The distance between the thermocouple	0.2 m
The material of circular pipe	Stainless steel
Height of test section from the ground	1.5 m
Flow condition of the test rig	
Heat flux boundaries conditions	Constant
Flow rates/Reynolds	Variable
External temperature	Room temperature
Test rig input voltage	220 V, AC
Heating power	600W
Fluid pump frequency	50Hz
Pump RPM	500
Pump input voltage	220V, AC

The experiment was conducted for four concentrations of GO/DW nanofluids as per mixture above and distilled water at the circular tube. Each run consists of nine different flow rates was tested (3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5 and 7.0) L/min. Reading for all thermocouple, Tout and differential pressure was taken when T_{in} at 30°C.

3.3 Mathematical Formulation

The convection heat transfer coefficient can be calculated by relating the Newton cooling law. With the obtained data of inlet temperature, outlet temperature, and bulk fluid temperatures and surface temperatures. The equation as below: Where T_w, Tb and q" represent by wall temperature, bulk temperature, and heat flux, respectively. Tb is derived by the average of the inlet temperature and outlet temperature of the flow.

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

To calculate the heat flux using the above equation. Where Q represents input power (P=VI) voltage and current supply to the heater has been measured in each cycle. The internal circular area of the test section is calculated πr2.

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

To calculate the Nusselt number using the above equation. Where h, D and K represent the heat transfer coefficient, inner tube diameter, and thermal conductivity respectively.

$$Nu = \frac{h \times D}{K} \tag{3.3}$$

To determine the Reynolds number (Re) using the following equation. Where ρ, v, D and μ represents the density of the nanofluids produce are very mild so the density of water will be considered, the density that obtain from the research attached in the (Table

3.4), velocity, diameter and dynamic viscosity of the working fluid (μ = 0.0007978) respectively.

$$Re = \frac{\rho v D}{\mu} \tag{3.4}$$

Table 3.4 : Density of nanofluids at 30°C

Concentration	Density at a temperature of 30°C
Distilled water	995.5
0.025 wt%	995.6
0.05 wt%	995.7
0.075 wt%	995.8
0.1 wt%	995.9

The following equation for single-phase fluids, the empirical correlations for Nusselt number proposed (Petukhov, 1970) (Duangthongsuk & Wongwises, 2008). In the equation Re is Reynolds number, Pr is the Prandlt number and f is the friction loss. Use of this equation, if $3 \times 10^3 < Re < 5 \times 10^6$ and $0.5 \leq Pr \leq 2000$

$$Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)} \tag{3.5}$$

Use of Nusselt equation, if $10^4 < Re < 5 \times 10^6$ and $0.5 \leq Pr \leq 2000$

$$Nu = \frac{\left(\frac{f}{8}\right)RePr}{1.07 + 12.7\left(\frac{f}{8}\right)^{0.5}(Pr^{2/3} - 1)} \tag{3.6}$$

Use of Nusselt equation, if $Re > 10^4$ and $0.7 < Pr \leq 160$

$$Nu = 0.023Re^{0.8}Pr^{0.4} \tag{3.7}$$

To determine the friction loss (f) in equation (3.5) and (3.6) using the relationship proposed by Petukhov (Petukhov, 1970).

$$f = (0.79 LnRe - 1.64)^{-2} \qquad (3.8)$$

If $10^4 < Re < 10^6$ calculate the friction loss for the GO/DW and DW according to the pressure drop across the test section:

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho v^2}{2}\right)} \qquad (3.9)$$

For the Reynolds number range of $3000 < Re < 10^5$ the empirical equation to determine the friction loss of the base fluid given below (Blasius, 1907).

$$f = 0.3164 Re^{-0.25} \qquad (3.10)$$

For the turbulent flow pumping power can be measured by:

$$\dot{W} = 0.158 \left(\frac{4}{\pi}\right)^{1.74} \left(\frac{L \dot{m}^{2.75} \mu^{0.25}}{\rho^2 D^{4.75}}\right) \qquad (3.11)$$

By inserting $\rho = \frac{\dot{m}}{V}$ and $v = \frac{\dot{V}}{A}$ into the equation (3.4) and substituting its result into the equation (3.11), the relative pumping power can be derived for the constant Reynolds number:

$$\frac{\dot{W}_{nf}}{\dot{W}_{bf}} = \left(\frac{\rho_{bf}}{\rho_{nf}}\right)^2 \left(\frac{\mu_{nf}}{\mu_{bf}}\right)^3 \qquad (3.12)$$

From the formula given value of Reynolds No, heat flux, heat transfer coefficient, Nusselt number and friction loss was calculated. From the result, a graph to differentiate the result of each concentration with distilled water was plotted.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Result and Discussion on GO/DW Nanofluids in Circular Heat Exchanger.

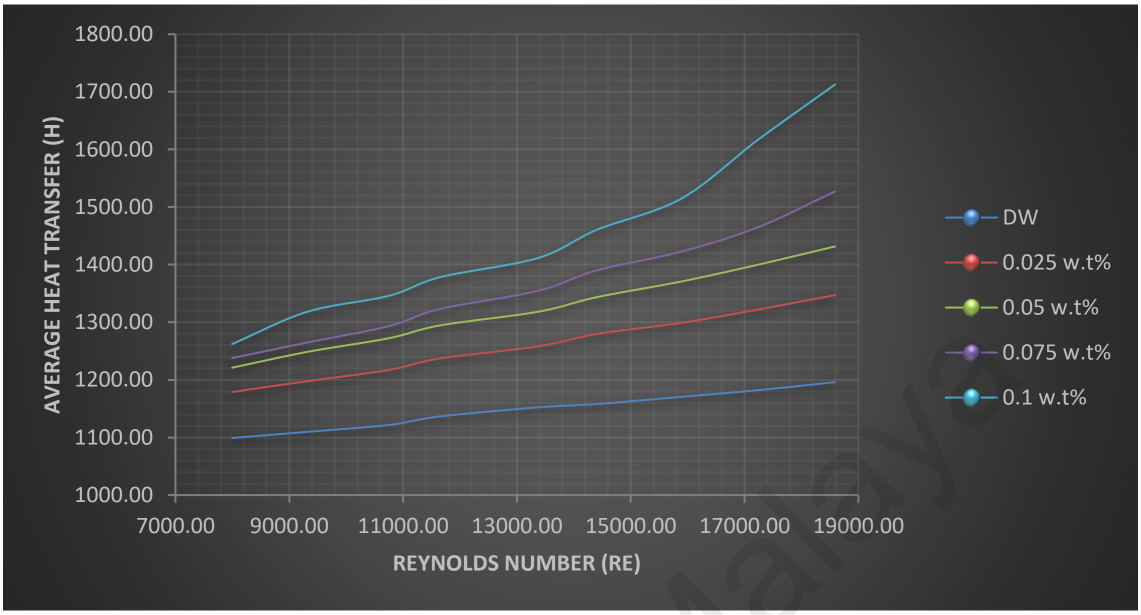


Figure 4.1 : Average heat transfer coefficient at various Reynolds number

As per our methodology, have done a sequence of experiments using GO/DW nanofluids and distilled water at constant heat flux boundary conditions in a circular tube. Nusselt number was calculated based on our experimental data which was collected. Hence, our experimental set-up can be employed to calculate the heat transfer properties of the GO/DW nanofluids and distilled water. To study the convective heat transfer coefficient and Nusselt number of the GO/DW nanofluids and distilled water.

With obtaining results from the experiment the heat transfer coefficient of GO/DW and distilled water using equation (3.1) was calculated. The result is presented between the heat transfer coefficient with the function of the Reynolds number in Figure 4.1. From the observation, there is an increase in the convective heat transfer coefficient when the Reynolds number increase from GO/DW nanofluids and distilled water.

Furthermore, an obvious effect on the convection heat transfer coefficient can be seen when the concentration of nanoparticle GO increase. To characterise this effect to the decrease thermal boundary layer thickness as well as the increased thermal conductivity in the presence of GO/DW nanofluids. Based on the data, Figure 4.1 it was identified that the convection heat transfer coefficient of the GO/DW nanofluids increased by almost 9.8%, 15.2%, 18.9% and 26% for a concentration of 0.025wt%, 0.05wt%, 0.075wt%, 0.1wt% respectively when compared to distilled water from the result obtain. These results were obtained by using constant heat flux of 21,500 W/m^2.

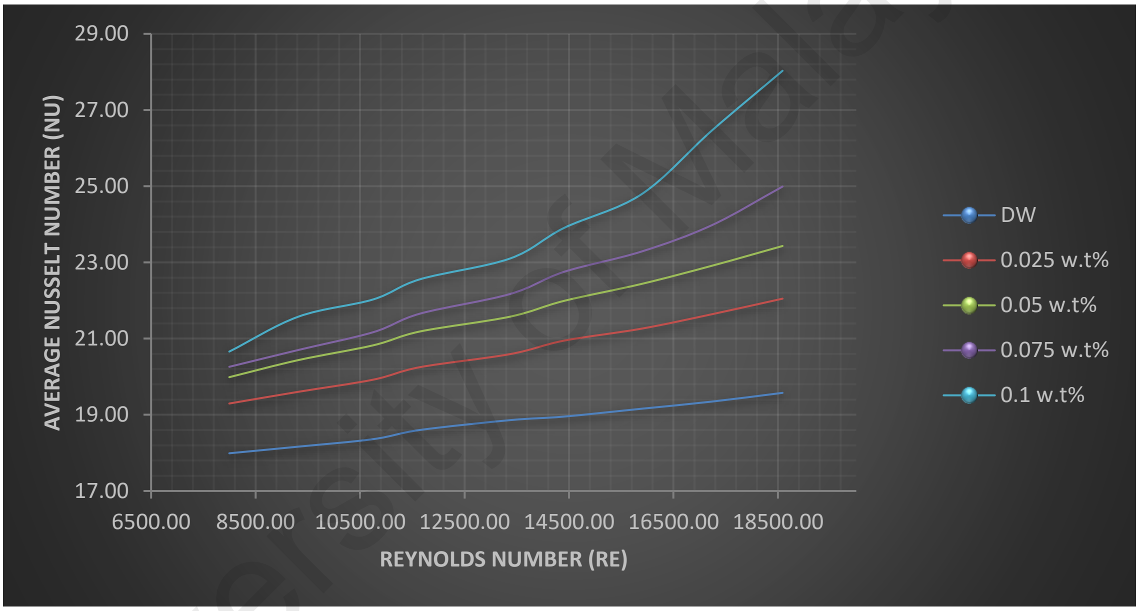


Figure 4.2 : Average Nusselt number at various Reynolds number

Equation (3.3) has been used to calculate the average Nusselt number by inserting the average convective heat transfer coefficient value for GO/DW nanofluids and distilled water. Figure 4.2 represents the result for average Nusselt number vs. Reynolds number. Based on the graph Figure 4.2 it is observed that there is increase in Nusselt number by increasing the Reynolds number. It was identified that the Nusselt number of the GO/DW nanofluids increased by almost 9.6%, 14.9%, 18.6% and 23.7% for a concentration of

0.025wt%, 0.05wt%, 0.075wt%, 0.1wt% respectively when compared to distilled water from the result obtain.

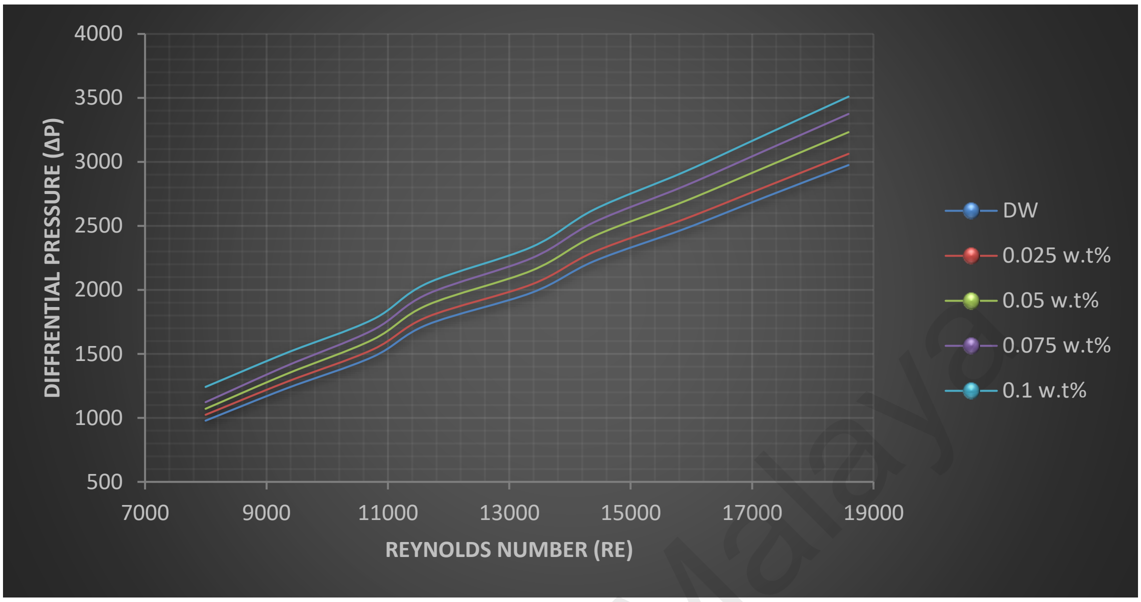


Figure 4.3 : Pressure drop at various Reynolds number

Based on the observation of the graph Figure 4.3 plotted on differential pressure versus Reynolds number, when the flow rate increases the pressure in the test section of circular increase gradually. When comparing the GO/DW nanofluids with the base fluid, GO/DW have slightly higher pressure in the test section. The increase of the pressure due to the viscosity and density of the fluid is slightly higher than the base fluid. This identify that the differential pressure of the GO/DW nanofluids increased by almost 3.3 %, 8.8 %, 13.7 % and 19.0 % for a concentration of 0.025wt%, 0.05wt%, 0.075wt%, 0.1wt% respectively in average differential pressure when compared to distilled water from the result obtained.

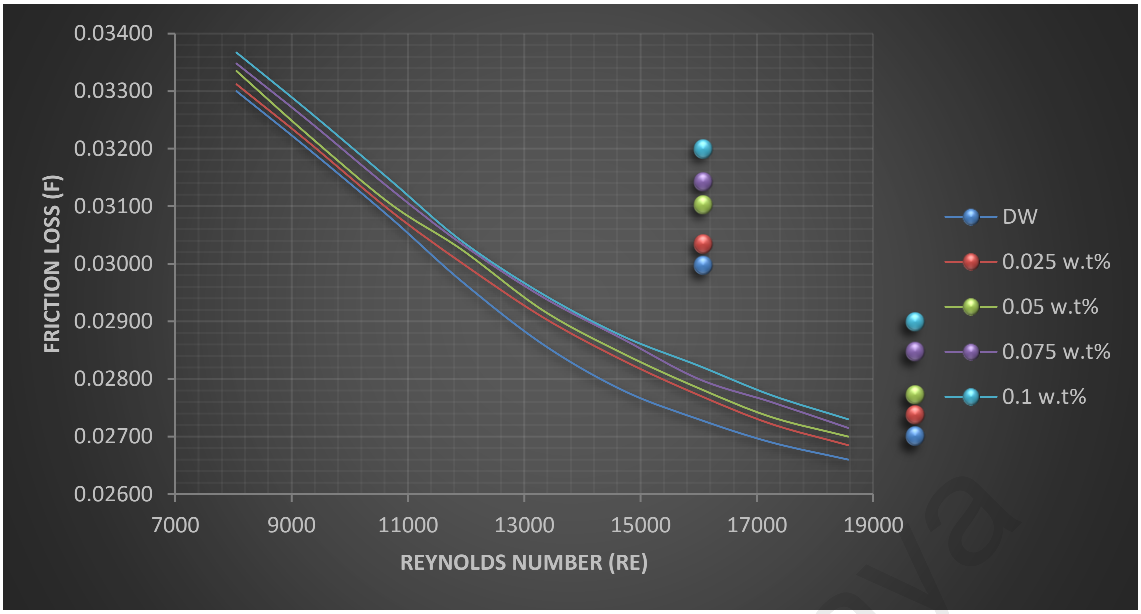


Figure 4.4 : Friction loss at various Reynolds number

To determine the friction loss, calculation the Reynolds number from the data collected. Calculation of friction loss at the circular test section was done using equation (3.10). As observed in the graph Figure 4.4 distilled water has a slightly lower friction loss compared to GO/DW nanofluids. The increase of friction loss by the increase of the concentration percentage on the base fluid. It was identified that the friction loss of the GO/DW nanofluids increased by almost 1.03%, 1.51%, 2.20% and 2.64% for a concentration of 0.025wt%, 0.05wt%, 0.075wt%, 0.1wt% respectively in average friction loss when compared to distilled water from the result obtained.

CHAPTER 5: CONCLUSION

In this study, preparation of graphene oxide through advance/modified hummer method was done with improved heat transfer. The graphene oxide was prepared in distilled water at four various particle concentrations: 0.025, 0.05, 0.075 and 0.1 wt. %. With the produced graphene oxide nanofluids, test was done in a horizontal circular tube heat exchanger and determined the heat transfer rate.

The reason behind this improvement is that the GO provides a maximum surface area in the base fluid which could transfer more heat. Also, it was identified that GO/DW nanofluids are contributing to maximum heat transfer at the higher weight percentage.

There is an increase in the convective heat transfer coefficient and Nusselt number for the GO/DW nanofluid when the Reynolds number increase from 7996 to 18588. This increase in the convective heat transfer coefficient and Nusselt happens when the concentration increased. When the concentration of GO/DW 0.1wt. % the heat transfer coefficient improvement about 23.7 % compared to base fluid and Nusselt improved 26.0% compared to the base fluid. Both values were only achieved when the Reynolds number is at 18588. However, an increase in the concentration causes the increase in the viscosity of the fluid leading to a slight increase in the friction loss. The slight increase in the corresponding friction loss with a value of 2.46 % compared to the base fluid. In summary from this study, it is concluded that water-based graphene oxide nanofluid has a high possibility to use as an alternative heat transfer fluid in the various heat transfer system.

5.1 Recommendation for Future Work

Majority research on GO nanofluid is done with distilled water as a base fluid. Would recommend for future researcher to test with other base fluid with GO to produce nanofluid. Future studies also can consider on higher inlet temperature and higher heat flux, this can get know more on the properties or behavior of GO based nanofluid. Comparison can be made with current in used heat exchanger fluid

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