SYNTHESIS OF NANOFLUID, HEAT TRANSFER AND FRICTION LOSS OF NANOFLUID IN DIFFERENT SHAPED HEAT EXCHANGER TUBES

OMAR FAYEZ ALMATAR ABD RABBUH

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2019

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DISSERTATION SUBMITTED IN FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF ENGINEERING
(MECHANICL)

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2019

UNIVERSITY OF MALAYA

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Matric No: KQK170041

Name of Degree: Master of Engineering (Mechanical).

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ABSTRACT

This thesis presents the impact of nanofluids on heat transfer and pressure drop utilizing different shaped heat exchanger tubes, which opens a new avenue in order to obtain the most effective higher energy transportation. To illustrate this aim, dispersing a nanoparticle in a host fluid to enhance the thermal conductivity of the resulted fluid has been considered for many applications than other traditional fluids as it has higher thermal conductivity than the conventional fluids. In this thesis, the turbulent heat transfer effectiveness of carbon based nanofluids has evaluated in a comprised of test section, cooling loop appliance, tank, piping, sensors and data logger. Graphene Nanoplatelets (GNP) was covalently functionalized with extractions of clove buds and dispersed in distilled water base fluid. At different concentrations, the results showed that the colloidal suspension has higher thermal conductivity than distilled water and the conductivity enhanced with the rising of concentrations. In the next section of this thesis, development of the stability of the Graphene Nanoplatelets (GNP) has been ensured by using Raman spectroscopy and the thermogravimetric analysis was conducted to address the issue of surface tension. These coolants compared with the traditional coolants like water and found the favorable characteristics such as high thermal conductivity. In the Last phase of the investigation of the performance of heat transfer, thermophysical properties and pressure drop of GNP-based water nanofluid in different configurations of heat exchanger tubes was conducted. Regarding the results of this investigation, there is a substantial improvement on the rate of heat transfer related with the loading of well-dispersed GNP in the base fluid. Heat transfer coefficient enhanced with the increase of concentrations of the nanoparticles in the fluid whereas the pressure loss enhancement was much less relevant to the gain in heat transfer. Thus, the graphene water based nanofluids could be a potential heat exchanging liquid.

ABSTRAK

Tesis ini membentangkan kesan nanofluid pada pemindahan haba dan penurunan tekanan dengan menggunakan penukar haba dengan bentuk yang berbeza, ini membuka saluran baru untuk mendapatkan pengangkutan tenaga yang paling berkesan.Untuk mencapai matlamat ini, menyuraikan nanopartikel dalam cecair tuan rumah untuk meningkatkan daya pemindahan haba, cecair nano yang dihasilkan telah diuji untuk aplikasi pemindahan haba dibandingkan dengan cecair tradisional yang lain kerana ia mempunyai kekonduksian haba yang lebih tinggi daripada cecair konvensional. Dalam tesis ini, keberkesanan pemindahan panas bergelora nanofluid berasaskan karbon telah dinilai terdiri daripada seksyen ujian, perkakas gelung penyejukan, tangki, pipa, sensor dan pencatat data. Graphene Nanoplatelets (GNP) adalah difungsikan secara kovalen dengan pengekstrakan tunas cengkeh yang diuraikan dalam air sulingan. Pada kepekatan yang berbeza, hasil kajian menunjukkan penggantungan koloid mempunyai kekonduksian termal yang lebih tinggi daripada air sulingan dan kekonduksian dipertingkatkan dengan peningkatan kepekatan. Di bahagian seterusnya dalam tesis ini, kestabilan Graphene Nanoplatelets (GNP) telah dipastikan dengan menggunakan spektroskopi Raman dan analisis termogravimetrik dijalankan untuk menguji ketegangan permukaan. Cecair pemindahan haba ini dibandingkan dengan cecair pemindahan haba tradisional seperti air dan kajian mendapati ciri-ciri yang baik seperti kekonduksian terma yang lebih tinggi. Fasah terakhir experimentasi ini menyiasatan prestasi pemindahan haba, sifat termofisis dan penurunan tekanan nanofluid air berasaskan GNP dalam konfigurasi yang berbeza tiub penukar haba. Secara keseluruhannya, hasil penyelidikan ini mendapat peningkatan mendadak pemindahan panas yang berhubung kait dengan GNP yang tersebar dengan baik dalam cairan dasar. Pekali pemindahan haba berjaya dipertingkatkan dengan peningkatan kepekatan nanopartikel dalam bendalir sedangkan peningkatan tekanan boleh diabaikan dibandingkan dengan peningkatan ynag diperolehi

dalam pemindahan panas. Oleh itu, nanofluid berasaskan air GNP berpotensi menjadi cecair pertukaran haba yang baik

ACKNOWLEDGEMENTS

First, I would like to thank my parents for guiding me through my first steps of life and education. I would also like to thank my supervisor, Dr. Kazi Md. Salim Newaz, Dr. Ali Hassan and Dr. Sean, of University of Malaya, who have guided my academic and professional development by guiding and supporting my research. I would also like to thank my brothers, who have been supportive towards me and my study throughout the tenure of my graduate education.

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LIST OF SYMBOLS AND ABBREVIATIONS

General and Greek Symbols

C_p : Specific heat capacity at constant presser $(J/Kg.K)$
h : Heat transfer coefficient based on mean temperature $(W/m^2\,K)$
K : Thermal conductivity (W/mk)
Nu : Nusselt number $(h\,.D/K)$
P : Static pressure (N/m^2)
Pr : Liquid Prandtl number
Re : Reynolds number
q : Heat flux (W/m^2)
T : Temperature (^{O}C)
v : Velocity (m/s)
d_p : Nanoparticle diameter (m)
s : Rate of deformation (s^{-1})
I : Turbulent intensity
r, z : 2D axisymmetric coordinates (m)
ρ : Density (Kg/m^3)
μ : Dynamic viscosity $(Kg/m.s)$
μ_t : Turbulent viscosity $(Kg/m.s)$
ε : Performance
τ : Shear stress (Pa)
ν : Kinematic viscosity
β : Friction coefficient $(Kg\,m^{-3}s^{-1})$

φ : Particle volume fraction (or mass fraction)

eff : effective

f : fluid

P : Particle phase

r : Radial direction

s : Solid

x : Axial direction

0 : Initial

D : Tube diameter (m)

LIST OF APPENDICES

CHAPTER 1:

CHAPTER 1: INRODUCTION

1.1 Background

Nanofluids are prepared by dispersing manometer scaled solid particles of sizes (10 nm-100 nm) in various base fluids to enhance thermal properties of the base fluid like water, oil, ethylene glycol etc. Recently conducted experiments have shown that nanofluids tend to have substantially higher thermal conductivity than the base fluids (J. Eastman, S. Choi, Li, J. Thompson, & Lee, 1996). Most common base fluids and nanoparticles which could be water and metal, metal oxide, carbon-based nanoparticles.

These types of fluids are presented as next – generation heat transfer fluids. It has better thermal characteristics than the traditional heat transfer fluids (Sadeghinezhad, 2013; Sadri et al., 2014). Over the previous three decades, nanofluids have displayed noteworthy development in thermal conductivity, heat transfer coefficients and stability which in turn could reduce the overall consumptions and costs of plant power on application of more efficient heat exchangers. Nanofluids are significantly being used in various heat exchanger applications in order to retard and optimize energy consumption. Thus, find out of suitable suspension fluid having enhanced heat transfer characteristics with high thermal conductivity has become a challenge (Chen, Witharana, Jin, Kim, & Ding, 2009) to the scientists and engineers.

1.2 Problem Statement

Global energy demand is escalating, so to meet this challenge energy recovery by efficient means has become vital. Heat Exchangers are used for transportation and recovery of energy, so to develop efficient heat exchanger, the current work has emphasized on developing high performance heat exchanger liquid and test its performance in a rig.

Heat transfer to nanofluids has been investigated for long time by researchers, many of them concentrated on metal oxide with surfactant, but a few a few of them used functionalization for stability. It has become essential to work on covalently functionalized synthesis of nanofluids for application in heat exchangers.

Present work has taken in hand to synthesis carbon based functionalized nanofluids and its application as heat exchanger liquid, this will enhance the performance of heat exchanger, save energy and provide economic benefit.

1.3 Research Objective

1- To study the thermophysical properties of carbon-based nanofluids.
2- To study the effect of carbon-based nanoparticles on the heat transfer and pressure drop characteristics of the base fluid.
3- To investigate the effect of flow passage on heat transfer and pressure drop of the flowing nanofluids.

1.4 Layout of Research Project

The research project begins with a glance at various mechanisms of transportation of energy in nanofluids, a summary of past literature review of thermos – physical characteristics, stability, convection heat transfer and friction loss (pressure drop) of nanofluids. In chapter 2, a part of the literature survey will be presented. This followed by characterization method, instruments, the experimental setup and test application are investigated in chapter 3. The results of heat transfer, pressure drop and performance of the prepared nanofluids are discussed in chapter 4. The chapter 5 contains a conclusion of the work done and proposed recommendation for future work.

CHAPTER 2:

CHAPTER 2:

CHAPTER 2: LITERATURE REVIEW

2.1 Implementation of the Concept of Nanofluids

In the wake of increasing global competition to improve cooling capabilities of various mechanical systems, the existing number of industries have a durable need to improve the heat transfer fluids with significantly high thermal conductivities. The researchers put efforts on heat transfer improvement which have been constrained because of the convenient fluids should have higher thermal conductivities compared with the presently available inherently poor thermal conductive fluids.

It is known that, the metals in the solid form have higher thermal conductivity than those in the fluid form (Cortes & Santamarina, 2012). For instance, at room temperature, the thermal conductivity of copper is about 700 times greater than that of using water and higher about 300 times than that of the engine oil, as shown in Table 2-1. Hence, thermal conductivity of metallic liquids is greater than the nonmetallic liquids. Therefore, when the fluids that contain suspended solid metallic particles, their expected thermal conductivity is higher in comparison to the traditional single-phase base fluid.

Table 2-1: Thermal Conductivity of Various Materials(Sadri et al., 2017)

	Material	Thermal Conductivity (W/m. K)
Metallic Solids	Sliver	429
	Aluminum	237
Nonmetallic Solids	Carbon nanotubes	3000
	Alumina, Al_2O_3	40
Metallic Liquids	Sodium at 644 K	72.3
Nonmetallic Liquids	Water	0.613
	Ethylene glycol	0.253

More than 1000 years ago, Maxwell (Maxwell, 1873) presented a theoretical basis for predicting the efficient conductivity of suspension, later scientists and engineers had given good efforts by adding solid particles in liquids in order to improve the inherently poor thermal conductivity of them. However, all the investigations had been confined to millimeter or – micrometer –sized particles for the thermal conductivity of suspensions.

Two major technical problems have been related to this conventional approach:

(1) micro and millimeter –sized solid particles settle rapidly in fluids.
(2) at low particle concentrations, the thermal conductivities are low.

Furthermore, these conventional suspensions can clog the tiny channels of such miniaturized devices. With the approximate size of particles below 100 nm, modern nanotechnology has come up with the production of nanoparticles of average size within the specified range.

2.1.1 Expected Properties of Nanofluids

Due to the improved thermal properties, in the last 2 decades, nanofluids have got substantial attention. Research investigations exhibit that the thermal conductivity of nanofluids relies on various factors for example, particle size, material and shape, host fluid and temperature. Researchers (Al-Nimr & Al-Dafaie, 2014; Peyghambarzadeh, Hashemabadi, Chabi, & Salimi, 2014) have shown that the features of nanofluids for various engineering application are uncommon. Some of the special qualities are stated below:

- Enhanced thermal conductivities excellent theoretical predictions.
- Enhanced electrical conductivity
- Increased ability of heat transfer.
- Justified pumping power.
- Supreme lubrication.
- Acceptable clogging and erosion within microchannel.

2.2 Preparation of Nanofluids

2.2.1 One –step technique

Because of the difficulty of preparation of stable nanofluids via two- step technique, an advanced method is employed to make nanofluids via one –step technique. This method utilizes physical technology in which the metals are vaporized and cooled into liquid to produce nanofluids which in turn leads to a good control over sizes of the particles and produce stable nanofluids (Lo, Tsung, & Chen, 2005).

2.2.2 Tow – step technique

This method is employed by several researchers to prepare nanofluids. The two – step method utilizes nanofibers, nanoparticles and nanomaterials, which primarily produced as dry powders via physical or chemical methods (J. A. Eastman, Choi, Li, Thompson, & Lee, 1996; Suresh, Venkitaraj, Selvakumar, & Chandrasekar, 2011).

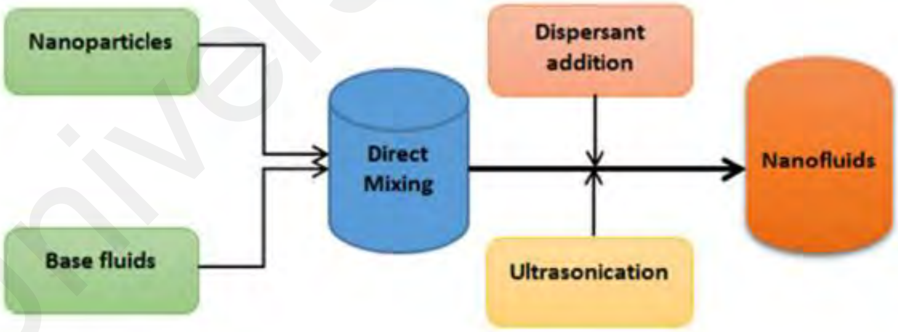

Figure 2-1: Two-step preparation process of nanofluids (Mukherjee & Paria, 2013)

This method is considered as the most economical process to produce nanofluids (Figure 2.1). By using this method, the nanofluids could be prepared on a large scale.

Amiri et al. (Amiri et al., 2015) used this method to prepare the covalent GNP nanofluid using the carboxyl groups as a surfactant and the non-covalent GNP nanofluids utilizing the sodium dodecyl bonze sulfonate (SDBS) as a surfactant, for both nanofluids the diameter of the pristine Graphene Nanoplatelet was 0.5-3μm and thickness of 0.55-3.74 nm with GNP concentration of 0.025,0.05 and 0.1%wt.To insure that the suspension fluid is stable and homogenous, both samples were sonicated in water for 30 min.

Sadri et al. (Sadri et al., 2018) produced the covalent GNP nanofluid using dried clove buds as a surfactant by extracting the main component of clove which are (eugenol, eugenyl acetate and β-caryophllene) with 0.025,0.05,0.15wt. The pristine GNP nanoparticles was 2nm as a thickness with lateral size of 2μm. Fully dispersion is obtained by exposed the covalent nanofluid to the ultrasonication process for 30 minutes.

Sadeg et al. (Sadeghinezhad et al., 2015) performed the technique mentioned above to produce a covalent GNP nanofluid without any surfactant with 0.025,0.05,and 0.1% wt. concentrations of nanoparticles . the geometric dimensions of the nanoparticles were 2μm for the diameter and 2nm for the thickness.

Mahmudul et al. (Mahmudul Haque et al., 2015) used in his experimental the graphene nanopowder with thickness of 8 nm. Good suspended of the nanoparticles in the base fluid obtained by using sodium dodecy1 benzene sulfonate (SDBS) and sodium dodecy1 sulfate (SDS) as surfactants to produce more stable suspensions. For the well dispersion, the ultrasonication process is applied to the nanofluid for 30 minutes.

Arzani et al. (Arzani, Amiri, Kazi, Chew, & Badarudin, 2015) prepared tow samples of GNP nanofluids ,covalent and non-covalent nanofluids, for the non-covalent nanofluid, the pristine GNP was grinded with (SDBS) which acts as a surfactant then with a ratio of SDBD/pristine GNP of 0.5:1 poured into the distillated water. on the other hand, the preparation of the covalent (GNP-COOH) conducted by the following steps, first of all, 1 g from the GNP pristine is mixed with a carboxylation solution contains (HNO_3 and

H_2SHO_4) ,then for 30 minutes, the mixture is sonicated to ensure the well dispersion. Then for 15 mins, the suspension fluid is heated up to 90 degree after that the resulting fluid was cooled at the temperature room, finally, the suspension fluids dried in a vacuum at 40 degree after diluted it with deionized water to remove the unreacted acids.

2.3 Thermophysical Properties of Nanofluids

Referring to the annual winter meeting of the American Society of Mechanical Engineer (ASME); it was found that, instead of increasing the power consumption of the pump by a factor of 10, it could be possible to double the convective heat transfer coefficient by adding nanoparticles(Choi, Zhang, Yu, Lockwood, & Grulke, 2001). Keblinski et al. (Keblinski, Phillpot, Choi, & Eastman, 2002) discussed the heat transfer to the nanofluids. Their report concluded that, the suspensions of nanofluids offer high thermal conductivity even at low concentrations of suspended nanoparticles. Several studies found out the improvement of thermal conductivity of heat transfer fluid with Nano sized solid particle content. Enhancement of thermal conductivity relies on adding and concentration of nanoparticle (Halelfadl, Estellé, & Maré, 2014).

Earlier measurements by many researchers show that the thermal conductivity of suspension fluid could be influenced by many factors, such as particle size, pH value in the base fluid, particle shape, fluid type and temperature (Xie et al., 2002). They tested the thermal conductivity of three different nanofluids by dispersing the treated CNT in different base fluids (decene, distilled water, and ethylene glycol) and found that the decene – based nanofluids had the highest thermal conductivity, followed by ethylene glycol-based, and the distilled water- based nanofluids. Olhero et el. (Olhero & Ferreira, 2004) discussed the distribution affects and size of the particles and the results showed that the fine particles increase the viscosity while the large particles resulted in a low viscosity. However, the rheological properties of suspension fluid rely on the method followed in synthesis of nanofluids and size of the particle and distribution (Chen, Ding, & Tan, 2007).

Emad et al. (Sadeghinezhad et al., 2015) examined the thermal conductivity of covalent functionalized nanofluid as a function of temperature and weigh concentration of the nanoparticles. They noticed an increment of the thermal conductivity with the increase of nanoparticle concentration and temperature. The percentage of increment was 22.92 for 0.1% wt. at 40 C^{o} in comparison to DI water. This increment can be attributed to the increase in the Brownian motion.

The dynamic viscosity was evaluated considering one of the important issues encountered in preparing the nanofluid, because adding the nanoparticle to the host fluid lead to increase of the dynamic viscosity which in turn increases the pressure drop and and pumping power. In the present investigation there was little increment of pumping power in the low range of nanofluid concentration. In terms of the specific heat capacity, the nanofluid has lower specific heat capacity than DI water which further reduces by increasing the concentrations of nanoparticles. The density was studied with the increase of temperature and was observed that the density decreases about 6% by increasing the temperature from 20 to 40 ^{O}C, while in general the density of the coolant nanofluid has greater density in comparison to the DI water data and this increment increases with the increase of concentrations.

Sadri et al. (Sadri et al., 2018) evaluated the thermophysical properties of the synthesized nanofluid as a function of temperature and the concentration of nanoparticles by weight percentage. Thermal conductivity is regarded as the main essential factor of the heat dissipation efficiency in heat exchangers, they found that the thermal conductivity of the GNP nanofluid is considerably higher than the DI water and the rate of increasement becomes higher with the increasing of the concentration of the nanoparticles. The enhancement was about 22.9% for 0.1%wt., at 40 ^{O}C. A slight increase in the dynamic viscosity is observed and the rate of increase is greater at higher particle weight concentrations. Since increasing of the dynamic viscosity lead to a higher pumping power and pressure drop, it's important to consider the low particle weight concentrations if the nanofluid will be used as coolant. This pronounced increment of the dynamic viscosity can be limited by improving a reliable synthesis of nanofluid. Interestingly, the dynamic viscosity decreases with the rise of temperature, which can be attributed to the reduction of the intermolecular forces. Due to the fact that the nanoparticles have a specific heat capacity lower than that of the host fluid, and it insignificantly decreases within a range of 0.43- 1.52% in comparison to the DI water as a function of the weight concentration, in contrary, to a light increase in the specific heat capacity observed with the increase of temperature. As the fluid temperature is increased, a noticeable decrease in the density is observed by approximately 6% when the temperature is raised from 20^{O}C to 40^{O}C and it happened due to the thermal expansion of the working fluid, whereby an increase by only 0.045% of the density is observed by increasing the nanoparticle concentration from 0.075 % to 0.1% wt.

Ahmad et al. (Amiri et al., 2015) examined the thermal conductivity covalently functionalized nanofluids, GNP-COOH and GNP-SDBS and observed higher thermal conductivity of the covalently functionalized nanofluids because of the layers created by the liquid molecules which possess a higher thermal conductivity than the bulk fluid. As a function of temperature and particle weight concentration, the thermal conductivity is increased by increasing the temperature and particle weight concentration. For a constant concentration, the viscosity is decreased with increasing the temperature and this can be attributed to the weakening of the forces between intermolecular. Low particle weight concentration of the nanoparticles should be considered because an increment in the dynamic viscosity may lead to increase the pressure drop which in turn increase the pumping power.

Researchers have been investigating the heat transfer performance of heat exchangers for further improvement of its performance, which in turn could affect the life style of people from the cumulative benefit. The requirement for a better heat transfer becomes more essential with the improvement of heat exchanger, solar collector, heat engines, heat pumps and similar equipment.

Due to the unique physical and chemical characteristics of the material like metal and metal oxide in nanometer size, the researches were attracted to investigate the nanofluid. The main purpose of the coolant fluid used in the heat exchanger equipment is to increase the heat transfer coefficient which lead to enhance the overall heat transfer. Many nanofluids exhibited increment in the thermal conductivity which in turn become suitable for utilize them as heat exchanger fluids.

2.4 Performance of Heat Transfer and Pressure Drop for nanofluid

Performance of heat transfer properties of nanofluids have considered under two essential different thoughts. The first one claims that the enhancement of heat transfer can be achieved without increasing the pumping power, while the other thought claims that without increasing the pumping power the desired heat transfer enhancement cannot be achieved because of its limitations (Choi et al., 2001; Williams, Buongiorno, & Hu, 2008).

Several researches have discussed flow properties and performance of heat transfer (Albadr, Tayal, & Alasadi, 2013; Kakaç & Pramuanjaroenkij, 2009) and they found that the improvement of the heat transfer coefficient is a suitable indicator than the thermal conductivity improvement for suspension fluids used in designing heat exchange tubes.

However, heat transfer coefficient and Nusselt number relies on many factors, for example specific heat and thermal conductivity of nanoparticles and base fluid, the viscosity of nanofluid, the dimensions and the shape of the particles and their concentration in the base fluid and the flow pattern. Studying the impact of using GNP nanofluids on the heat transfer and pressure drop at different flow conditions was conducted for different pipe cross-sections by many researchers.

2.4.1 Circular pipe Flow

Ramin et al. (Ranjbarzadeh, Karimipour, Afrand, Isfahani, & Shirneshan, 2017) performed an experimental study to investigate the effect of using graphene oxide/Distilled water nanofluid on the heat transfer and pressure drop through a copper circular tube of 8.5 mm internal diameter, and its outer surface is isothermally treated. A turbulent flow regime was considered, and Reynolds number range was between 5250 and 36,500. A volume fraction concentration of 0.025%, 0.05%, 0.075%, and 0.1% were prepared and the. They found that, the enhancement of heat transfer parameters such as Nusselt number and convection heat transfer coefficient increase when the nanofluid concentration increases as well and they got a maximum enhancement of Nu equals to 17.6% comparing to that of the base fluid. The enhancement of convection heat transfer coefficient was varied with Reynolds number, where they got a maximum enhancement of 40.3% at the lower value of Re and a minimum enhancement of 16% at the highest value of Re. Also, the friction factor was affected by using graphene oxide (GO)/DW nanofluid as they got a increment of 16% with the highest concentration comparing to the DW.

Hossein et al. (Akhavan-Zanjani, Saffar-Avval, Mansourkiaei, Ahadi, & Sharif, 2014) conducted an experimental work to investigate the performance of GNP/DW nanofluid as a convective heat transfer medium. A turbulent flow regime with Re number range between 4000 and 12000   was considered in a horizontal stainless-steel tube of 4.2 mm and 6 mm inner and outer diameters respectively, and 2740.2 mm length. The test section was subjected to a uniform heat flux at its outer surface and the volumetric concentrations of nanofluid used in the experiment were 0.005%, 0.01%, and 0.02%. They reported a maximum enhancement of convection heat transfer coefficient of 6.04% comparing to the base fluid at Re of 10850 and 0.02% vol. concentration. Moreover, they found that, the Nusselt number decreased with the increasing of nanofluid concentration, and there was no remarkable increment in the pressure drop compared to the data from DW.

Emad Sadeg et al. (Sadeghinezhad et al., 2015) performed an experimental work to evaluate the heat transfer performance and pressure drop of a GNP nanofluid with concentrations of 0.025,0.05, 0.075 and 0.1wt%. The experiment was conducted under turbulent flow with Reynolds number from 4583 to 18.187 in a circular steel tube that located horizontally and exposed to uniform heat flux. A noticeable enhancement of 25 % for the convection heat transfer coefficient was observed compared to the base fluid. They mentioned that, the Nusselt number increases with the increasing of the heat flux and Reynolds number. Regarding the pressure drop, a reasonable increase in the pressure drop were noticed from 0.4 % to 14.6% for the nanofluid in comparison to the base fluid due to the increase of the viscosity of nanofluid.

Arzani et al. (Arzani et al., 2015) investigates the effect of utilizing a covalent and a non- covalent nanofluid as the coolant fluid with the concentrations of 0.025, 0.05 and 0.1% by flowing in an annular circular tube located horizontally, the experiment was conducted under Reynolds number varied from 5000 to 17000 and the outer surface of the tube was subjected to a constant heat flux. The experiment presented an increase in the heat transfer performance with the increase of Reynolds number in comparison with the base fluid and this increment was further enhanced with the concentration of nanoparticles. Increase of the pressure drop was observed with the increase of concentration of the nanoparticles.

2.4.2 Square Pipe Flow

Hooman et al. (Yarmand et al., 2017) performed an experimental study to evaluate the enhancement of convection heat transfer coefficient in a horizontal tube of square cross section using GNP/ platinum hybrid nanofluid with concentrations of 0.02 wt.%, 0.06 wt.%, and 0.1 wt.%. The test section was 1000 mm, it was subjected to a uniform heat flux at its outer surface and the flow was turbulent with Re range from 5000 to 17500. They reported a significant enhancement in the convection heat transfer coefficient for all the samples, compared to the base fluid with the max enhancement value of 30% at the highest concentration of Re at 17500. Moreover, they found a remarkable increment of the friction factor of about 10%.

Yarmend et al. (Yarmand et al., 2016) examined a water based nanofluid GNP with a different range of weight concentrations of nanoparticles 0.02 and 0.1%wt. by flowing the nanofluid in a stainless steel tube with a square cross –sectional area located horizontally. The geometrical dimensions of the test section were, 1.4 m and 10 mm length and inner diameter respectively. The boundary conditions are applied by surrounding the rig test section with an insulator layer and a tape heater for providing constant heat flux. The overall heat transfer was evaluated in turbulent flow and at Reynolds number varied from 5000 to 17500.

The remarkable enhancements were observed in the overall heat transfer coefficient and Nusselt number as 19.68% and 26.5% respectively in comparison to the host fluid, and these enhancements were further increased with the increase in concentrations of the nanoparticles. As the viscosity is a function of weight concentrations, a noticeable increment in pressure drop was noticed about 9.22 % at 0.1 wt. % concentration in comparison to that of the base fluid.

Garbadeen et al. (Garbadeen, Sharifpur, Slabber, & Meyer, 2017) investigated the effects of dispersing a multi – walled carbon nanotubes MWCNT into the base fluid and evaluated the enhancement in the effective heat transfer which increased about 45% at 0.1wt. nanoparticles concentrations compared to the base fluid while a noticeable increment is observed for the pressure drop and dynamic viscosity 15% and 6% for the pressure drop and dynamic viscosity respectively and the rate of the increment is greater at higher particles concentrations and this increment can be attributed to the fact that the MWCNT has higher density than the water.

2.5 Summary

Nowadays, cooling and heating considered as the most crucial challenges of several engineering applications. Nanofluids are one of the promising solutions for heat transfer improvement due to their high thermal conductivity.

The major efforts are taken place in determining the convection heat transfer coefficient and pressure losses in a heated horizontal tube. In the evaluation process, it is needed to determine firstly the required method to describe the colloid's mass loading, PH, size of the nanoparticle, and the chemical constituents, then the temperature and viscosity and thermal conductivity can be determined to measure the pressure loss and convection heat transfer coefficient. In general, the nanofluids containing carbon nanotubes and metal oxide acts as non-Newtonian fluids due to their shear thinning behavior. When the interaction forces between the particles decreased and there is no substantial forces interacted between the particles, then the particles become separated in the form of precipitation. The rheological studies enhance the stability and the interactions between the host fluid and nanoparticles. In addition, the literature presents that there is a significant improvement in heat transfer when nanofluids are used. This enhancement in heat transfer relies mainly on the heat capacity and thermal conductivity of the host fluid and nanoparticles, the concentration of the suspended particles, the viscosity and density of the nanofluid, the dimensions and the shape of these particles as well as the flow pattern.

Thermal conductivity of the host fluid and the nanoparticles represent the total thermal conductivity of the nanofluids. Research output reveals that there is a pressure drop increase with the increase of the particle concentration. The pumping power is higher when the flow is maintained in the laminar regime, but when it enters into the turbulent regime the pumping power decreases due to the viscosity effect. Therefore, by using higher quality of the suspension fluid the pumping power can be reduced. Pressure loss and heat transfer improvement for the carbon – based nanofluids were little. Thus, an investigation on carbon-based nanofluids in different flow regimes are essential to develop correlations for predicting pressure losses and heat transfer are great interest.

In this chapter a literature survey on the studies about using carbon-based nanofluids (especially GNP) in heat transfer and pressure drop are presented which indicates that, there is a shortage in the studies performed to compare the effect of test section shapes on heat transfer and pressure drop using nanofluids. In the present work a study of the thermophysical properties of the GNP nanofluid and a comparative study will be conducted to investigate the performance of GNP nanofluid with three different concentrations as a convective medium in two test sections with different shapes, circular and square cross section under the same flow conditions. Both the test sections have the same hydraulic diameter and their outer surface subjected to a uniform heat flux.

CHAPTER 3:

CHAPTER 3: METHODOLOGY

3.1 Experimental set-up

In the field of thermo fluid properties, the performance of the heat transfer can be evaluated by heat transfer coefficient (h) which plays a key role in that field.

The experimental setup for this work was implemented in the test –section of the set-up of Figure 3-1, which consists of several main sections, such as heating unit, flow loop, cooler, measuring instruments and the control unit and data logger. The flow loop contains a pump, flowmeter, valves, piping, test section, tank etc. as shown in the schematic diagram in Figure 3-1.

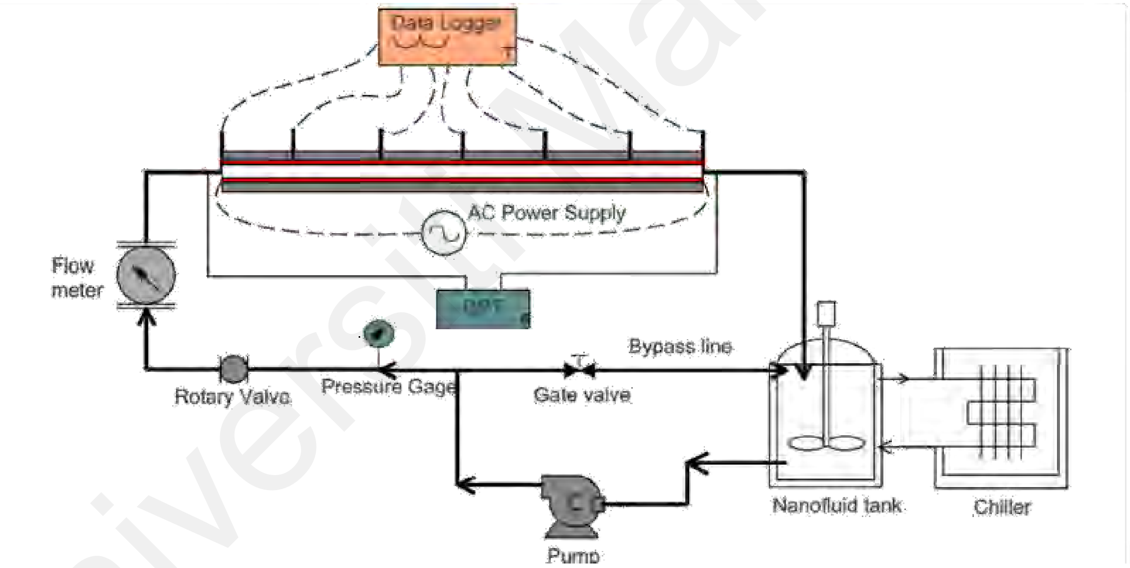

Figure 3-1: Experimental setup for investigation of convective heat transfer coefficient.(Abdelrazek et al., 2018)

The experiment was conducted in two horizontal straight tubes of squared and circular cross-sections. The inner diameter of the tubes were 10 mm, length 1400 mm, and material stainless steel. The heated portion of the tubes were thermally insulated carefully by wrapping with glass wool at the outer surface of the cross section of the test section, about 1200 mm length . The test section was heated by wrapping with flat wire heating element, where a variable voltage transformer controlled the power supply.

The maximum power capacity of the heating element was 900 W. Heat loss to the surroundings were negligible in comparison to the heat supplied to the flowing fluids inside the tube. Surface temperatures of the test section was measured by five thermocouples spaced equally at the upper heated portion of the tubes by K-type thermocouples (accuracy ± 0.1 ^{O}C)which were fixed by using high-epoxy adhesive material .Bulk temperature of the fluid in the test section was measured by taking the average of the inlet and outlet temperature of the tube, where two resistance temperature sensors of (PT 100) were installed at the inlet and outlet sections of the test section as presented in Figure 3-2.

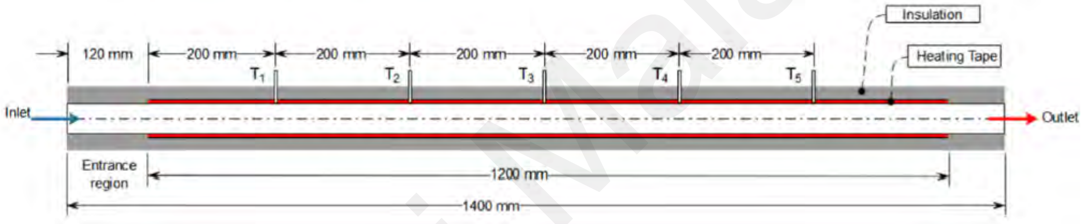

Figure 3-2: Sectional view of the Experimental test section.(Abdelrazek et al., 2018)

The fluid was pumped by a magnetic pump (EX-70R, maximum capacity 80 L/min) through the flow loop from an insulation jacketed reservoir tank of capacity around 10 L. The fluid inside the jacketed tank was stirred to keep at uniform temperature and to prevent sedimentation of the particles inside the tank. The flowing fluid passed through the test section, being heated and returned to the reservoir where it was cooled to the initial state and recirculated. A pressure transducer with an accuracy of ± 0.75%, was used to measure the pressure drop across the test section.

3.2 Material and Method

In this study, GNP nanofluid was synthesized following the procedure of bio based functionalization of GNPs with clove buds extracts, hydrogen peroxide and ascorbic acid (Sadri et al., 2018). Table (3-1) presents the measured thermophysical properties at 30 ℃ which is considered at the inlet flow temperature for all the experiment cases.

Bio based synthesis of functionalized GNP nanofluid is an environmentally friendly process which utilizes dried clove buds in a polar solvent. This technique guaranteed the improvement of stability. In this technique, hydrogen peroxide and ascorbic acid were used to graft the main components of cloves onto GNPs, these components are eugenol, eugenyl acetate and β-caryophyllene. The hydrogen peroxide was considered one of the most oxidizers that produces a non-toxic substance, the ascorbic acid works as the redox pioneer. This technique was built on two phases, the preparation of the cloves and functionalization process. Figure (3-3) below presents the steps followed in preparation of clove extract which begins by adding 15 g of ground cloves which was dissolved into 1000 ml of distilled water, this water was heated at 80 ^{O}C, the solution was then homogenized at average speed of 1200 rpm for 30 minutes at 80℃. Polytetrafluoroethylene (PTFE) membrane of 45 µm was used to filter the solution.

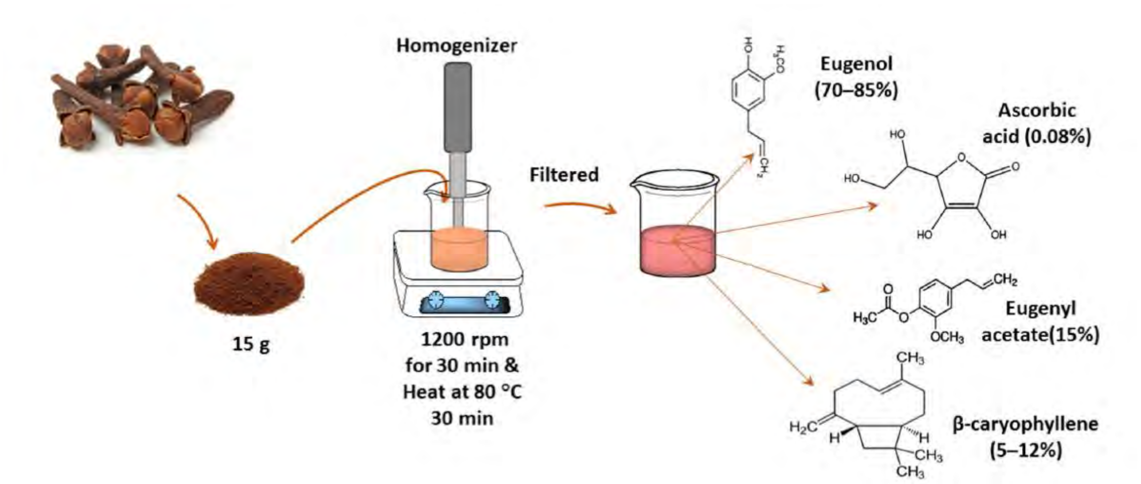

Figure 3-3: Steps of preparing cloves extract

Functionalization of GNP was achieved by the following process:

Added 5 g of pristine GNPs into a bicker with the produced clove extracts from the first stage. In order to get a homogenous black solution, the suspension was agitated for 15 minutes continuously at that time. 25ml of hydrogen peroxide was added to the solution drop by drop. The solution was then sonicated for 10 minutes. The solution was then heated in an autoclave for 6 hours at 80 ^{O}C. Then at 14000 rpm, the solution was centrifuged and washed with distilled water until the pH was neutralized. The supernatants were then dried in an oven at 60 ^{O}C. The dried CGNPs are extremely stable in aqueous medium. Then CGNP-water nanofluids were synthesized by dispersing in the polar liquid water. Calculated amount of CGNP was added in distilled water and sonicated for 10 minutes to disperse and obtain the nanofluids of 0.1, 0.075, 0.025 wt.% concentrations.

3.3 Mathematical formulation

3.3.1 Properties of nanofluids

After dispersing the nanoparticles in a host fluid, the thermophysical properties of the fluid was altered. The thermophysical properties of nanofluids were measured by many researchers in improved ways and they had explored various equations, and correlations to compare and evaluate the characteristics of nanofluids and attempted to find out the reasons caused the changes of the properties of the dispersed nanoparticles.

Researchers have obtained improved thermal properties of nanofluids in comparison to base fluids. Many experiments were conducted to compare the experimental results with the analytical solutions. One of those established models was presented by Crosser and Hamilton, who investigated the effects of the ratio of surface area of a sphere and the volume equal to that of the nanoparticles on the thermal conductivity of the nanofluids by the equation (3-1) (Kakaç & Pramuanjaroenkij, 2009).

$$K_{nf} = K_{bf}\left[\frac{K_p+(n-1)K_{bf}-(n-1)\emptyset_p\,(K_{bf}-K_p)}{K_p+(n-1)K_{bf}-\emptyset_p\,(K_{bf}-K_p)}\right] \tag{3-1}$$

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

which is the experimental shape factor in Eq. (3-1) and φ is the sphericity of the nanoparticles as mentioned above. Thermophysical characteristics of the nanofluid are essentially relies on the properties of the host fluid, particle size, volume concentration and pH value of the nanofluid.

By applying balance of the mass of the mixture of host fluid and the solid nanoparticles, the effective density (ρ_{nf}) of the nanofluid can be calculated by the following formula, (3-2):

$$\rho_{nf} = (1 - \emptyset_p)\rho_{bf} + \emptyset_p \, \rho_p \qquad (3\text{-}2)$$

Where; ρ_{bf} , ρ_p, $\emptyset_p$ are the density of the host fluid, the density of particles, and the volume fraction of the solid nanoparticles respectively.

(Xuan & Roetzel, 2000) improved a formula to obtain the specific heat of the suspended fluids, as stated below, equation (3-3).

$$C_{P,nf} = \frac{(1-\emptyset_p)\,\rho_{bf}\,C_{bf} + \emptyset_p\,\rho_p C_P}{\rho_{nf}} \qquad (3\text{-}3)$$

Viscosity is one of the most important properties of nanofluids and results of pressure drop, pumping power and heat transfer are relying on it. Sharma et al. (Sharma et al., 2012) tried to find a correlation for this property taking into account the particle diameter. volume concentration and temperature as shown in Eq. (3-4).

$$\mu_{nf} = \left[(1+\varphi_P)^{11.3}(1+\frac{T_{nf}}{70})^{-0.038}(1+\frac{d_P}{170})^{-0.061}\right]\mu_{bf} \qquad (3\text{-}4)$$

Table (3-1) shows the thermophysical properties of the tested materials. The correlation formulas above are used to calculate the most important thermophysical properties of the nanofluids. These properties are the density, specific heat, thermal conductivity and viscosity.

Table 3-1: Measured thermophysical properties at 30 ºC (Sadri et al., 2018).

Nanofluid	µ (Pa. s)	ρ(m3/kg)	Cp (J/kg. K)	k (W/m. K)	Pr
DW	8.29E-04	995.5	4142	0.611	5.62E+00
GNP0.025	0.000844	995.6	4123	0.636	5.47E+00
GNP0.075	0.000868	995.8	4096	0.681	5.22E+00
GNP 0.1	0.000885	995.9	4080	0.708	5.10E+00

3.3.2 Formulas of heat transfer and pressure drop

Calculating pressure drop between the inlet and outlet point of the test section when the fluid flows through the tube considered the most important characteristic, which could evaluate the power required by the pump.

Pressure drop in the tubes, are evaluated by the equations (3-5 to 3-8).

$$C_f = \frac{\tau_s}{\frac{\rho V^2}{2}} \tag{3-5}$$

Where, τ_s indicates the shear stress, C_f is the Fanning friction factor and average velocity is denoted by V. Friction coefficient can be obtained from the equation (3-6).

$$C_f = \frac{f}{4} \tag{3-6}$$

Where, f is the Darcy–Weisbach friction factor. Friction factor was correlated with the pressure drop in the ducts and this feature depends mainly in the flow regime, present investigation was performed in the turbulent flow regime The friction factor can be calculated in the laminar range by equation (3-7).

$$f = \frac{64}{Re} \tag{3-7}$$

In the turbulent regime theoretically the friction factor can be obtained from the empirical equations or from Moody chart where at first the surface roughness property could be obtained from the data tables. Then the pressure drop formula can correlate friction factor and pressure loss as stated in equation (3-8).

$$\Delta P = f\left(\frac{L}{D}\right)\frac{\rho V^2}{2} \tag{3-8}$$

In the case of testing different nanofluids and to keep the Reynolds number constant, the velocity needs to be changed, then the velocity for the new fluid at the same Reynolds number can be obtained from the Reynolds number equation (3-9).

$$V = \frac{\mathrm{Re}\,\mu}{\rho\, D} \qquad (3\text{-}9)$$

By substituting the velocity in Eq. (3-9) and into Eq. (3-8), the pressure drop per unit length can be calculated by the following equation, (3-10).

$$\frac{\Delta P}{L} = \frac{Re^2 f}{2D^3}\,\vartheta.\mu \qquad (3\text{-}10)$$

In the case of turbulent flow, friction factor can be determined by implementing Petukhov equation (3-11).

$$f = (0.79 ln Re - 1.64)^{-2} \qquad (3\text{-}11)$$

Regarding calculations of heat transfer and heat transfer coefficient, and Nusselt number in the ducts, many researchers were discussed about these. The correlations developed are relied on which type of flow where the experiment was conducted, type of fluid and properties of the fluid.

Gnielinski (Gnielinski, 2013) developed a Nusselt number correlation for fully developed flow in circular tube at various boundary conditions, equation (3-12).

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7\sqrt{\frac{f}{8}}\left(Pr^{2/3}-1\right)}\left[1+\left(\frac{D}{L}\right)^{2/3}\right]k_c \qquad (3\text{-}12)$$

Were; k_c consider a factor which can be obtained for the fluids as presented by Eq. (3-13).

$$k_c = \left(\frac{Pr}{Pr_s}\right)^{0.11} \qquad (3\text{-}13)$$

Here, Pr_s is referring to the Prandtl number at the surface temperature, whereas Pr can be calculated by the following Eq. (3-14).

$$Pr = \frac{\mu\, C_P}{K} \qquad (3\text{-}14)$$

Dittus and Boelter showed an experimental correlation to evaluate Nusselt number for fully developed flow through the tubes as presented by Eq. (3-15).

$$Nu = 0.023\ Re^{0.8} Pr^{n} \tag{3-15}$$

When the fluid is heated then $n = 0.4$ wherease $n = 0.3$ if the fluid is cooled.

From the equations (3-12) and (3-15), it can be noticed that the Reynolds and Prandtl numbers are the only two parameters which could affect the value of Nusselt number in the case of turbulent forced convection heat transfer. So, the effect will come from Prandtl number in the case of keeping Reynolds number constant.

Xuan and Roetzel (Xuan & Roetzel, 2000) investigated the Nusselt number and examined the parameters which could affect Nu. Then they suggested a new general function containing the influence factors of Nusselt numbers as presented by equation (3-16).

$$Nu_{nf} = f\left[Re\,, \mathrm{Pr}, \frac{K_P}{K_{bf}}\ \frac{(\rho\ C_P)_P}{(\rho\ C_P)_{bf}}, \emptyset, flow\ geometry, particle\ geometry\right] \tag{3-16}$$

From the Newton's low of cooling, the average value of heat transfer coefficient for convection can be calculated by equation (3-17).

$$h = \frac{Nu\,K}{D} = \frac{q}{(T_s - T_b)} \tag{3-17}$$

Where, q refers to the total heat flux, T_s denotes the temperature of the inner surface, and T_b the bulk temperature of the flowing fluid. The described formulas can be used to evaluate the local Nusselt number at a specific location in the test section based on the temperature of the fluid.

Thermo-physical properties of the fluid after adding nanoparticles to the base fluid are changed which should be considered. So, the Eq. (3-18) can be used to calculate the velocity of nanofluid at constant Reynolds number.

$$V_{nf} = \frac{\rho_{bf}}{\rho_{nf}} \frac{\mu_{nf}}{\mu_{bf}} V_{bf} \tag{3-18}$$

Where, from the Eq. (3-9), the velocity of the base fluid could be calculated.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Test rig validation

The experimental test rig with both the circular and square test sections was firstly validated by comparing the values of Nusselt number obtained experimentally with those obtained by the empirical correlations of Dittus-Boelter and Gnielinski (3-12), (3-15) respectively. Figure 4-1 shows a good agreement between the experimental Nusselt number as the functions of flow velocity for the circular test section and those obtained from empirical correlations of Gnielinski and Dittus with an average error of 9.05% and 7.98% respectively.

Figure 4-2 illustrates that for the square test section, the difference between the average Nusselt number calculated by the empirical correlations and the average Nusselt number obtained experimentally within an acceptable range as the average errors are 6.9% and 7.5% for the Dittus and Gnielinski data respectively.

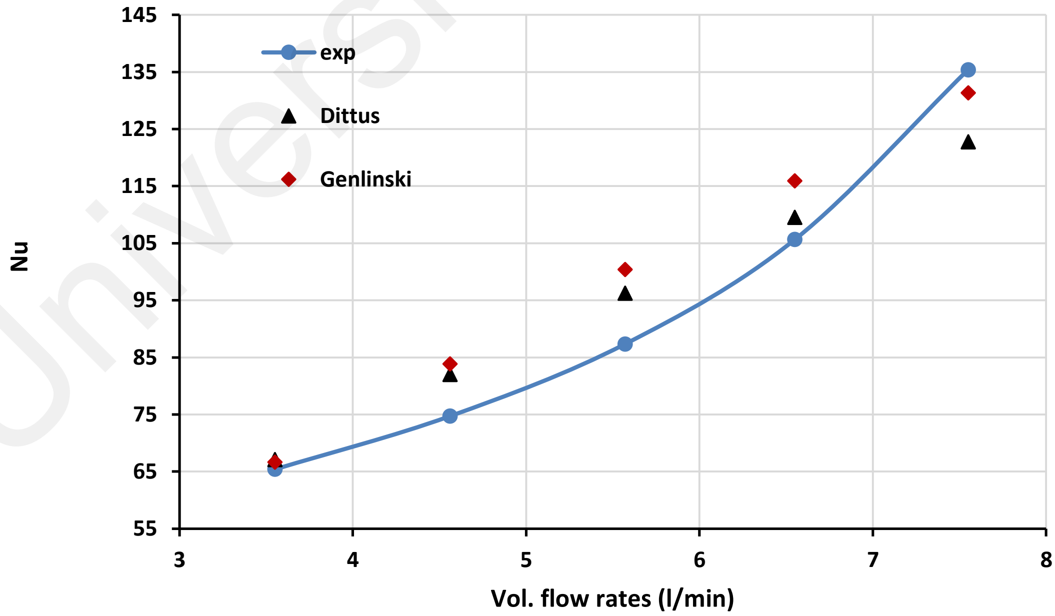

Figure 4-1 : profile of Nusselt Number for circular test section, experimental and standard correlations

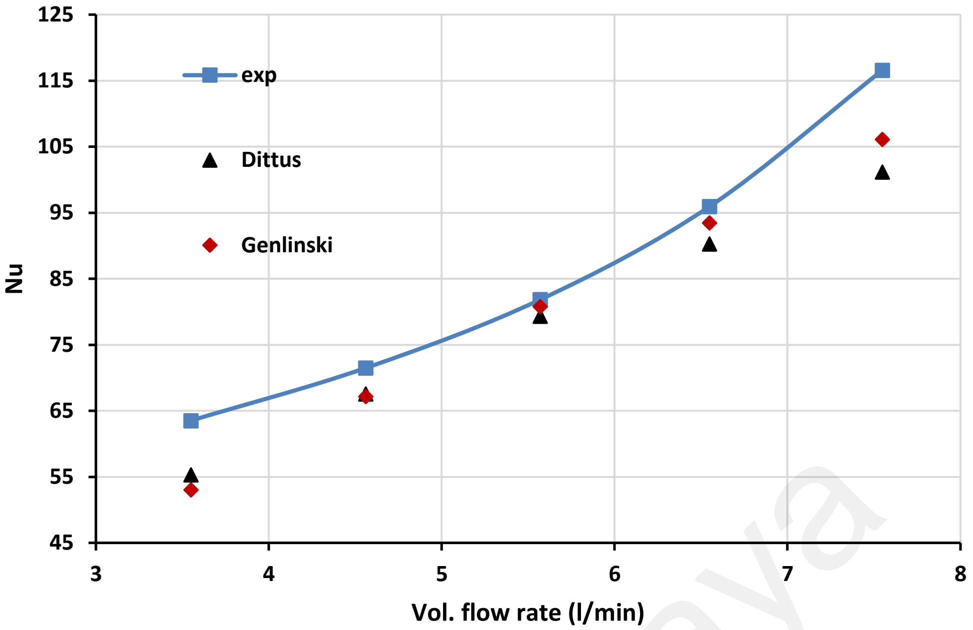

Figure 4-2 : profile of Nusselt number for square test section, experimental and standard correlations

The average errors for both the circular and square test section are less than 10% which indicate that the test rig is efficient and can be utilized to evaluate the convection heat transfer coefficients.

Another set of data for evaluation of the reliability and accuracy of the experimental system is to compare the pressure drop measured experimentally and those obtained by the empirical equations such the Blasius' equation for both the circular and square test sections at the same range of volume flow rate.

Figure 4-3 shows good agreement between the measured pressure drop per unit length of the tube with those calculated by Blasius equation for both the circular and square test sections with average error of 9.4%, 8.8% respectively. These results indicate the reliability of present investigations of the pressure drop measurements.

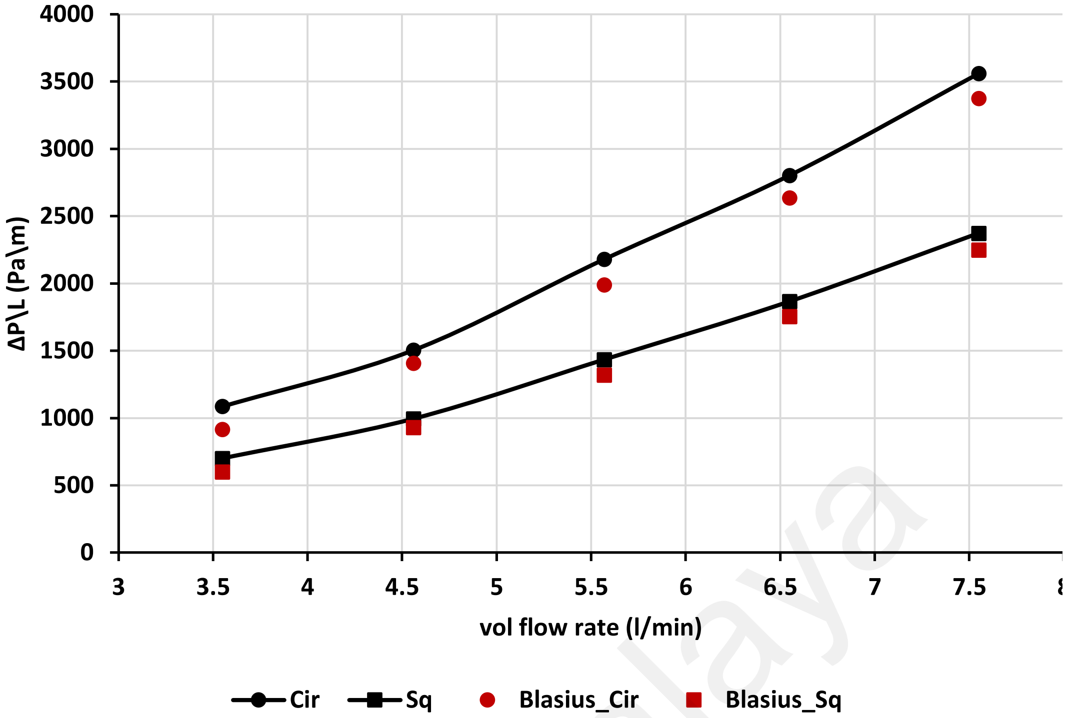

Figure 4-3: Profile of measured pressure drop for the circular and square test section in comparison with the calculated pressure drop using Blasius equation.

4.2 Heat Transfer of Nanofluids

This experiment was conducted for distilled water and GNP nanofluid with three different concentrations of 0.025, 0.075 and 0.1 wt. % of nanoparticles in turbulent flow regime.

For the evaluation of heat transfer performance, the temperature, flow rate, power supply data in the fully developed turbulent flow regime were reduced to calculate heat transfer coefficient and Nusselt number. In these cases, the parameters were calculated by considering average value.

Figure 4-4 and Figure 4-5 show that with the increase of volume flow rate, the heat transfer coefficient is increased. Graphically it could be seen a noticeable increase in the value of heat transfer coefficient by the growing concentrations of nanoparticles for both the test sections, the circular and square. This can be attributed to the Newtonian motion of nanoparticles where the advection is increased which enhances the heat transfer coefficient. The average ratios of enhancement in heat transfer coefficient are 2.05%, 6.15%, and 7.29% for 0.025, 0.075 and 0.1 wt. % respectively for both the test sections in comparison to the base fluid.

Figure 4-6 shows the comparison of the convection heat transfer coefficient for the both test sections, which indicates that the circular one has a better performance than the square one due to the higher velocity inside the circular test section compared to the square one for the same flow rate.

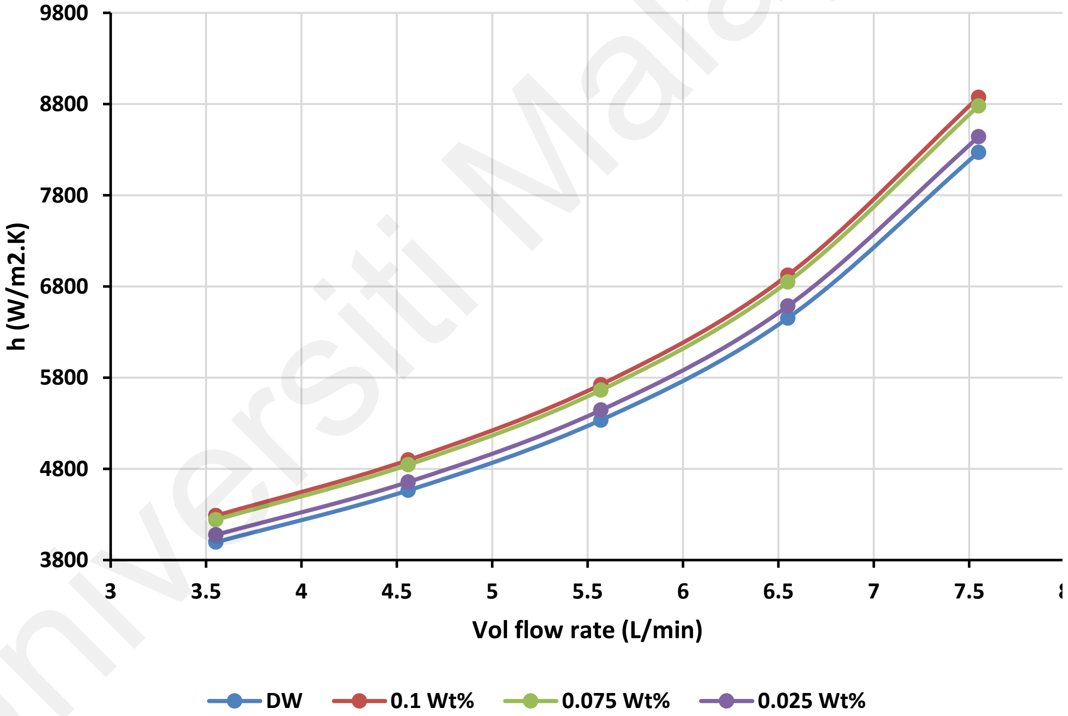

Figure 4-4: Average values of heat transfer coefficient at various volume flow rate for circular test section.

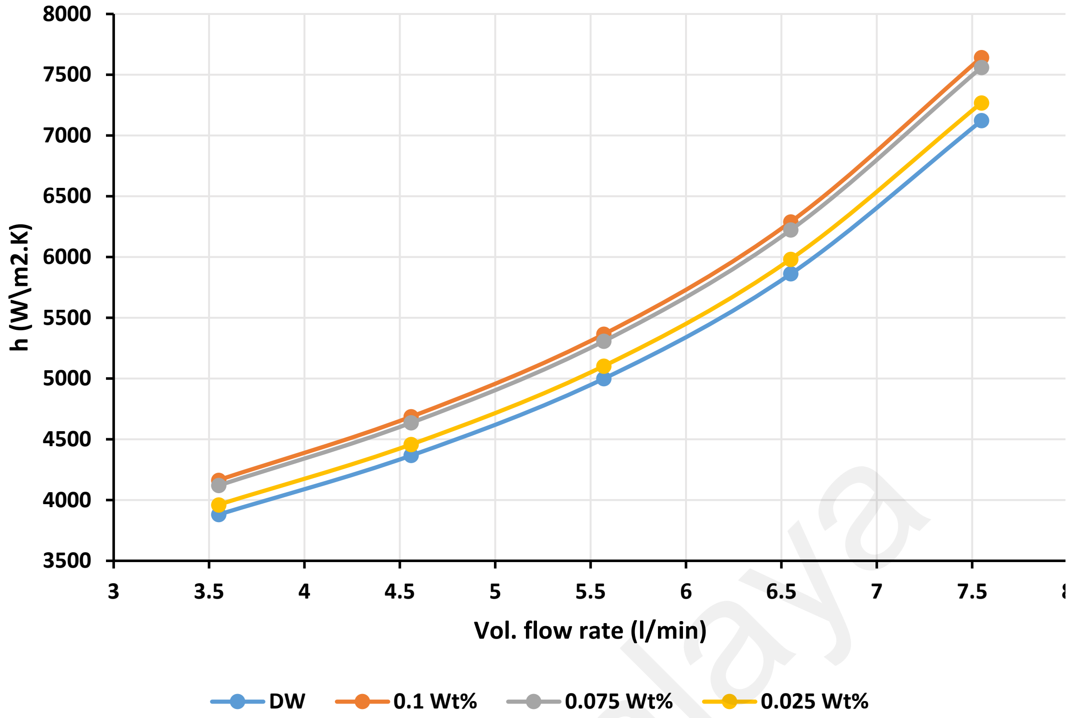

Figure 4-5: Average values of heat transfer coefficient at various volume flow rate for square test section.

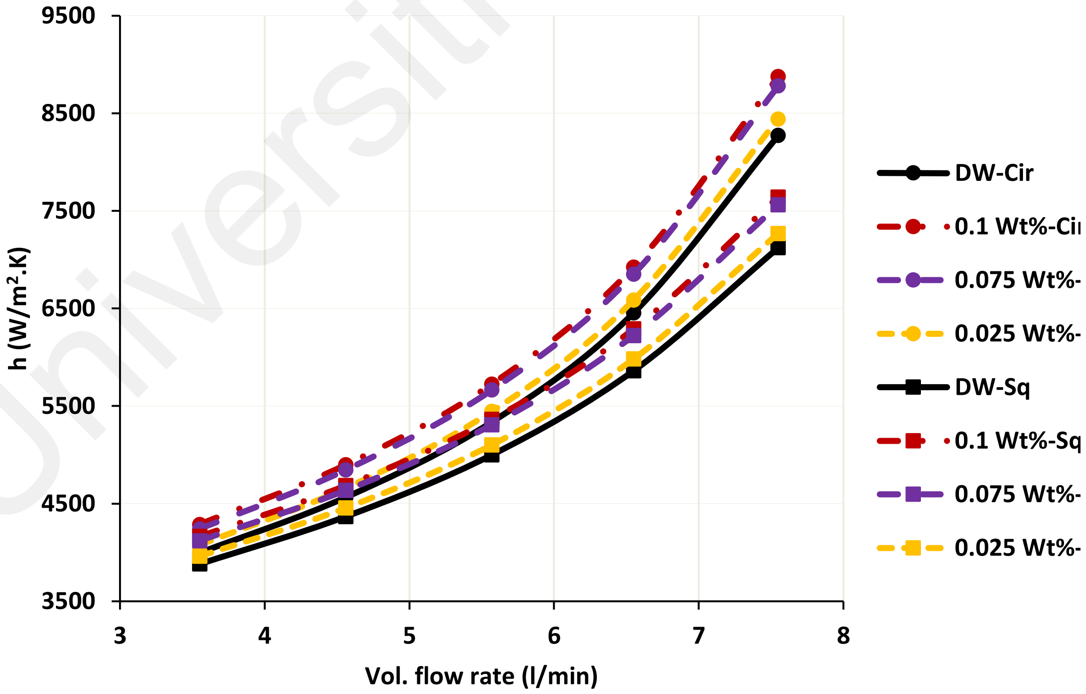

Figure 4-6: Profiles of convection heat transfer coefficient for circular and square pipes

Another important point to be explained is that, the increment rate of heat transfer in the square test section is less than the circular test section, although it should be higher in the square due to the secondary flow and swirls formation at the corners which in turn should enhance the rate of heat transfer, but the opposite happened because the cross section of square test section is higher than the circular test section, which would reduce the velocity for the same flow rate and hence the Reynolds number which leads to reduction of the Nusselt number and heat transfer coefficient.

Regarding Nusselt number data, as the Nusselt number is primarily dependent on two types of non-dimensional numbers which are Reynolds and Prandtl numbers, the experiment shows that by increasing the concentrations of nanoparticles, a noticeable reduction in the values of Prandtl number is observed, and the Reynolds number is decreased as well due to the increasing of kinematic viscosity at the same flow velocity as shown by the Equation (3-9).

Decreasing Prandtl number (the ratio of momentum diffusivity to thermal diffusivity) is another reason to decline Nusselt number, despite the increase of dynamic viscosity, which is proportional with Prandtl number, Prandtl number is declined due to the increase in the thermal conductivity by raising the concentration of nanoparticles, which is inversely proportional with Prandtl number, and it has higher average growth than dynamic viscosity which leads to decreasing Prandtl number. Equation (3-14) presents inversely proportionality of Prandtl Number with the thermal conductivity.

As a result, the Nusselt number is decreased because of the reduction in the values of Reynolds and Prandtl number. Figure 4-7 and Figure 4-8 clearly present that reduction in Nusselt number for both the test sections.

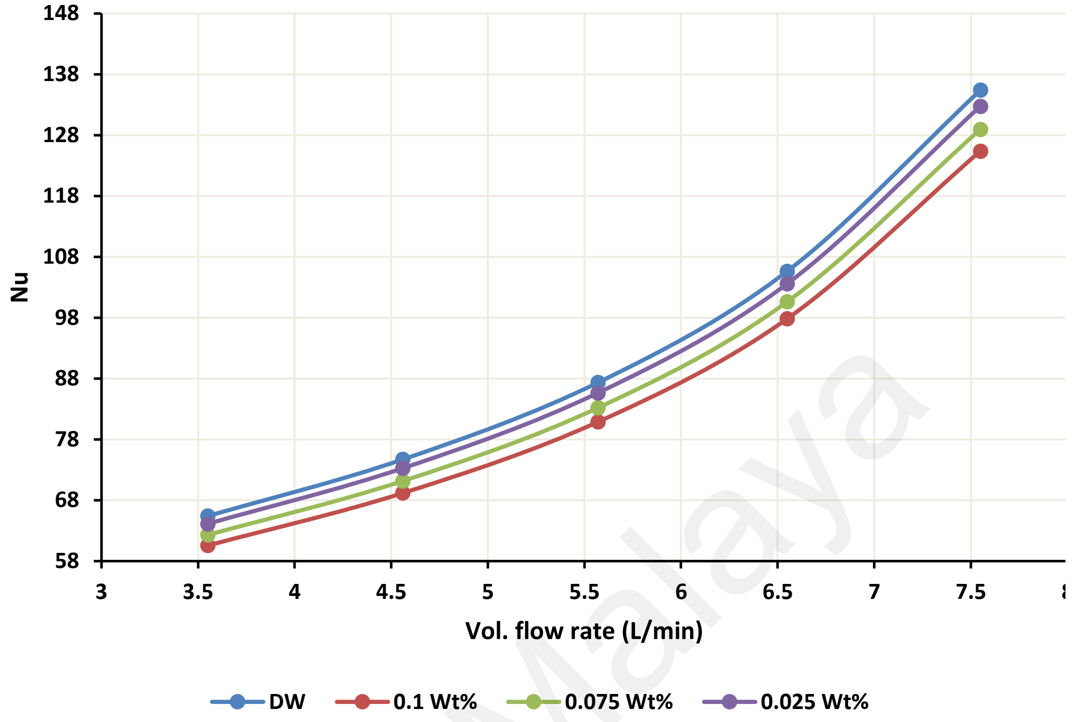

Figure 4-7: Variation of Nusselt number with the volume flow rate for circular test section.

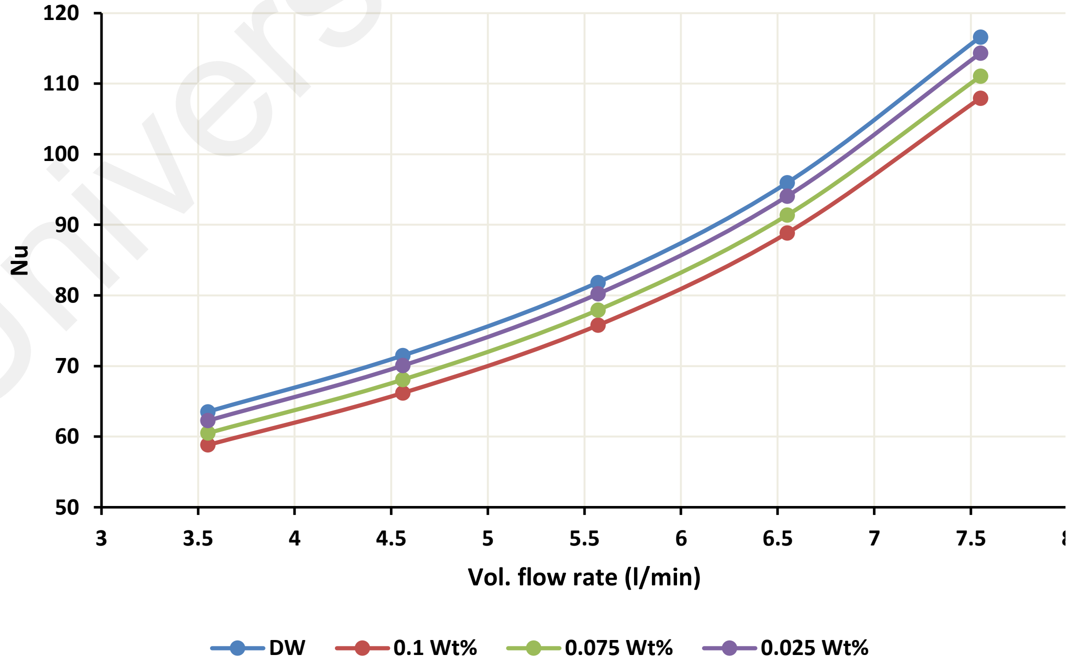

Figure 4-8**: Variation of Nusselt number with the volume** flow rate for square test section.

4.3 Pressure Drop of Nanofluid

Researchers have taken the pressure drop across closed conduit flow under intensive investigations, which is the most important parameter to evaluate the requirements of pumping power, following the importance of energy consumption in heat transfer applications.

The pressure drop mainly depends on friction factor which also depends on flow regime and roughness of the tube. In the present case, the flow is turbulent hence the friction factor is calculated from equation (3-11), then the pressure drop per unit length is determined by utilizing equation (3-10).

Figure 4-9 and Figure 4-10 predict that the increase in the concentration of nanoparticles is accompanied by the growth of the pressure drop. This observation confirms the significance of GNP concentration on the viscosity of nanofluid. The average ratio of increasing the pressure drop with increasing the GNP concentration are 2%, 5% and 7% for 0.025, 0.075 and 0.1 wt. % respectively for the circular test section. Similar trend has observed in case of the square test section.

Referring to Figure 4-11, the pressure drop along the square test section is lower than the circular one. For example; the pressure drop for the square test section is lower than that of the circular one by 35% at the volume flow rate of 3.5 (L/min) and the GNP concentration of 0.1 wt. %. This observation can be attributed to the decrease of Reynolds number for the square test section compared to those of the circular tube due to the difference in cross sectional area between the both test sections..

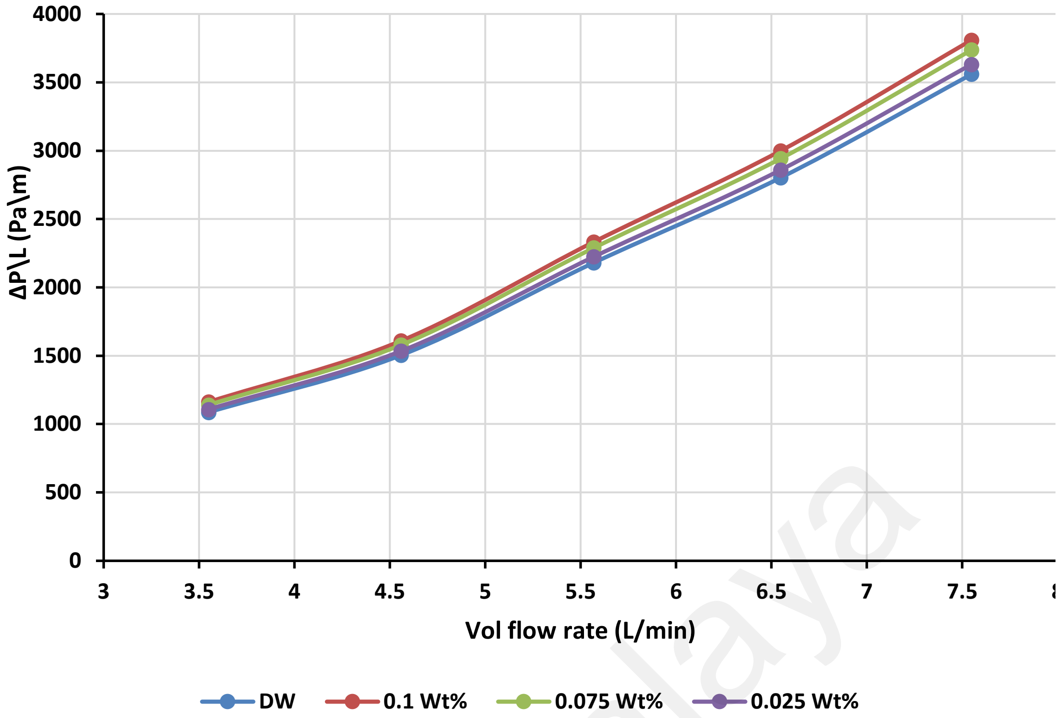

Figure 4-9**: Pressure drop profile per unit length for various volumetric mass flow rate through circular test section.**

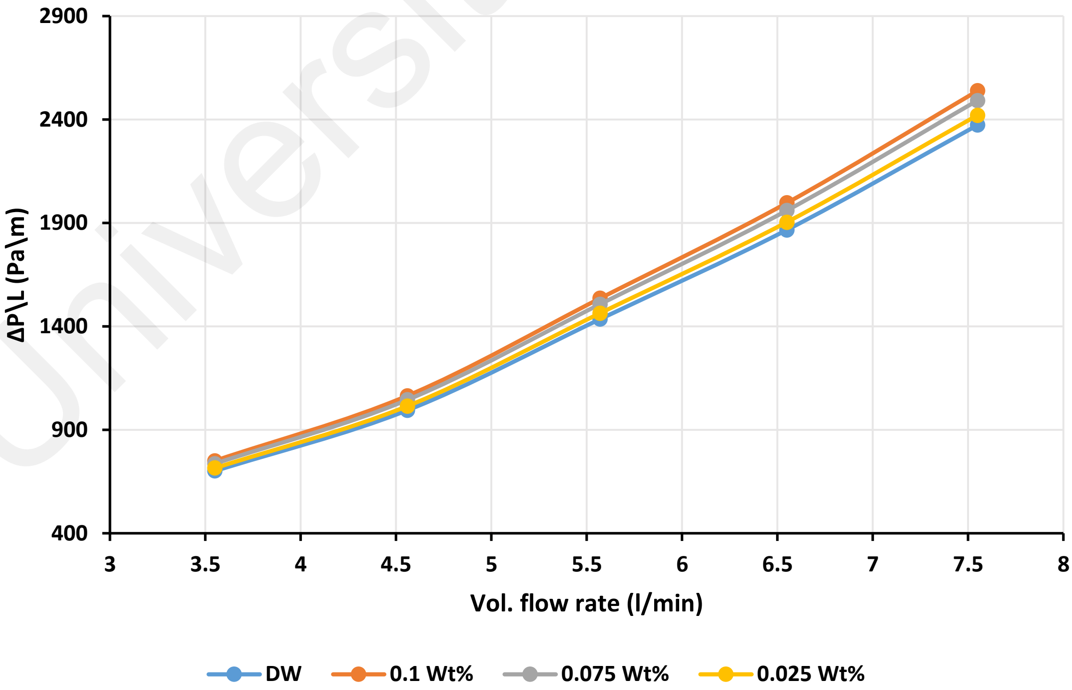

Figure 4-10: Pressure drop profile per unit length for various volume mass flow rate through square test section.

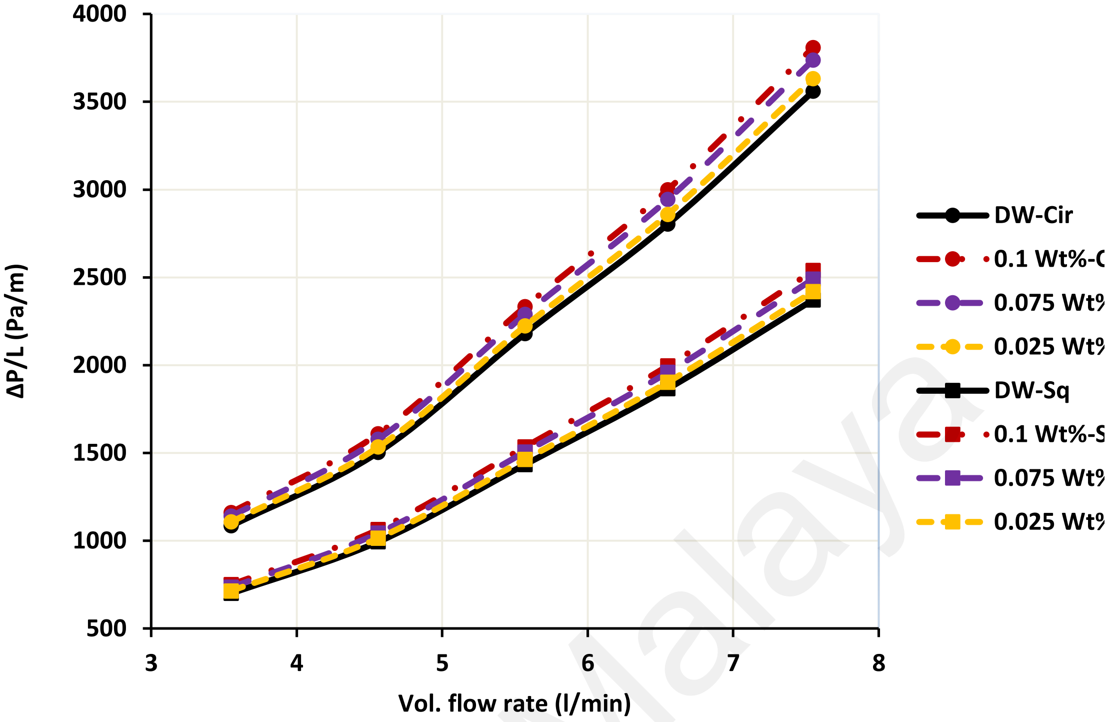

Figure 4-11: Pressure drop profile per unit length for various volume flow rate through square and circular test sections.

CHAPTER 5:
CHAPTER 5: CONCLUSION

In this study, GNPs nanofluids were prepared by bio-based ecofriendly method using extracts of clove buds, hydrogen peroxide and ascorbic acid. GNPs nanofluids were synthesized by dispersing the clove based functionalized GNPs (CGNP) in distilled water at three different particle concentrations: 0.025, 0.075 and 0.1 wt. %. The CGNPs-water Nano-coolants were then tested in a horizontal tube heat exchanger with different cross-sections, such as circular and square. Heat transfer and frictional pressure drop of the flowing nanofluids were then evaluated and compared with those obtained for water alone. From the experimental observation the following conclusions could be drawn:

- Use of GNP nanofluid as a coolant could enhance the heat transfer coefficient consequently in different configurations of flow passages such as circular and square.
- Heat transfer coefficient enhances with the increase of concentration of GNP in the nanofluid.
- Nusselt number declines by increasing the concentrations of GNP and this is because of the enhancement of thermal conductivity. Prandtl number also reduces due to the enhanced effect of the dynamic viscosity has compensated by the enhanced thermal conductivity of the CGNPs nanofluid.
- Reynolds number decreases by increasing the weight of nanoparticles concentrations; because of that the rate of increase the dynamic viscosity is higher than the rate of the increment of the density.

- There is a considerable growth in the pressure drop with increasing the concentration of GNP nanofluid due to enhancement of density and viscosity of the CGNPs nanofluids.
- Heat transfer in circular cross sectional tube is higher than the square cross sectional tube due to the higher cross sectional area in the square test section for a certain volumetric mass flow rate which lead to decreasing the velocity and Reynolds number, hence the rate of heat transfer reduced in circular cross sectional tube.

RECOMMENDATION FOR FUTURE WORK

The present work highlighted several new insights towards pursuing an enhancement in convective heat transfer and evaluation of the pressure drops for different shapes of the heat exchanger tubes. As the future works, the experimental investigation could be extended by considering constant Reynolds number, study the thermophysical properties in more detail and perform simulation by ANSYS for comparison with the experimental results.

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