HEAT TRANSFER AND PRESSURE LOSS ANALYSIS OF A NOVEL COLLOIDAL SUSPENSION IN TURBULENT FLOW CONDUITS.

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FACULTY OF ENGINEERING
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ORIGINAL LITERARY WORK DECLARATION

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Title of Research Report: Numerical Analysis and Experimental of Acid Treated GNP

Heat Transfer Growth in Circular and Square Tube Comparison

Field of Study: Heat Transfer

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ABSTRACT

The common working fluid in a heat exchanger can be identified as oil, water and ethylene glycerol. These fluids exhibit advantages in terms of ease of handling, recycling and disposing. Besides that, it has a low market price. Despite the advantages listed, these fluids are exhibits low thermal properties. Moreover, characteristic such as fouling and low total surface energy makes the overall heat transfer performance low resulting in the design of heat exchanger to be larger so that desired energy can be harnessed for the operations in the time duration.

Nanofluid has been identified as a substitute to water and oil as a working fluid in the heat exchanger. There were attempts done to incorporate it into the industry. Graphene based nanofluid is found to be having significant thermal conductivity increase compared to other nanofluid. Thus, this study focuses on the acid treated GNP that has a better dispersion to flow in circular and square tube.

The heat transfer ability of both the scenario is measured by the average heat transfer coefficient and Nusselt Number.

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

ABSTRAK

Cecair kerja biasa dalam penukar haba boleh dikenal pasti sebagai minyak, air dan etilena gliserol. Cecair ini mempamerkan kelebihan dari segi kemudahan pengendalian, kitar semula dan pelupusan. Selain itu, ia mempunyai harga pasaran yang rendah. Walaupun kelebihan yang disenaraikan, cecair ini mempamerkan sifat termal yang rendah. Selain itu, ciri-ciri seperti fouling dan jumlah tenaga permukaan yang rendah menjadikan keseluruhan prestasi pemindahan haba rendah menyebabkan reka bentuk penukar haba menjadi lebih besar supaya tenaga yang diinginkan dapat dimanfaatkan untuk operasi dalam tempoh masa.

Nanofluid telah dikenalpasti sebagai pengganti kepada air dan minyak sebagai cecair kerja di penukar haba. Terdapat percubaan untuk memasukkannya ke dalam industri. Nanofluid berasaskan Graphene didapati mempunyai peningkatan kekonduksian haba yang ketara berbanding dengan nanofluid yang lain. Oleh itu, kajian ini memberi tumpuan kepada GNP yang dirawat asid yang mempunyai penyebaran yang lebih baik untuk mengalir dalam tiub pekeliling dan persegi.

Keupayaan pemindahan haba kedua-dua senario diukur oleh pekali pemindahan haba purata dan Nusselt Number.

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

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LIST OF SYMBOLS AND ABBREVIATIONS

GNP	:	Graphene Nanoplatelet
HNO_3	:	Nitric Acid
H_2SO_4	:	Sulphuric Acid
DPT	:	Differential Pressure Transmitter

CHAPTER 1: INTRODUCTION

Heat Transfer enhancement is an interesting topic that has been widely researched throughout the globe. The possibility of using nanofluid and nanoparticles to enhance the heat transfer properties has driven the interest of many researchers (Ha, Jeon, Choi, & Kim, 2019; Kakavandi & Akbari, 2018; Ueki, Fujita, Kawai, & Shibahara, 2018). Application of heat transfer in engineering depend upon a few factors such as size and weight. The increase in efficiency can reduce the initial setup cost.

1.1 Working Fluid

The common working fluid in a heat exchanger can be identified as oil, water and ethylene glycerol. These fluids exhibit advantages in terms of ease of handling, recycling and disposing. Besides that, it has a low market price. Despite the advantages listed, these fluids are exhibits low thermal properties. Moreover, characteristic such as fouling and low total surface energy makes the overall heat transfer performance low resulting in the design of heat exchanger to be larger so that desired energy can be harnessed for the operations in the time duration (Zubir et al., 2016). Therefore, efforts have been taken to identify fluid that can increase the heat transfer performance (Åkerstedt, Högberg, & Lundström, 2013).

Notable technique used to improvise the fluid properties is by addition of particles in order to form two-phase fluid slurries. Example of substance mixed with the base fluid are Hitherto, micron particles such as metal, non-metal and polymeric (A. Amiri et al., 2015; Kazi, Duffy, & Chen, 1999; X. Wang et al., 2007).

In this study, Graphite Nanoparticles (GNP) are used as working fluid to improve the efficiency of the heat exchanger. The better thermal conductivity exhibited by this solution helps the increase of heat transfer rate.

1.2 Heat Exchanger

In order to transfer thermal energy from a medium to another, heat exchanger is used. Classification of heat exchanger is defined by the arrangement of flow and its construction. Focus of the current studies lies upon the plate heat exchanger which is used extensively in various applications such as refrigeration, air condition, power generation and recovery industries (Huminic & Huminic, 2012).

Figure 1-1: Working Principal of Heat Exchanger

Increasing price of energy has driven industries to enable energy saving measures in their facilities. The efforts focused on

1. Enhancement in heat transfer of heat exchanger
2. Reduction of heat transfer time
3. Improvisation of efficiency and energy utilization.

The heat exchanger's efficiency can be improved by 2 parameters that are being studied here. Firstly, the shape of the heat exchanger is studied and how it can improve its performance followed by the working fluid in the heat exchanger is studied, in which the thermal properties of working fluid is tested as manipulated variable. These methods are known as the passive method to improve the heat transfer performance(Nakhchi & Esfahani, 2019).

1.3 Turbulent Flow

Turbulent flow is random and chaotic movement of particles in a fluid. It doesn't flow in parallel as opposed to the laminar flow. Turbulent flow occurs when the Reynold Number is higher than 4000 in a circular pipe. High Reynold number means high velocity which aids in the heat transfer process.

Table 1-1: Type of Flow and Reynolds Number

Problem Configuration	Laminar regime	Transition regime	Turbulent Regime
Flow around a foil parallel to the main flow	$Re < 5 \cdot 10^5$	$5 \cdot 10^5 < Re < 10^7$	$Re > 10^7$
Flow around a cylinder whose axis is perpendicular to the main flow	$Re < 2 \cdot 10^5$	$Re \cong 2 \cdot 10^5$	$Re > 2 \cdot 10^5$
Flow around a sphere	$Re < 2 \cdot 10^5$	$Re \cong 2 \cdot 10^5$	$Re > 2 \cdot 10^5$
Flow inside a circular-section pipe	$Re < 2300$	$2300 < Re < 4000$	$Re > 4000$

1.4 Problem Statement

The need for a better working fluid in heat exchanger has increased now more than ever. The current working fluid used such as oil and water exhibit very poor thermal properties which requires a bigger heat exchanger design in order to meet the energy demand.

This research is focused on the synthesis of a novel colloidal nanofluid which is the functionalized Graphene Nanoplatelet (GNP) and studying the thermal properties of the nanofluid to be compared with the heat transfer ability in both circular and square tubes.

A working fluid with higher thermal conductivity will enable a much more efficient heat transfer process.

1.5 Objectives

This study is conducted to analyze the following objectives:

1. To investigate the conduit geometry effect in the heat transfer in experimental and numerical analysis.
2. To experiment the effect of acid treated GNP's concentration to the heat transfer profile.
3. To study the thermophysical properties of acid treated GNP.
4. To conduct simulation and investigate the effect of acid treated GNP's concentration to the heat transfer.

CHAPTER 2: LITERATURE REVIEW

2.1 Nanofluid

Nanofluid can be defined as a fluid which particles in the size of nanometers called nanoparticles are present. These particles are uniformly and stably suspended in the fluid which termed as colloidal suspension. Nanofluid is to be considered as a very prospectus heat transfer application of future. Various nanomaterial have been tested in the past decade for the purpose as heat transfer application with the factors such as volume fraction, dimension, thermal properties and shape which has stark effect on heat transfer coefficient and thermal conductivity by suspension in a base fluid (Bhanvase, Barai, Sonawane, Kumar, & Sonawane, 2018).

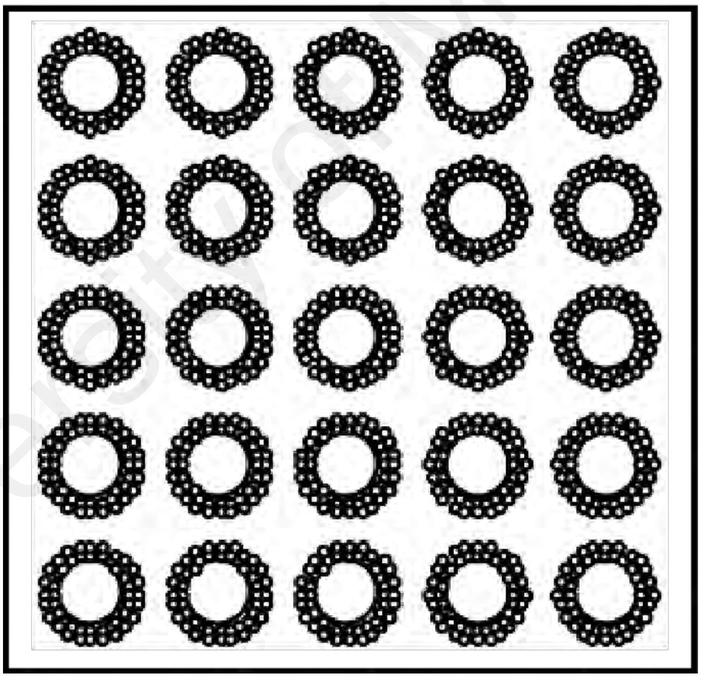


Figure 2-1: The structure of a nanofluid.

A new category of fluid was found in 1995 by Choi that was called nanofluid in which there were suspension of nanoparticles in it. They study conducted showed that presence of nanoparticles in the base fluid enhances the thermal conductivity of the fluid. This could be applied in various field across the industry. (Aly, 2014; Choi & Eastman, 1995)

Tin Oxide (TiO_2), Aluminium Oxide (Al_2O_3), Copper Oxide (CuO) and Zinc Oxide (ZnO) were examined in the past to be used in nanofluid (Khoshvaght-Aliabadi, 2014). Later, materials that are carbon based such as CNT, GO (Taha-Tijerina, M. Sudeep, Ajayan, Narayanan, & Anantharamaniyer, 2014), and Graphene (Ahmad Amiri et al., 2015) were experimentally analysed. Nanofluid is seen as an alternative working fluid because its enhanced thermal properties.

Carbon based nanomaterials have been subject of experiment in recent years to improve the efficiency of the working fluid. Graphene Platelet were reportedly used to produce nanofluid in the literature of Ding et all (Ding, Alias, Wen, & Williams, 2006). The results showed that the enhancement of thermal conductivity when compared with other nanofluids. Properties of carbon-based material are high thermal conductivity, mechanical properties and electrical conductivity.

2.2 Nanofluid Preparation

The most important step of this study is the synthesis of nanofluid. This process involves two processes which is the single step method and the two-step method. The single step method involves producing the nanofluid and nanoparticle directly from physical vapour deposition method. This process has a limitation where only it is only applicable to low vapour pressure fluids (Y. Li, Zhou, Tung, Schneider, & Xi, 2009).

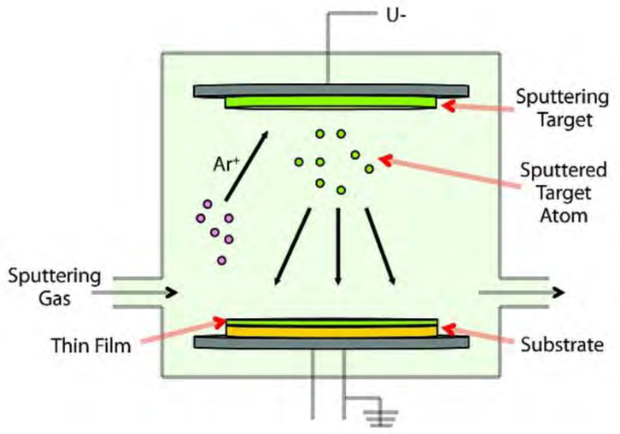


Figure 2-2: Physical Vapour Deposition Method.

Meanwhile, the two-step method involves dispersion of nanoparticles in base fluid. Dry nanoparticles are produced from methods such as mechanical alloying, inert gas condensation, and chemical vapour depositions. After dry nanoparticles are produced, it is then dispersed in a liquid. Agglomeration is an occurrence where particles bind together to form lumps. This is an issue for this method as it decreases thermal conductivity. Sedimentation in channel and also clogging causes the thermal properties to decline.

Nevertheless, there are methods to ease the agglomeration and improve the dispersion. Addition of surfactant which increases the charge of the particle followed by functionalization of the nanoparticles. Nano powders are being synthesised in large quantity in the industry. This could be a cost saving measure taking advantage of the two-step method (Hong, Hong, & Yang, 2006).

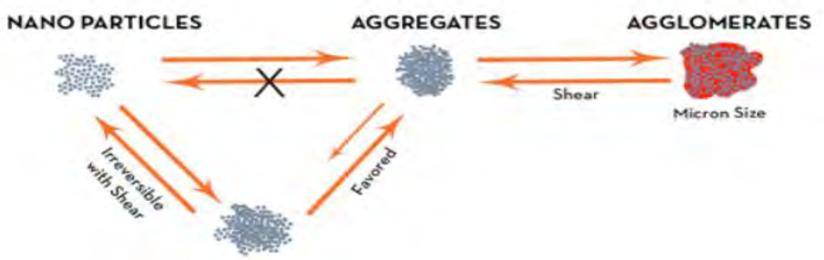


Figure 2-3: Agglomeration process

2.3 Stability of Nanofluid

The suspensions stability is the key factor in nanofluid applications. Agglomeration occurs in nanofluid due to strong van der Waals forces between the nanoparticles. The homogenous suspension has adverse effect to the thermal and heat transfer conductivity of nanofluids. There was a study conducted to test that aggregation and clustering are factors contributing to the enhancement of thermal conductivity establishing a link between both thermal conductivity and stability of fluid (Evans et al., 2008).

Stability of nanofluid can be enhanced by methods (Ghadimi, Rahman, & Metselaar, 2011) such as:

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

Figure 2-4: Probe Sonicator to carry out ultrasonic vibration

2.3.1 Surface Chemical Treatment

The charge and electro kinetic properties have an effect to the aqueous nanofluid's stability. Enhancement of surface charge density and stronger repulsive force can significantly stabilize a well homogenous dispersed suspension (X.-j. Wang, Zhu, & yang, 2009). Acid treatment can stabilise the suspension as the surface nature will be changed from hydrophobic to hydrophilic due to the presence hydroxy functional group (Xie, Lee, Youn, & Choi, 2003).

This can be explained through the Isoelectric Point (IEP) theory. The further the pH of nanofluid from the IEP point, the higher the surface charge rise. This is due to increased chemical interaction between phenyl sulfonic and hydroxyl group which results in a stable colloidal particle with better thermal conductivity (Yousefi, Shojaeizadeh, Veysi, & Zinadini, 2012).

2.3.2 Ultrasonic Vibration

This method is also done to obtain stable homogenous nanofluid. As the surface chemical method, this method also aims to break the surface properties of the particles and overcome aggregation in order to achieve a stable nanofluid. The particles were broken down using Probe Sonicator to avoid agglomeration (X. F. Li et al., 2008).

2.3.3 Addition of Surfactant

This method is used to enhance dispersion and stability. A change in the hydrophobic surface feature to hydrophilic would occur with the addition of surfactant. There should always be care to add the appropriate amount of surfactant to the mixture as inadequate amount will result failure to overcome the electrostatic repulsion (Jiang, Gao, & Sun, 2003).

Besides that, there are also some setback for this method:

1. The increment in viscosity value
2. Can't be used effectively for application of fluid with temperature more than 60 ^{0}C. As the bond between surfactant and nanoparticles will decrease (Assael, Metaxa, Arvanitidis, Christofilos, & Lioutas, 2005).

2.4 Nanofluid thermophysical properties

One of the investigations we made is to investigate the thermophysical properties of nanofluid synthesized. Numerous method and equipment were used to conduct this study. Parameters that were measured:

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

2.4.1 Thermal Conductivity

Researchers had a breakthrough where addition of a small number of nanoparticles could result in an increased thermal conductivity of a base fluid. Maxwell and Hamilton theories along with aggregation of particles and Brownian motion were introduced to explain this. There are 4 methods to measure the thermal conductivity of nanofluid.

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

(Eastman, S. Choi, Li, J. Thompson, & Lee, 1996) have done research to add copper oxide and alumina and found out that the thermal conductivity can be increased by 60%

in comparison to its base fluid. Nevertheless, the largest rise in the thermal conductivity is observed when carbon is used as nanoparticle in the base fluid as observed by (U. S. Choi, Zhang, Yu, E. Lockwood, & Grulke, 2001). A single wall carbon nanotubes showed an increase of 125%.

2.5 Numerical Analysis for Nanofluid

ANSYS software used to run simulation for heat transfer problem. This software runs of the FLUENT code which applies finite volume method. Studied were conducted to run simulation for backward step flows in ANSYS (Oon, Togun, Kazi, Badarudin, & Sadeghinezhad, 2013). Besides that, laminar flow using nanofluid in a tube were studied also (Al-aswadi, Mohammed, Shuaib, & Campo, 2010). Annular passage simulation with nanofluid was also done by (Oon et al., 2013). Focus on this study will be to run ANSYS simulation for circular and square tubes with thermal properties of GNP nanofluid.

CHAPTER 3: METHODOLOGY

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

3.1 Nanofluid Preparation

As previously discussed in literature, there are 2 ways a nanofluid can be synthesized which is the single step and two step method. In this study, the two-step method was used to prepare acid treated Graphene Nanoplatelets. GNP in natural state is hydrophobic. This characteristic makes it non dispersible in polar solutions. In order for dispersion to occur, functionalization through acid treatment has to be done. This acid treatment was carried out by dispersing GNP in HNO_3 and H_2SO_4 in a ratio of 1:3. The process last a duration of 3 hours under bath ultrasonic.

Once the process is done, the GNP nanopowder will be formed. This was washed a few times with distilled water and placed in oven at a temperature of 70 ^{0}C for more than 24 hours. Now this sample is used to prepare GNP nanofluid with various concentration. A calculated amount of nanopowder was mixed with water and dispersed using the probe sonicator for a duration of 1 hour. Once the ultra-sonification process is done, the solution was left for 24 hours to be examined for sedimentation. After 24 hours, the nanofluid was found to be stable with no sedimentation.

3.2 Experimental Set Up

The experimental Set Up as shown in the figure below was used at the Computational Fluid Dynamics Lab of University Malaya. A circular tube with 1cm diameter and a square tube with 1cm sides were insulated. Equipment and instruments such as data logger, chiller, pump and heater were used to run the experimental set up.

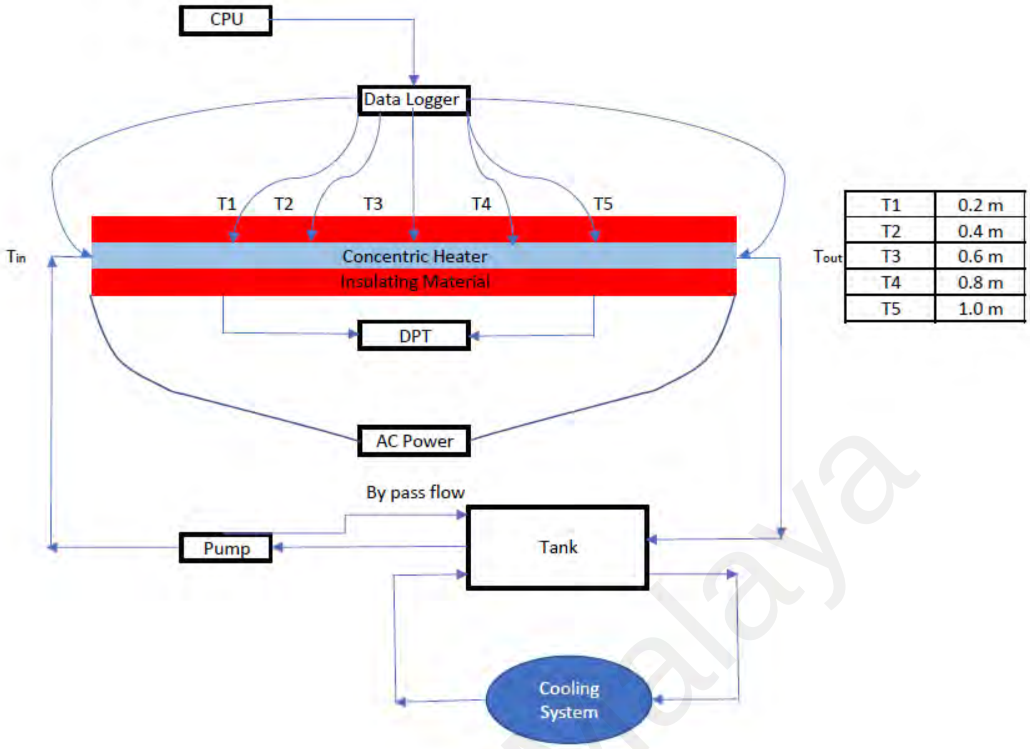


Figure 3-1: Schematic drawing of experimental set up

Figure 3-2: Actual set up in the lab

3.3 Experimental Procedure

The rig was cleaned to ensure there are no sedimentation deposited in it. The reservoir where the water and GNP are stored was filled. The chiller is connected to reservoir to ensure the heat is removed before the nanofluid or water been pumped into the system again. The pump is used to manipulate the flowrate into the tubes. A total of 6 flowrates were used in this study. Those are 3.5 L/m, 4.5 L/m, 5.5 L/m, 6.5 L/m, 7.5 L/m and 8.5 L/m.

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

Concentric heater is used to heat the tube with a constant heat flux. A DPT is used to study the pressure drop from the one end to another end of the circular and square tube. Graphtec midi Logger GL220 was used to record the temperature reading at the surface of the tubes from T1 until T5. A 10-channel input enables us to save time as there was no need for the change of inputs when the geometry of pipes changed.

Figure 3-3: Graphtec midi Logger GL220

3.4 Nanofluid Properties

Nanofluid dispersion enhances the thermo physical properties of a colloidal suspension. This is a result of extensive research done by researchers to enhance the thermo physical of fluid with suspensions.

Among the research that was done, the first equation that was applied in this study was of Crosser and Hamilton whom studied the effect of size of, volume percentage of nanoparticle and type of nanoparticles base fluid as per equation (1).

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

K_{nf} = Nanofluid thermal conductivity

K_p = Nanoparticle thermal conductivity

K_{bf} = Base fluid thermal conductivity

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

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

Where φ = Nanoparticles sphericity

The common value that would be selected to compute nanofluids thermal conductivity for β is 0.1. Followed by that the next thermophysical properties to be computed wuld be density through the equation (2)

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

ρ_{bf} = Host fluid density

ϕ_P = Fractional volume of solid nanoparticles

ρ_p = Density of particle

The formula was further improved by (Xuan & Roetzel, 2000) as per equation (3)

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

After the density, a vital property for nanofluid in this study is its viscosity. The pumping power and heat transfer rate heavily relied on the viscosity. Sharma, K et al (M Hussein, Sharma, Abu Bakar, & Kadirgama, 2013) has conducted study to identify the properties by taking into account volume portion, diameter of particle and temperature as of equation (4)

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

The obtained thermo-physical properties are shown in Table 3.1

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

	Distilled water	GNP0.025%	GNP 0.05%	GNP 0.1%
k (W/m.K)	0.615	0.623	0.639	0.71
µ (Pa. s)	0.00086	0.000906	0.000927	0.001005
ρ (m^3/kg)	995.3	995.45	995.7	996
C_p (J/kg. K)	4105	4038.25	4019.5	3815

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

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

Where,

q = heat flux

T_s = Surface Temperature

T_b = Bulk Temperature

Nu = Nusselt Number

D = Hydraulic Diameter

K = Thermal Conductivity

3.5 Numerical Analysis

The software ANSYS Fluent was used to run the simulation for the study. The model was made using the Design Modeler for both the circular and square tubes. A mesh independence study was initially conducted to determine the best mesh that produce minimal changes to the results. Then simulation was run based on the thermo physical properties of nanofluid that was obtained through analytical equation and in sub chapter 3.4.

The semi cylinder shape was modelled to study the interior of the cylindrical tube. Figure 3-4 shows the half cylinder simulation.

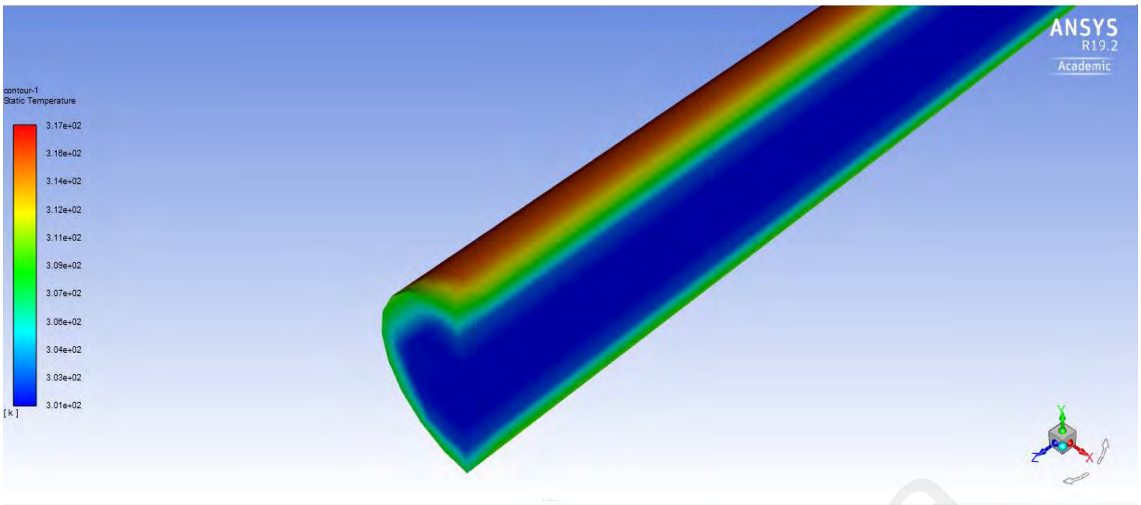


Figure 3-4: Cross-sectional view of the inlet for circular tube.

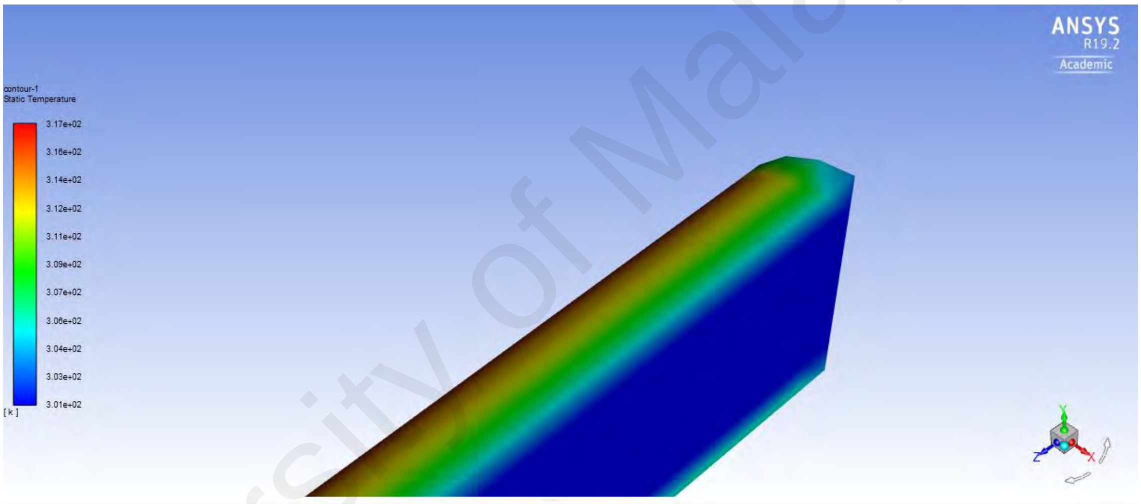


Figure 3-5: Cross-sectional view of the outlet for circular tube.

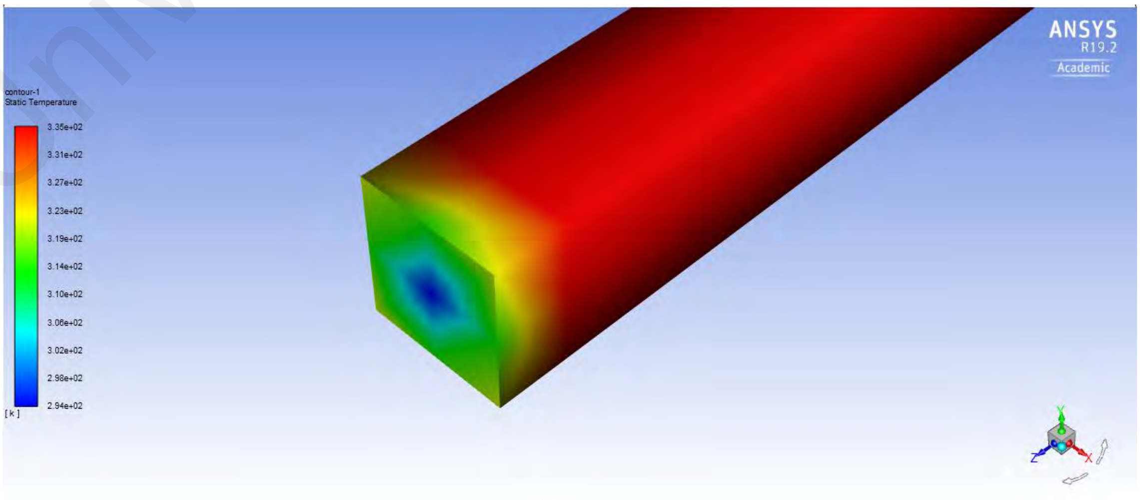


Figure 3-6: Cross-sectional view of the inlet for square tube.

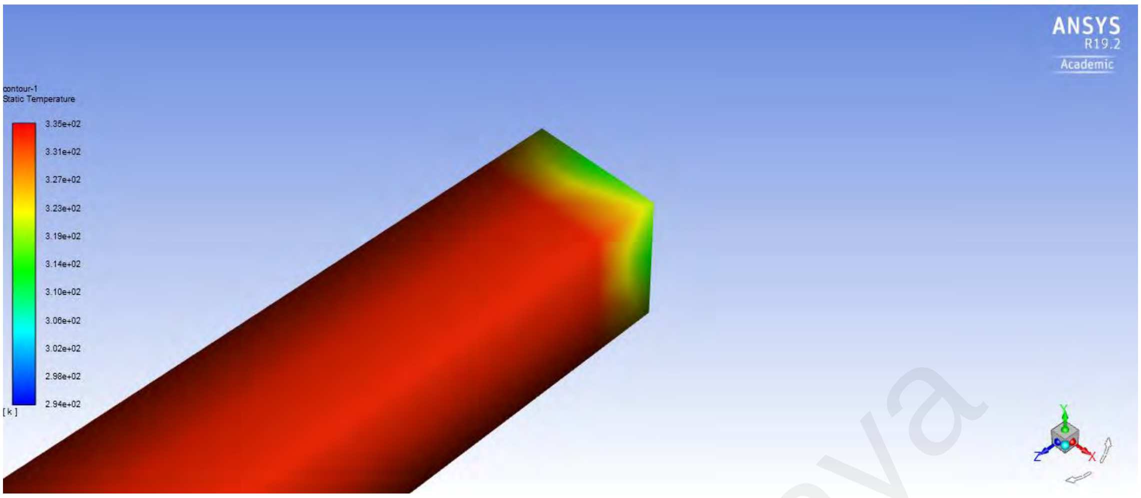


Figure 3-7: Cross-sectional view of the outlet for square tube.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Geometrical Study with Experimental Results

The comparison between conduit geometry and its effect on heat transfer and pressure drop is studied. The data from water run, GNP with 0.1%, GNP with 0.05% and 0.025% of circular geometry is compared with rectangular geometry. The constant flowrates of 4.5 L/m and 7.5 L/m are chosen to make the comparison.

Water

Table 4-1: Circular and Square Tube Water Data.

Square

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	971.5025907	15.92627198	1071.428571	17.56440281
0.4	811.6883117	13.30636577	840.8071749	13.78372418
0.6	702.247191	11.51224903	759.1093117	12.44441495
0.8	657.8947368	10.78515962	691.8819188	11.34232654
1	484.496124	7.94255941	500	8.196721311

Cylinder

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	1455.685455	23.86369599	1570.607991	25.74767198
0.4	1311.716564	21.50355023	1492.077591	24.46028839
0.6	1218.022524	19.96758236	1421.026278	23.29551275
0.8	1126.096295	18.46059501	1326.291192	21.74247856
1	1065.769708	17.47163456	1297.458775	21.26981599

Comparison Table

Flowrate, L/m	4.5		7.5	
	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
Increase Percentage, %	33.26150321	33.26150321	31.78255952	31.78255952
	38.1201447	38.1201447	43.64856227	43.64856227
	42.34530336	42.34530336	46.58020589	46.58020589
	41.57739978	41.57739978	47.83333232	47.83333232
	54.54026134	54.54026134	61.46313012	61.46313012

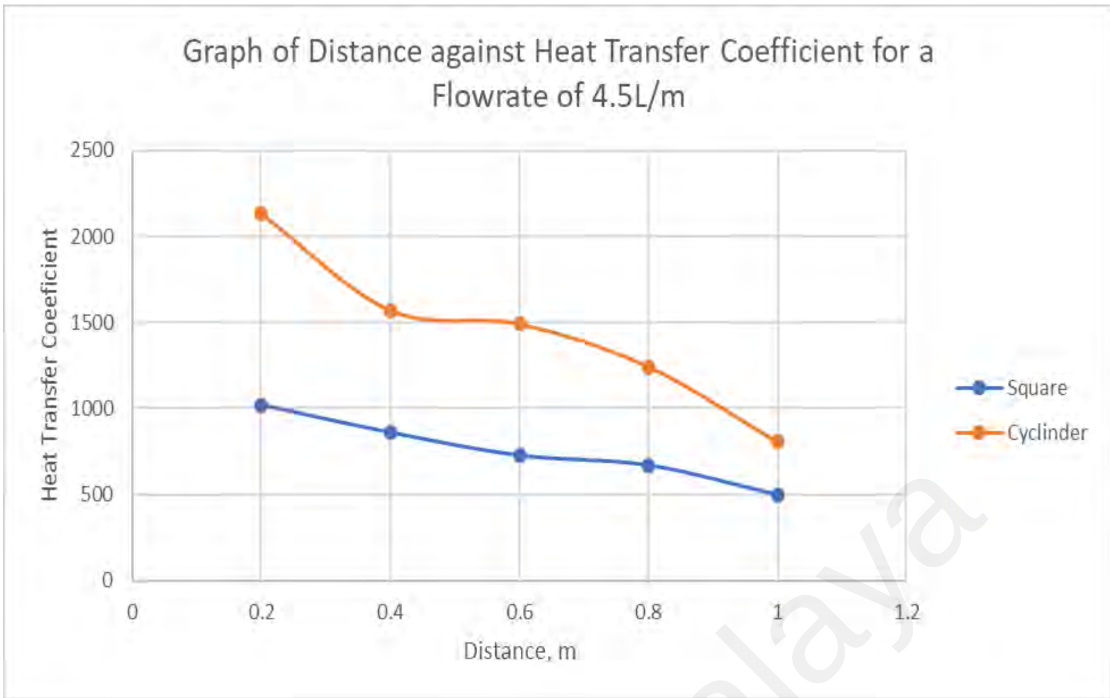


Figure 4-1: The graph of Heat Transfer Coefficient of water against Distance for 4.5 L/m flowrate

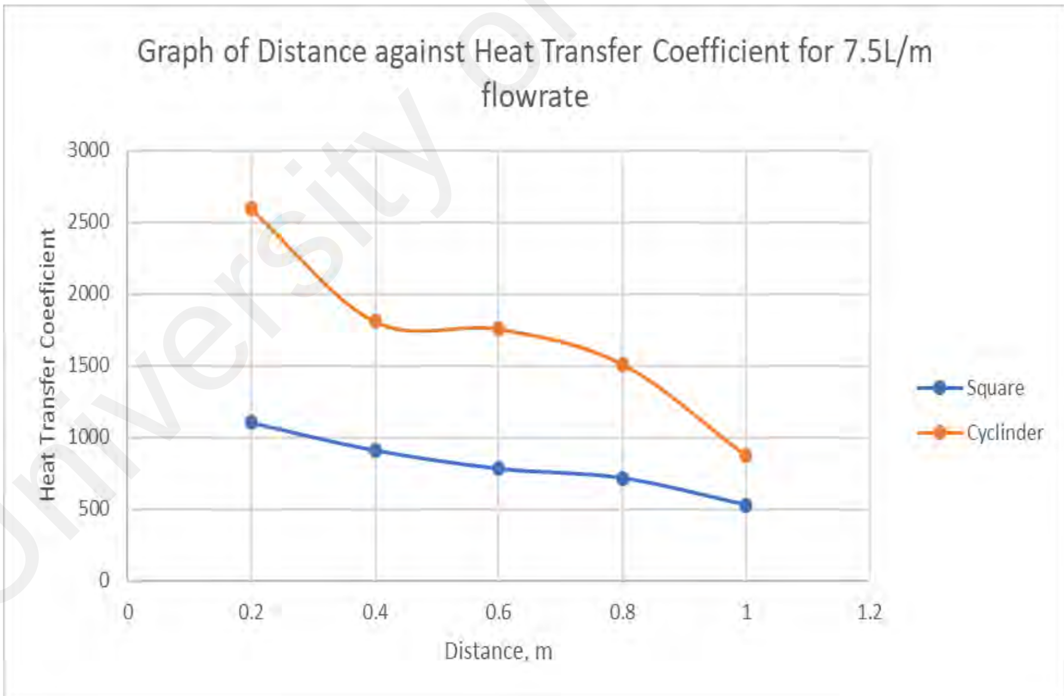


Figure 4-2: The graph of Heat Transfer Coefficient of water against Distance for 7.5 L/m flowrate

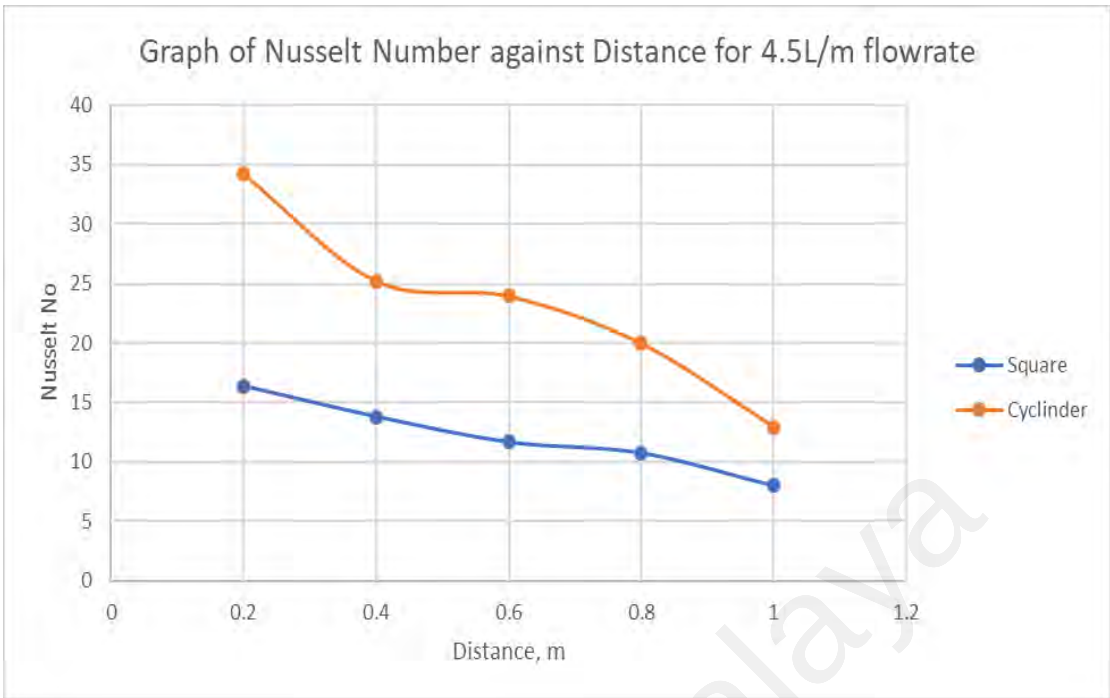


Figure 4-3: The graph of Nusselt Number of water against distance for 4.5 L/m flowrate

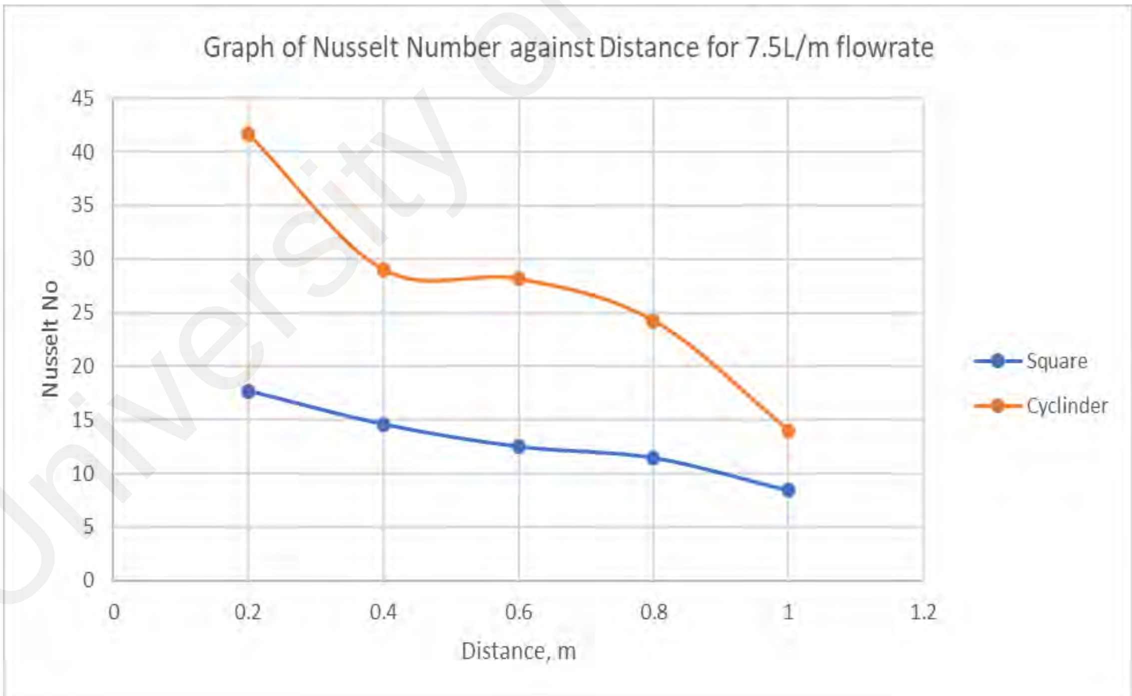


Figure 4-4: The graph of Nusselt Number of water against distance for 7.5 L/m flowrate

From the graph, it can be observed that the value of heat transfer coefficient of circular tube in comparison with square tube is higher in both the flow rate of 4.5 L/m and 7.5 L/m.

Flow rate 4.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 33%. When the distance increase, the percentage of heat transfer coefficient also increases. This peaks at the distance of 1 m where the percentage of increase is 54%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 33% in Nusselt number, while the peak percentage increase is 54% at the distance of 1 m

Flow rate 7.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 31.7%. When the distance increase, the percentage of heat transfer coefficient also increases. This peaks at the distance of 1 m where the percentage of increase is 61.5%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 31.7% in Nusselt number, while the peak percentage increase is 61.5% at the distance of 1 m.

GNP 0.1%

Table 4-2: Circular and Square Tube GNP 0.1% Data.

Square

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	1402.91807	19.75940943	1593.710157	22.44662193
0.4	885.8965273	12.47741588	929.8289115	13.09618185
0.6	802.4823454	11.30256824	861.4748449	12.13344852
0.8	733.424604	10.329924	788.975384	11.11232935
1	582.9317581	8.210306452	617.4872386	8.697003361

Cyclinder

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	3410.463066	48.03469107	3410.463066	48.03469107
0.4	2984.155183	42.03035469	2984.155183	42.03035469
0.6	2712.868348	38.20941335	2842.052555	40.02890923
0.8	1570.607991	22.12123931	1613.056856	22.71911064
1	939.8913962	13.23790699	954.9296586	13.4497135

Comparison Table

Flowrate, L/m	4.5		7.5	
	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
Increase Percentage, %	58.86429372	58.86429372	53.26997753	53.26997753
	70.31332243	70.31332243	68.84113411	68.84113411
	70.41941435	70.41941435	69.68828591	69.68828591
	53.30314069	53.30314069	51.08818507	51.08818507
	37.9788175	37.9788175	35.33688758	35.33688758

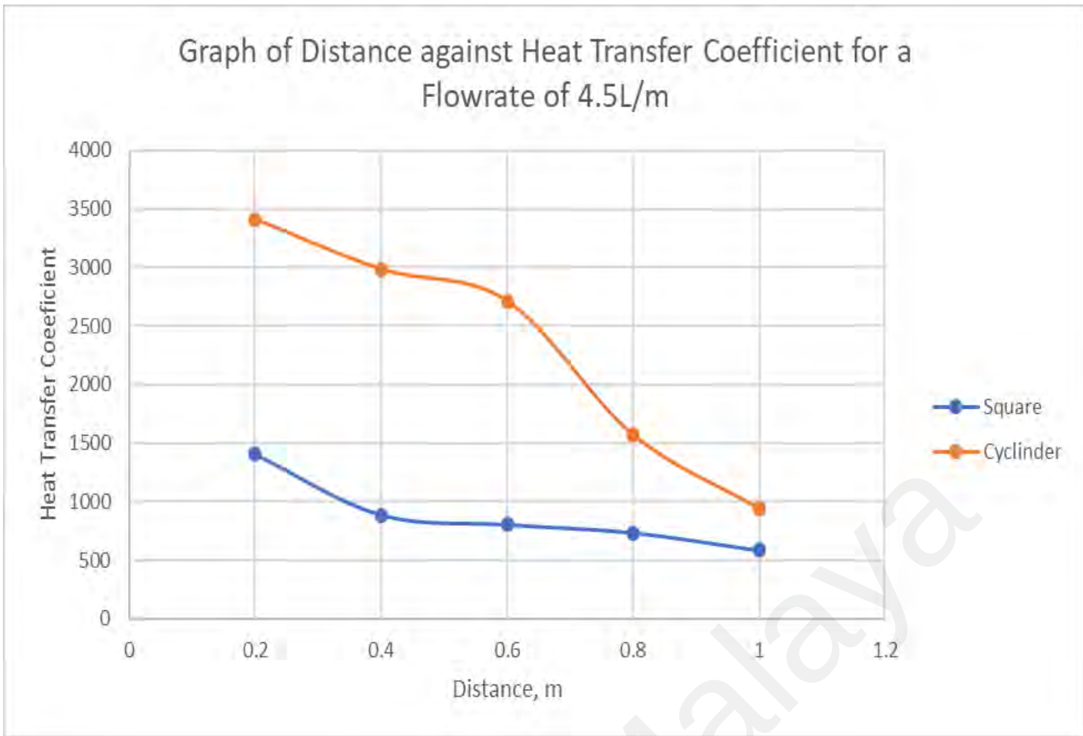


Figure 4-5: The graph of Heat Transfer Coefficient of GNP 0.1% against Distance for 4.5 L/m flowrate

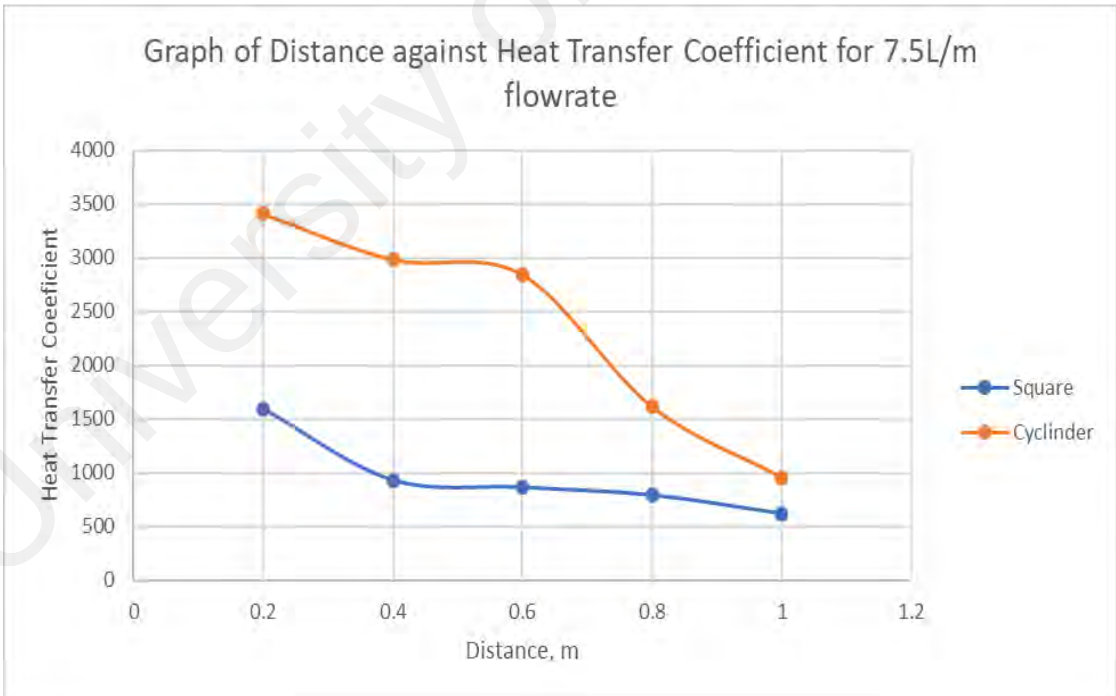


Figure 4-6: The graph of Heat Transfer Coefficient of GNP 0.1% against Distance for 7.5 L/m flowrate

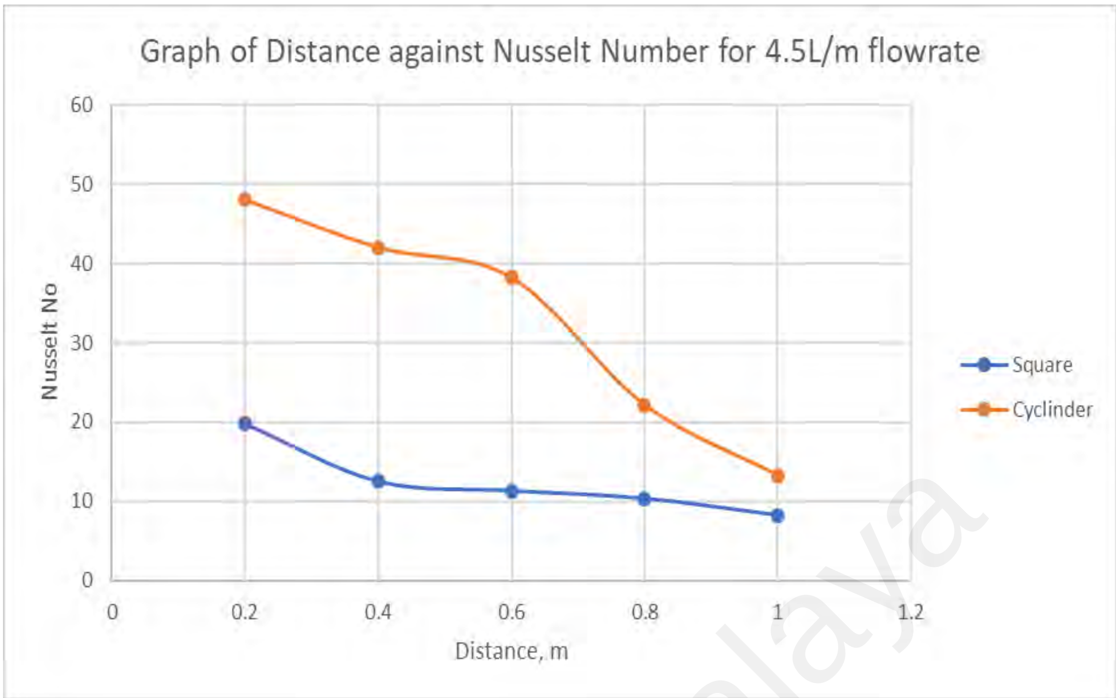


Figure 4-7: The graph of Nusselt Number of GNP 0.1% against distance for 4.5 L/m flowrate

Figure 4-8: The graph of Nusselt Number of GNP 0.1% against distance for 7.5 L/m flowrate

From the graph, it can be observed that the value of heat transfer coefficient of circular tube in comparison with square tube is higher in both the flow rate of 4.5 L/m and 7.5 L/m.

Flow rate 4.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 58.9%. When the distance increase, the percentage of heat transfer coefficient also increases. This peaks at the distance of 0.6 m where the percentage of increase is 70.4%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 58.9% in Nusselt number, while the peak percentage increase is 70.4% at the distance of 0.6 m

Flow rate 7.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 53.2%. When the distance increase, the percentage of heat transfer coefficient also increases. This peaks at the distance of 0.6 m where the percentage of increase is 69.6%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 53.2% in Nusselt number, while the peak percentage increase is 69.6% at the distance of 0.6 m.

GNP 0.05%

Table 4-3: Circular and Square Tube GNP 0.05% Data.

Square

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	1090.116279	17.06639967	1102.941176	17.26718084
0.4	910.1941748	14.24961526	910.1941748	14.24961526
0.6	726.744186	11.37759978	781.25	12.23091977
0.8	679.3478261	10.6355824	715.648855	11.20389597
1	512.295082	8.020275256	526.6853933	8.245563887

Cylinder

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	2842.052555	44.49397347	3060.671983	47.91658681
0.4	2340.513869	36.6420958	2436.045047	38.13769154
0.6	1808.578899	28.31434675	1808.578899	28.31434675
0.8	1158.895217	18.14317365	1136.821022	17.79758939
1	871.2861848	13.64048822	864.9725168	13.5416441

Comparison Table

Flowrate, L/m	4.5		7.5	
	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
Increase Percentage, %	61.64334551	61.64334551	63.96408427	63.96408427
	61.11135307	61.11135307	62.63639805	62.63639805
	59.81683815	59.81683815	56.80310101	56.80310101
	41.3797023	41.3797023	37.04823881	37.04823881
	41.20243258	41.20243258	39.10958059	39.10958059

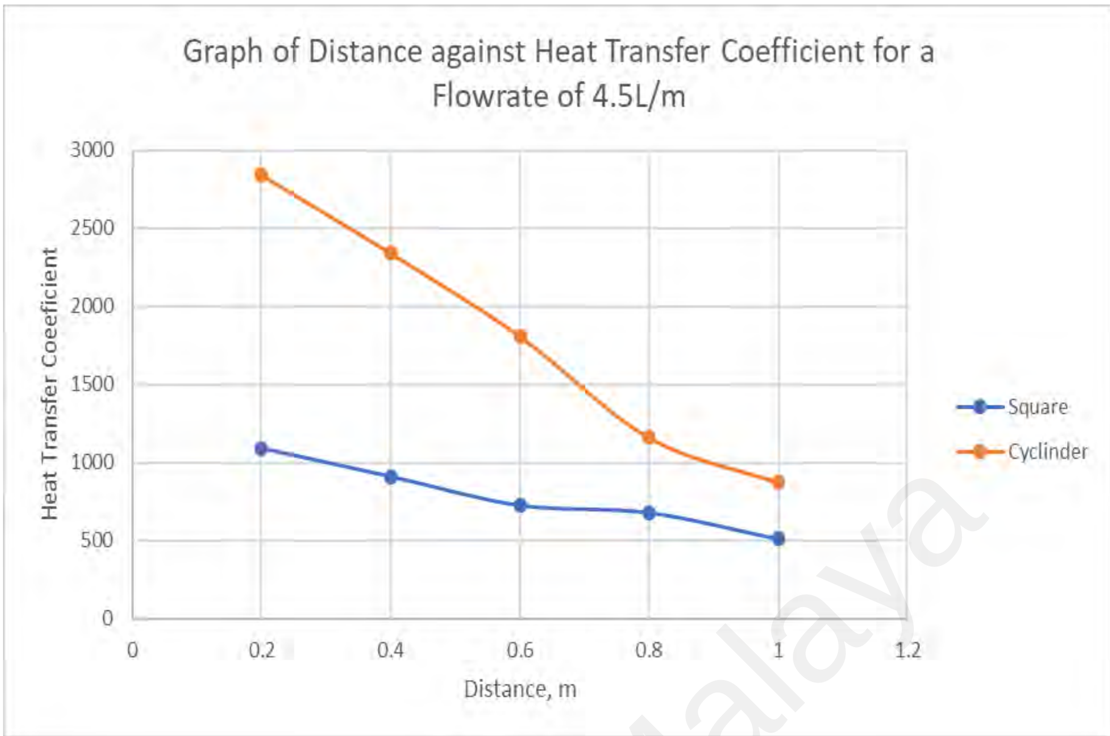


Figure 4-9: The graph of Heat Transfer Coefficient of GNP 0.05% against Distance for 4.5 L/m flowrate

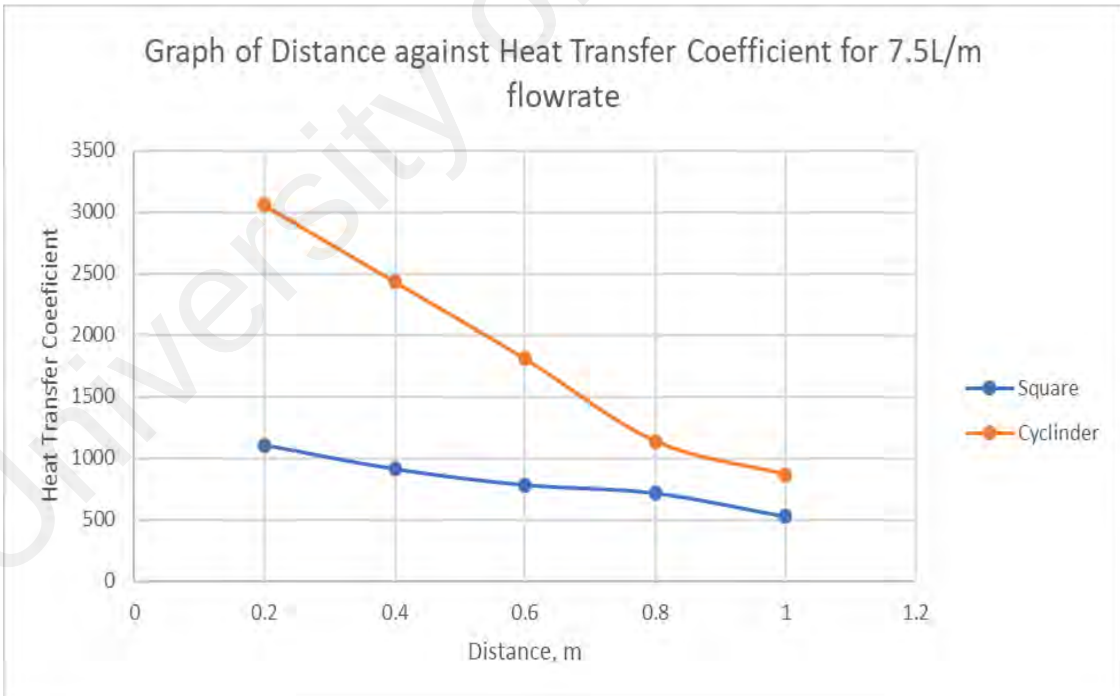


Figure 4-10: The graph of Heat Transfer Coefficient of GNP 0.05% against Distance for 7.5 L/m flowrate

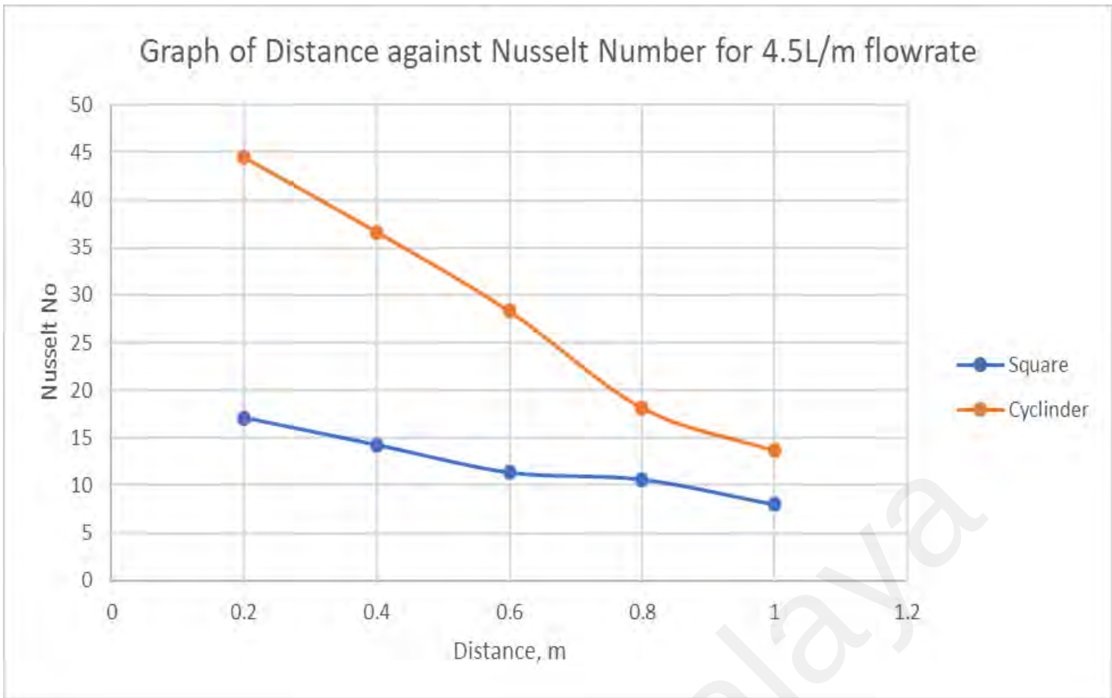


Figure 4-11: The graph of Nusselt Number of GNP 0.05% against distance for 4.5 L/m flowrate

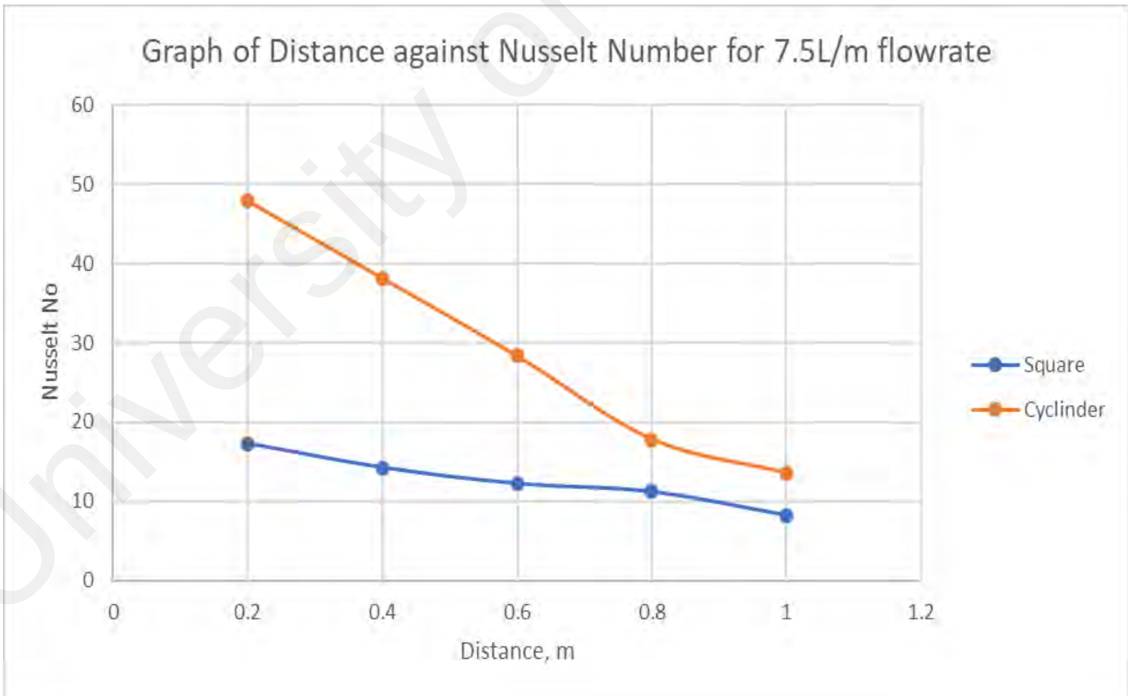


Figure 4-12: The graph of Nusselt Number of GNP 0.05% against distance for 7.5 L/m flowrate

From the graph, it can be observed that the value of heat transfer coefficient of circular tube in comparison with square tube is higher in both the flow rate of 4.5 L/m and 7.5 L/m.

Flow rate 4.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 61.1%. When the distance increase, the percentage of heat transfer coefficient increases. This peaks at the distance of 0.2 m where the percentage of increase is 61.6%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 61.6% in Nusselt number, while the peak percentage increase is 61.6% at the distance of 0.2 m

Flow rate 7.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 64%. When the distance increase, the percentage of heat transfer coefficient also increases. This peaks at the distance of 0.2 m where the percentage of increase is 64%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 64% in Nusselt number, while the peak percentage increase is 64% at the distance of 0.2 m.

GNP 0.025%

Table 4-4: Circular and Square Tube GNP 0.025% Data.

Square

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	1019.021739	16.35340805	1102.941176	17.7001593
0.4	860.0917431	13.80287652	910.1941748	14.60692758
0.6	726.744186	11.66289566	781.25	12.53761284
0.8	669.6428571	10.74652529	715.648855	11.48483619
1	498.6702128	8.002731599	526.6853933	8.452323262

Cyclinder

Flowrate, L/m	4.5		7.5	
Position, m	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
0.2	2131.539416	34.20725242	2594.91755	41.64361164
0.4	1570.607991	25.20534389	1808.578899	29.02433539
0.6	1492.077591	23.94507669	1755.385402	28.17067846
0.8	1243.397993	19.95423058	1510.96465	24.24817893
1	806.5284278	12.9432847	871.2861848	13.98252654

Comparison Table

Flowrate, L/m	4.5		7.5	
	Heat Transfer Coefficient	Nusselt Number	Heat Transfer Coefficient	Nusselt Number
Increase Percentage, %	52.19315527	52.19315527	57.49609939	57.49609939
	45.23829319	45.23829319	49.67351574	49.67351574
	51.29313715	51.29313715	55.49410407	55.49410407
	46.14412594	46.14412594	52.63629396	52.63629396
	38.17078288	38.17078288	39.55081551	39.55081551

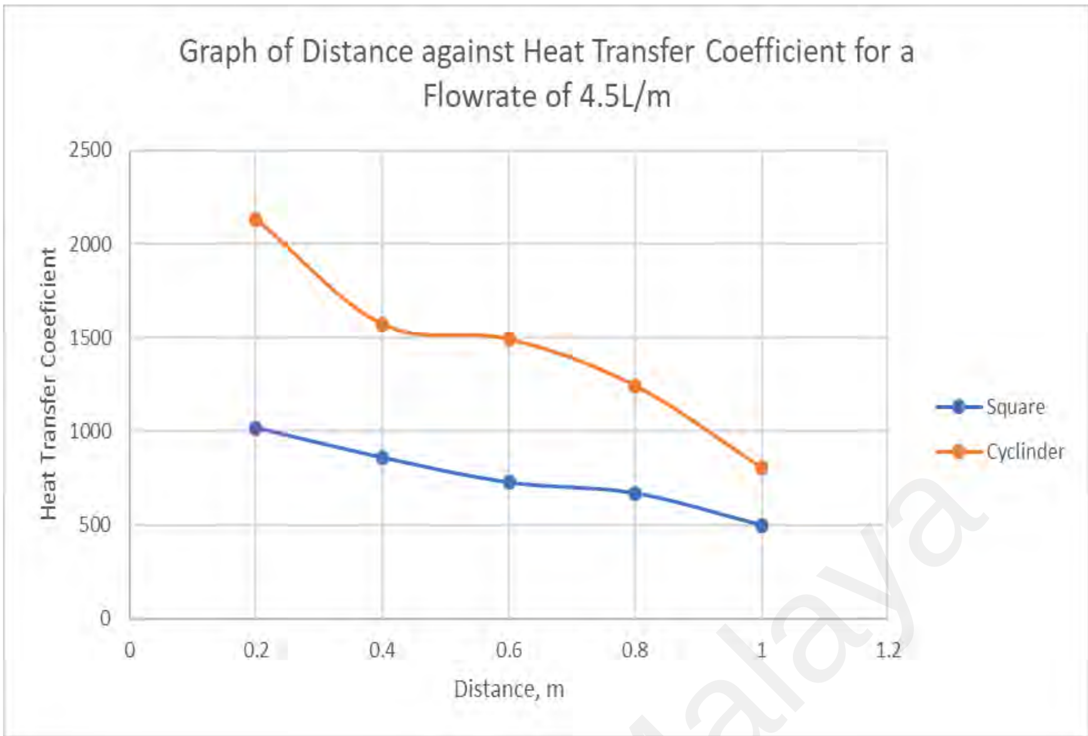


Figure 4-13: The graph of Heat Transfer Coefficient of GNP 0.025% against Distance for 4.5 L/m flowrate

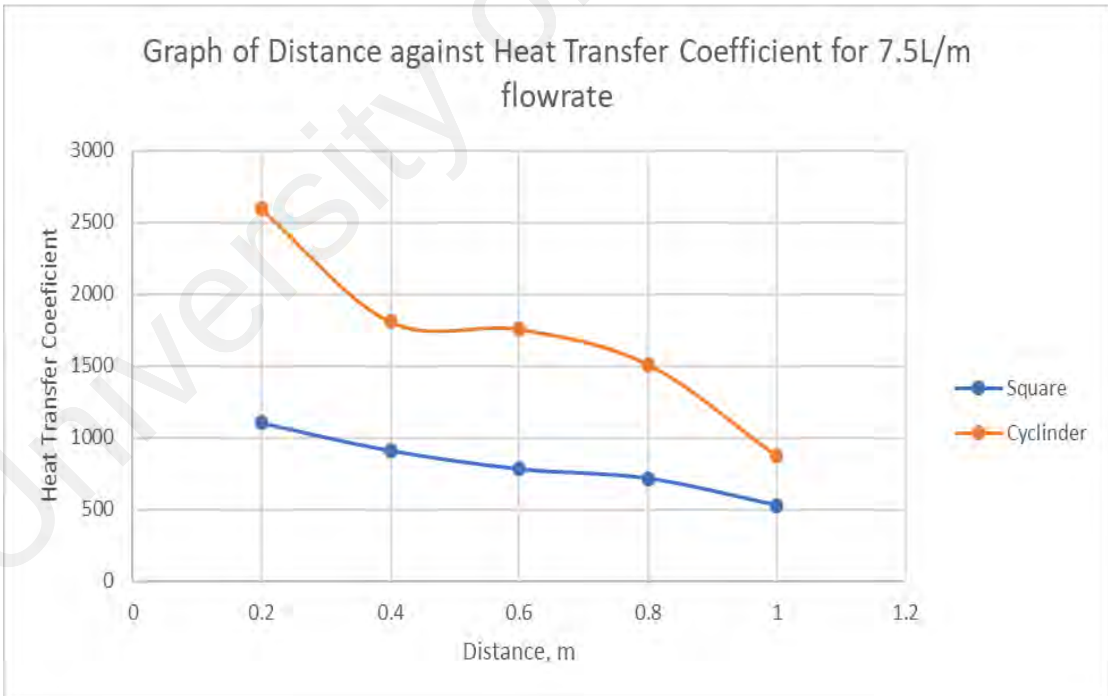


Figure 4-14: The graph of Heat Transfer Coefficient of GNP 0.025% against Distance for 7.5 L/m flowrate

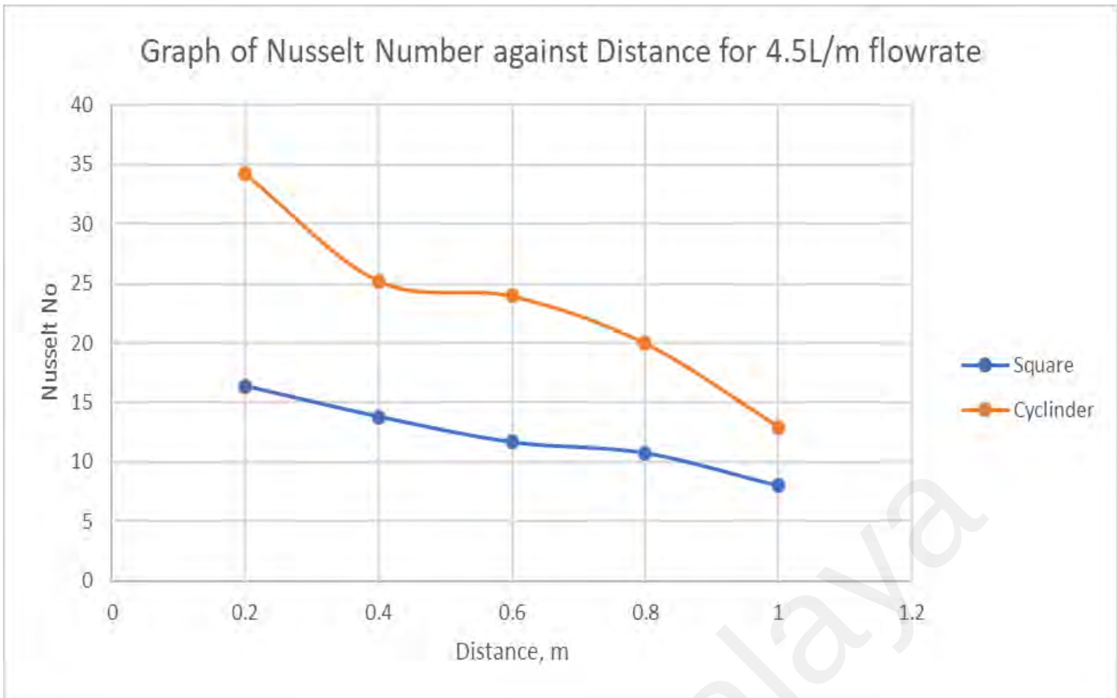


Figure 4-15: The graph of Nusselt Number of GNP 0.025% against distance for 4.5 L/m flowrate

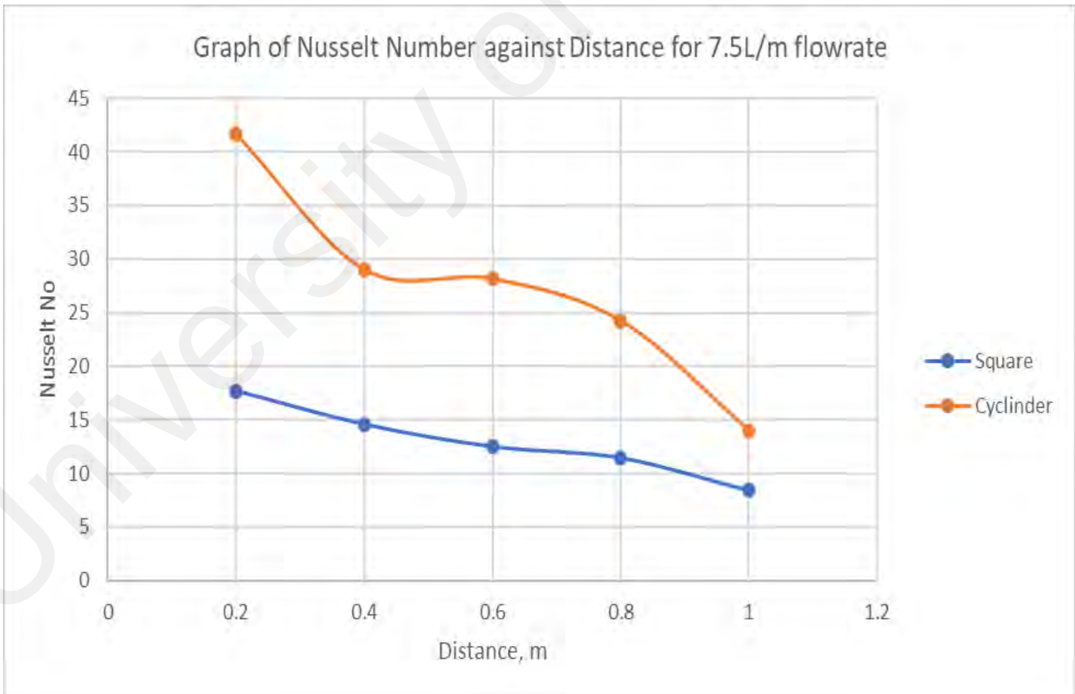


Figure 4-16: The graph of Nusselt Number of GNP 0.025% against distance for 7.5 L/m flowrate

From the graph, it can be observed that the value of heat transfer coefficient of circular tube in comparison with square tube is higher in both the flow rate of 4.5 L/m and 7.5 L/m.

Flow rate 4.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 52.2%. When the distance increase, the percentage of heat transfer coefficient increases. This peaks at the distance of 0.2 m where the percentage of increase is 52.2%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 52.2% in Nusselt number, while the peak percentage increase is 52.2% at the distance of 0.2 m

Flow rate 7.5 L/m

At a distance of 0.2 m, the increase in heat transfer coefficient for the circular tube is 57.5%. When the distance increase, the percentage of heat transfer coefficient also increases. This peaks at the distance of 0.2 m where the percentage of increase is 57.5%. The same trend can be observed in the Nusselt number also. The Nusselt number increases as the distance increases. The distance of 0.2 shows an increase of 57.5% in Nusselt number, while the peak percentage increase is 57.5% at the distance of 0.2 m.

4.2 GNP Concentration and Heat Transfer Properties.

Next, the study was conducted to analyse the effect of different concentration of GNP to the heat transfer ability. GNP with concentration of 0.1%, 0.05%, and 0.025% were used to analyse this. Besides that, water was used as a reference parameter as it is widely used as working fluid. This flowrate was also varied from 3.5 L/m, 4.5L/m, 5.5 L/m, 6.5 L/m, 7.5 L/m, and finally 8.5 L/m. Besides the varying flowrate, the shape of the tube is also studied to analyse the effect of concentration o heat transfer properties.

<u>Water – Circular Tube</u>

Table 4-5: Data of Temperature to distance and flowrate for water circular tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	310.8	310.6	310.4	310.3	310	309.7
0.4	311.6	311.5	311.2	310.9	310.4	310.2
0.6	312.6	312.2	312	311.1	310.8	310.6
0.8	313.2	313	312.8	312.4	311.4	311.2
1	314.4	313.6	313.5	312.7	311.6	311.4

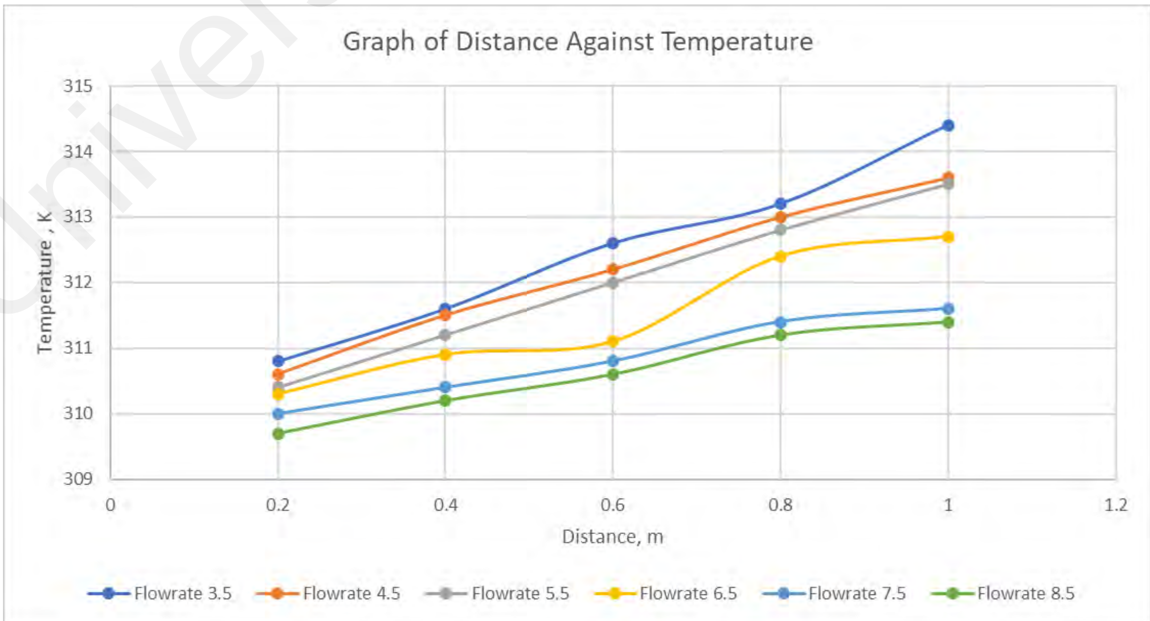


Figure 4-17: The Graph of Temperature against distance for water run in a circular tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 314.4 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 311.4K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 309.7 K and it travels through the tube the temperature increase to 310.2 K, 310.6 K, 311.2 K and 311.4 K.

Table 4-6: Data of Heat Transfer Coefficient and Nusselt Number to Distance and Flowrate for water circular tube

	Heat Transfer Coefficient					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	1421.026	1455.685	1492.078	1510.965	1570.608	1635.154
0.400	1297.459	1311.717	1356.434	1404.308	1492.078	1530.336
0.600	1170.257	1218.023	1243.398	1372.025	1421.026	1455.685
0.800	1105.243	1126.096	1147.752	1193.662	1326.291	1356.434
1.000	994.718	1065.770	1075.371	1158.895	1297.459	1326.291

	Nusselt Number					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	23.296	23.864	24.460	24.770	25.748	26.806
0.400	21.270	21.504	22.237	23.021	24.460	25.087
0.600	19.185	19.968	20.384	22.492	23.296	23.864
0.800	18.119	18.461	18.816	19.568	21.742	22.237
1.000	16.307	17.472	17.629	18.998	21.270	21.742

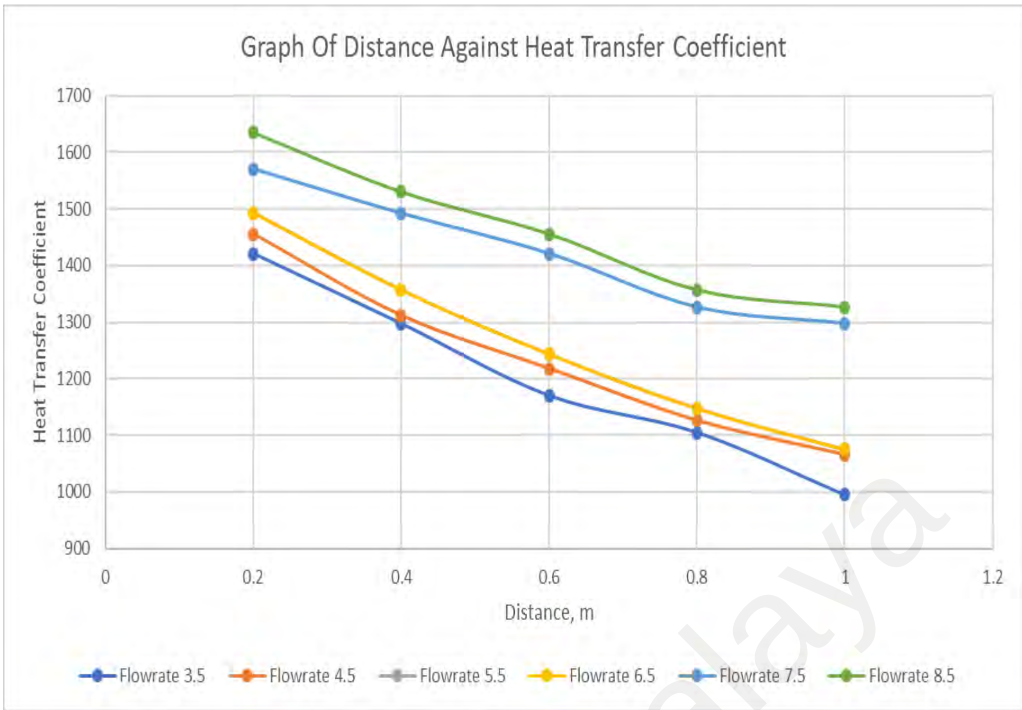


Figure 4-18: The Graph of Heat Transfer Coefficient against distance for water run in a circular tube.

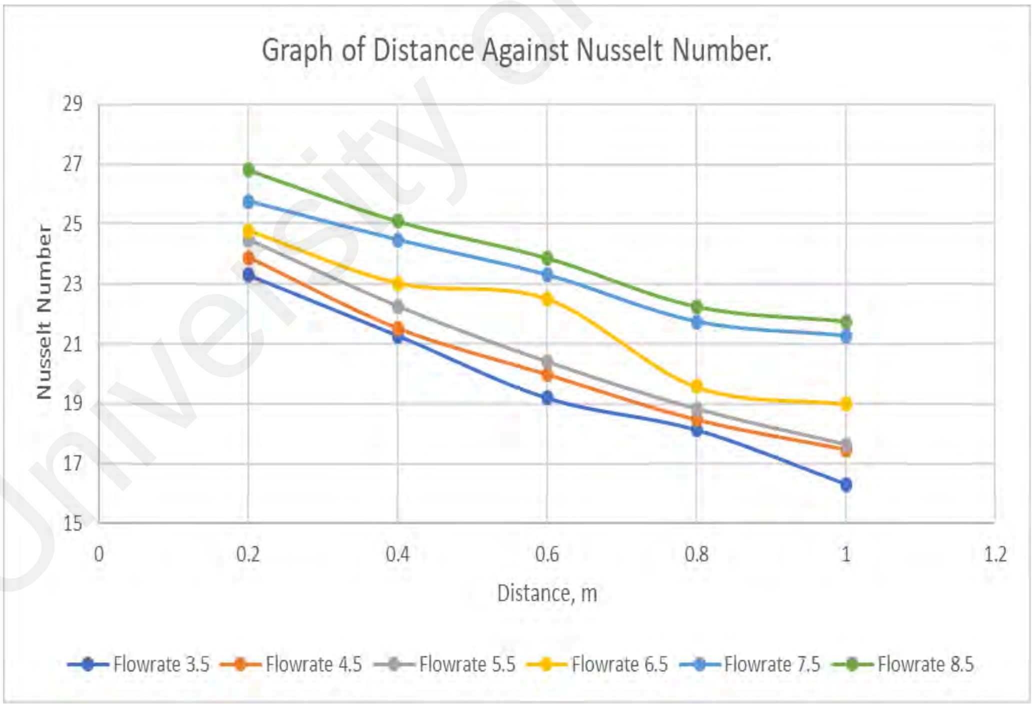


Figure 4-19: The Graph of Nusselt Number against distance for water run in a circular tube.

From the graph, it can be observed that the Nusselt number for the flow rate of 8.5 L/m is the highest in comparison to the other flowrates. The highest Nusselt number is recorded at the 0.2 distance for the 8.5 L/m flowrate which is 26.8. The lowest Nusselt number is recorded by the 3.5 L/m flowrate at the distance of 1m which is 16.3.

From the graph, it can be observed that the Nusselt number for the flow rate of 8.5 L/m is the highest in comparison to the other flowrates. The highest Nusselt number is recorded at the 0.2 distance for the 8.5 L/m flowrate which is 1635.15 W/(m^2K). The lowest Nusselt number is recorded by the 3.5 L/m flowrate at the distance of 1m which is 994.7 W/(m^2K).

Besides that, the heat transfer coefficient also exhibits the same characteristic as Nusselt's number in which at a given point, provided that the flow rate is increased, the Nusselt number and heat transfer coefficient also increases. It is a directly proportional relationship.

Water – Square Tube

Table 4-7: Data of Temperature to distance and flowrate for water square tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	310.2	310.2	310.2	310	309.3	309.3
0.4	312	312.1	312.1	311.9	311.7	311.7
0.6	313.9	313.9	313.9	313.7	312.9	312.1
0.8	314.8	314.8	314.8	314.8	314.1	313.4
1	320	319.9	319.8	319.8	319.3	318.7

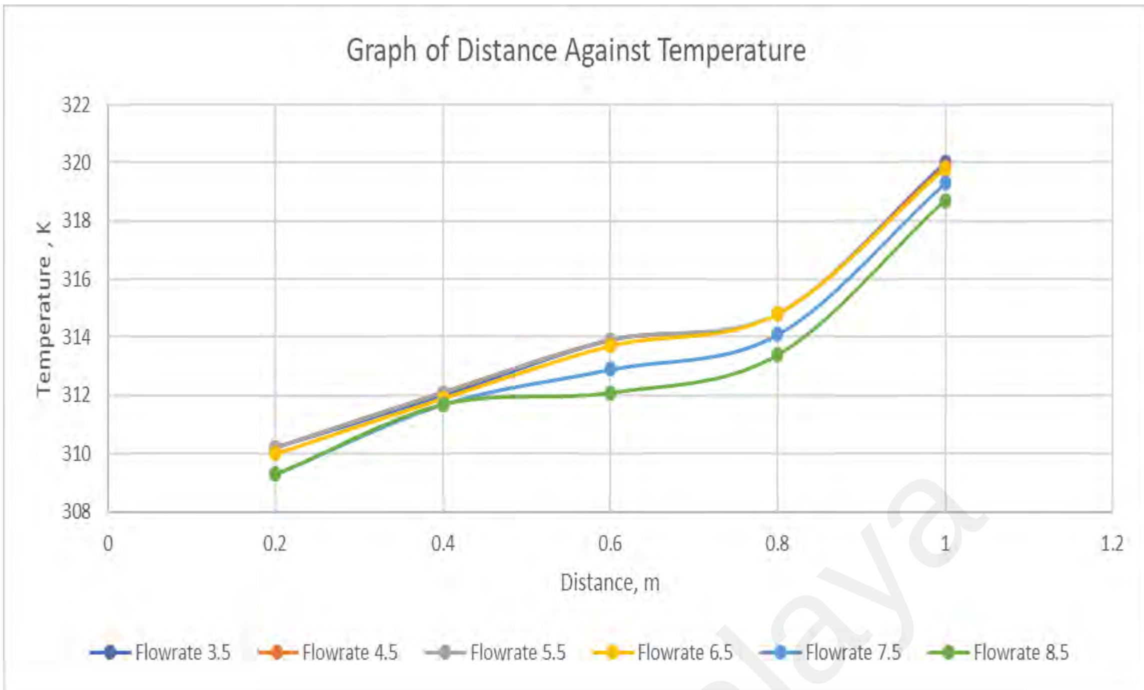


Figure 4-20: The Graph of Temperature against distance for water run in a square tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 320 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 318.7K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 309.3 K and it travels through the tube the temperature increase to 311.7 K, 312.1 K, 313.4 K and 318.7 K.

Table 4-8: Data of Heat Transfer Coefficient and Nusselt Number to Distance and Flowrate for water square tube

	Heat Transfer Coefficient					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	971.503	971.503	971.503	992.063	1071.429	1071.429
0.400	818.777	811.688	811.688	825.991	840.807	840.807
0.600	702.247	702.247	702.247	712.928	759.109	811.688
0.800	657.895	657.895	657.895	657.895	691.882	729.572
1.000	482.005	484.496	487.013	487.013	500.000	516.529

	Nusselt Number					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	15.926	15.926	15.926	16.263	17.564	17.564
0.400	13.423	13.306	13.306	13.541	13.784	13.784
0.600	11.512	11.512	11.512	11.687	12.444	13.306
0.800	10.785	10.785	10.785	10.785	11.342	11.960
1.000	7.902	7.943	7.984	7.984	8.197	8.468

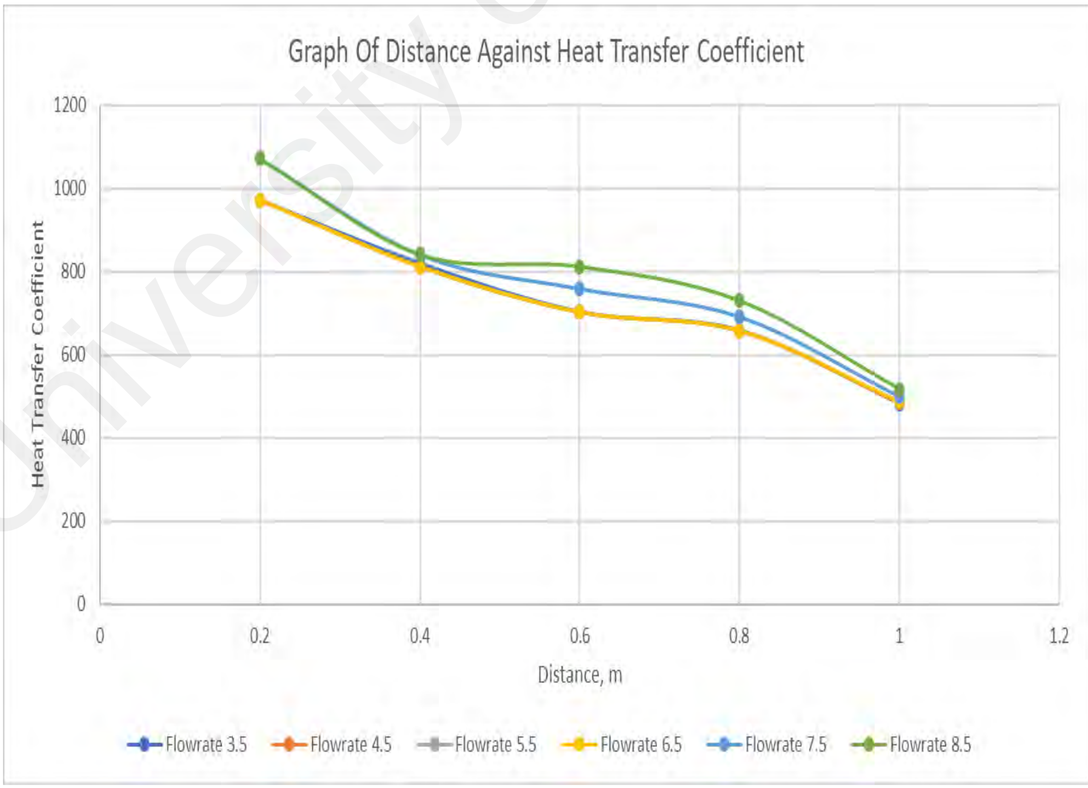


Figure 4-21: The Graph of Heat Transfer Coefficient against distance for water run in a square tube.

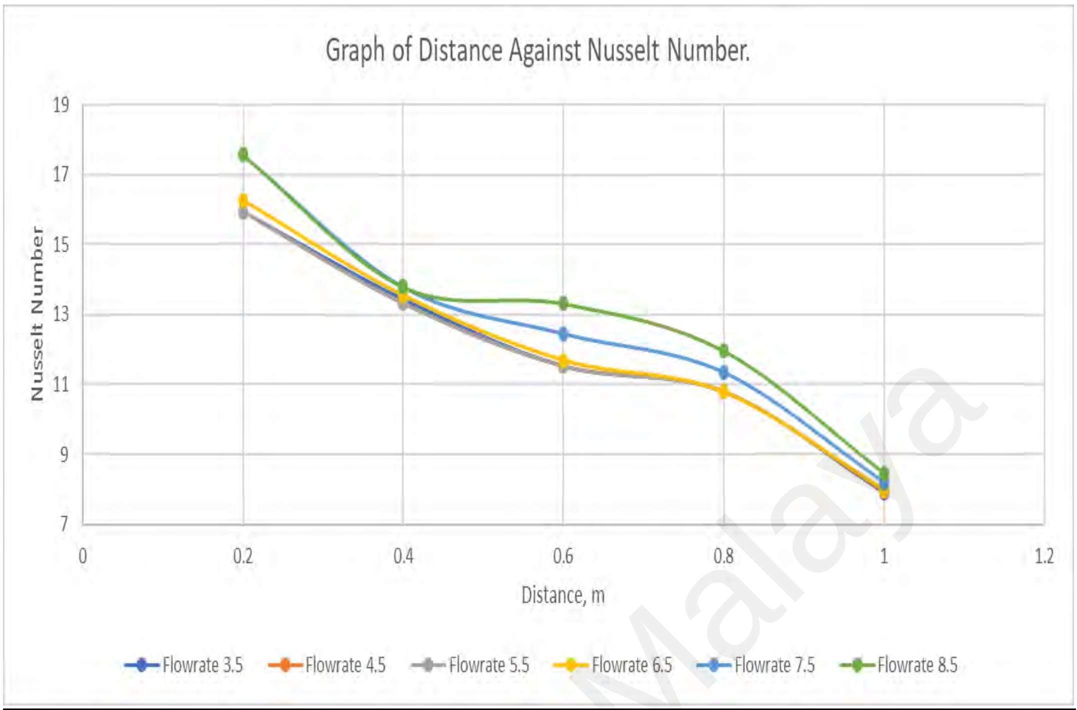


Figure 4-22: The Graph of Nusselt Number against distance for water run in a square tube.

From the graph, it can be observed that the Nusselt number for the flow rate of 8.5 L/m is the highest in comparison to the other flowrates. The highest Nusselt number is recorded at the 0.2 distance for the 8.5 L/m flowrate which is 17.56. The lowest Nusselt number is recorded by the 3.5 L/m flowrate at the distance of 1m which is 7.9.

From the graph, it can be observed that the Nusselt number for the flow rate of 8.5 L/m is the highest in comparison to the other flowrates. The highest Nusselt number is recorded at the 0.2 distance for the 8.5 L/m flowrate which is 1071.4 W/(m^2K). The lowest Nusselt number is recorded by the 3.5 L/m flowrate at the distance of 1m which is 482 W/(m^2K).

Besides that, the heat transfer coefficient also exhibits the same characteristic as Nusselt's number in which at a given point, provided that the flow rate is increased, the

Nusselt number and heat transfer coefficient also increases. It is a directly proportional relationship.

GNP 0.1% - Circular Tube

Figure 4-23: Data of Temperature to distance and flowrate for GNP 0.1% circular tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	311.4	310.9	310.6	310.1	310.1	309
0.4	311.9	311.4	311.1	310.6	310.6	309.3
0.6	312.3	311.8	311.3	310.9	310.8	309.5
0.8	315.7	315	314.7	314.1	314	312.9
1	320.4	320.1	319.6	319.1	319.1	317.6

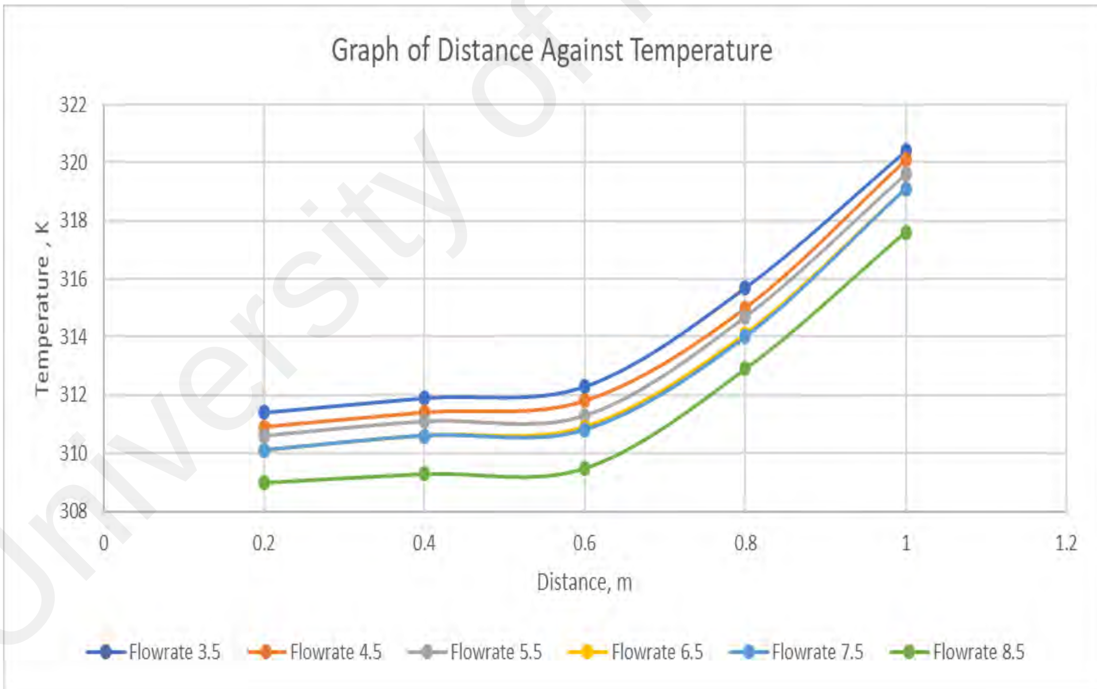


Figure 4-24: The Graph of Temperature against distance for GNP 0.1% run in a circular tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 320.4 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 318.7K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 309.3 K and it travels through the tube the temperature increase to 311.7 K, 312.1 K, 313.4 K and 318.7 K.

Table 4-9: Data of Heat Transfer Coefficient and Nusselt Number to Distance and Flowrate for GNP 0.1% circular tube

	Heat Transfer Coefficient					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	3510.771	3410.463	3141.216	3410.463	3410.463	3410.463
0.400	3060.672	2984.155	2775.958	2984.155	2984.155	3141.216
0.600	2775.958	2712.868	2652.582	2775.958	2842.053	2984.155
0.800	1550.210	1570.608	1510.965	1591.549	1613.057	1613.057
1.000	962.631	939.891	932.548	954.930	954.930	986.498

	Nusselt Number					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	49.447	48.035	44.242	48.035	48.035	48.035
0.400	43.108	42.030	39.098	42.030	42.030	44.242
0.600	39.098	38.209	37.360	39.098	40.029	42.030
0.800	21.834	22.121	21.281	22.416	22.719	22.719
1.000	13.558	13.238	13.134	13.450	13.450	13.894

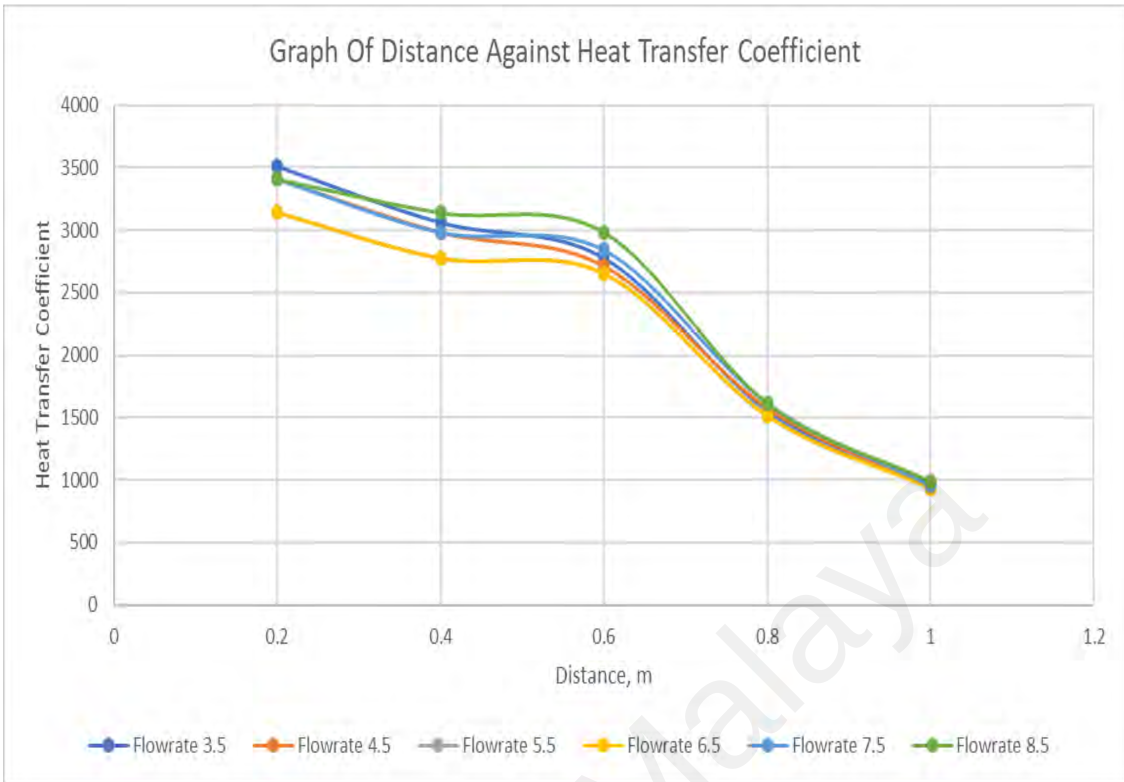


Figure 4-25: The Graph of Heat Transfer Coefficient against distance for water run in a circular tube.

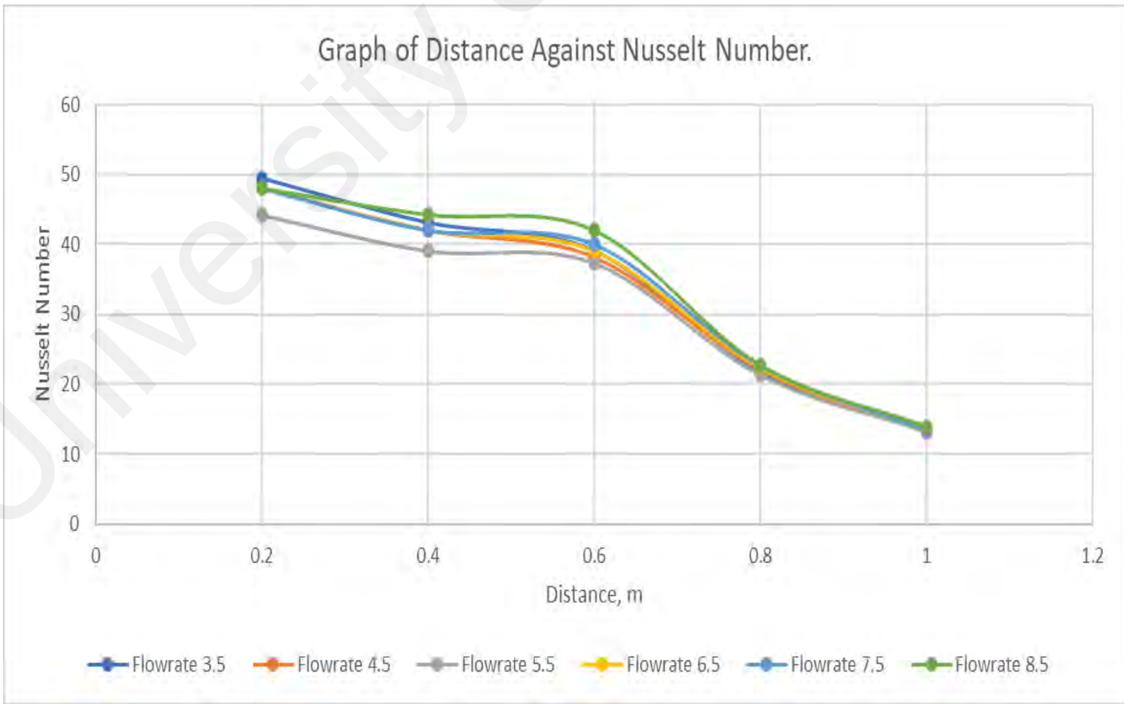


Figure 4-26: The Graph of Nusselt Number against distance for water run in a circular tube.

From the graph, it can be observed that the 8.5 L/m flow rate has the highest gradient of Nusselt number in comparison to other flows. This is due to the high flow rate which could absorb heat faster.The highest gradient for heat transfer coefficient is displayed by the 8.5 L/m flowrate as well

Besides that, the heat transfer coefficient also exhibits the same characteristic as Nusselt's number in which at a given point, provided that the flow rate is increased, the Nusselt number and heat transfer coefficient also increases. It is a directly proportional relationship

GNP 0.1% - Square Tube

Table 4-10:Data of Temperature to distance and flowrate for GNP 0.1% square tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	310.8	310.8	310.8	310.3	310	310
0.4	314.7	314.7	314.6	314.5	314.2	314.2
0.6	315.9	315.8	315.4	315	315	314.7
0.8	316.9	316.9	316.7	316.2	316	315.9
1	320.3	320.2	320.1	319.6	319.3	319.3

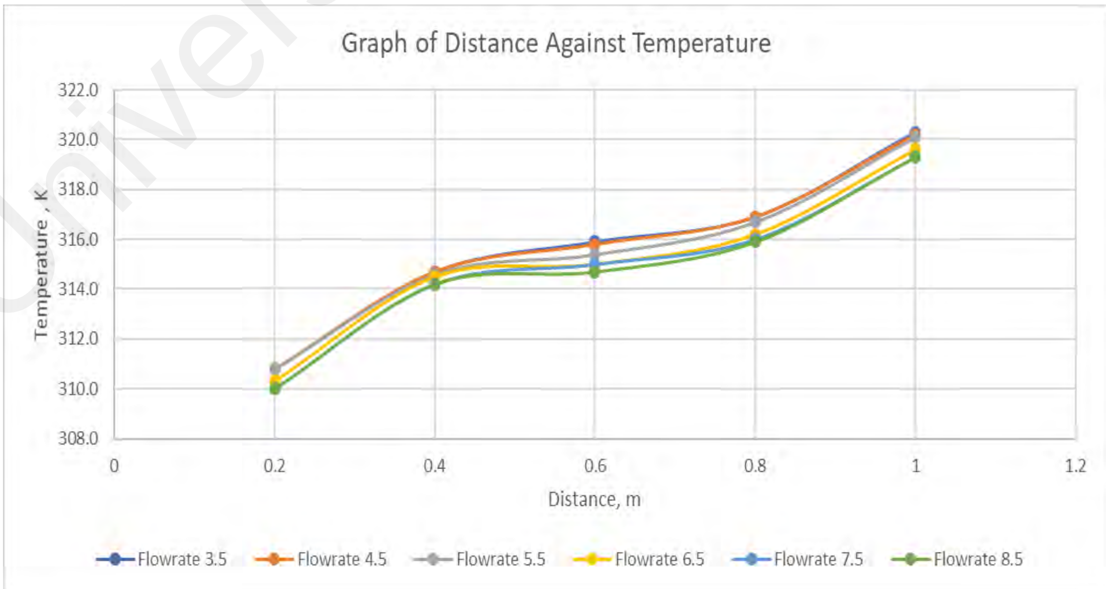


Figure 4-27: The Graph of Temperature against distance for GNP 0.1% run in a square tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 320.3 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 319.3 K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 310 K and it travels through the tube the temperature increase to 314.2 K, 314.7 K, 315.9 K and 319.3 K.

Table 4-11: Data of Heat Transfer Coefficient and Nusselt Number to Distance and Flowrate for GNP 0.1% Square tube

	Heat Transfer Coefficient					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	1402.918	1402.918	1402.918	1516.377	1593.710	1593.710
0.400	885.897	885.897	894.348	902.962	929.829	929.829
0.600	795.672	802.482	830.933	861.475	861.475	885.897
0.800	733.425	733.425	745.082	775.916	788.975	795.672
1.000	579.330	582.932	586.579	605.522	617.487	617.487

	Nusselt Number, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.200	19.759	19.759	19.759	21.357	22.447	22.447
0.400	12.477	12.477	12.596	12.718	13.096	13.096
0.600	11.207	11.303	11.703	12.133	12.133	12.477
0.800	10.330	10.330	10.494	10.928	11.112	11.207
1.000	8.160	8.210	8.262	8.528	8.697	8.697

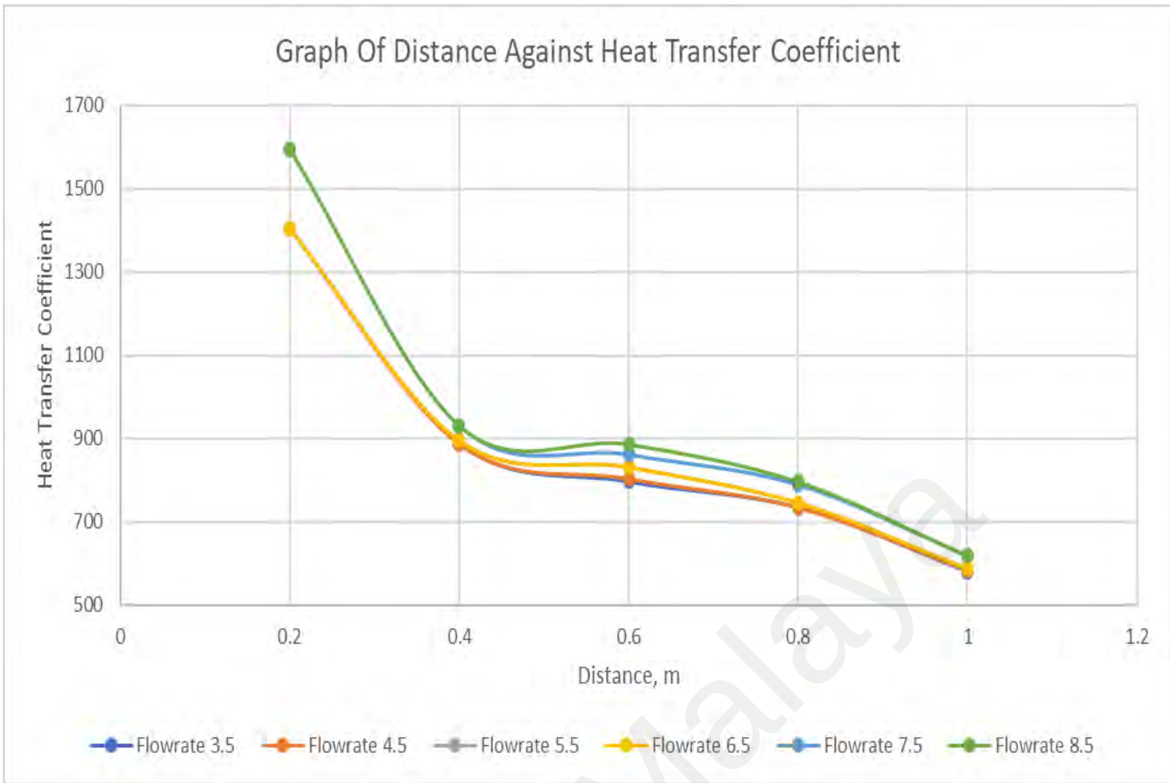


Figure 4-28: The Graph of Heat Transfer Coefficient against distance for water run in a square tube.

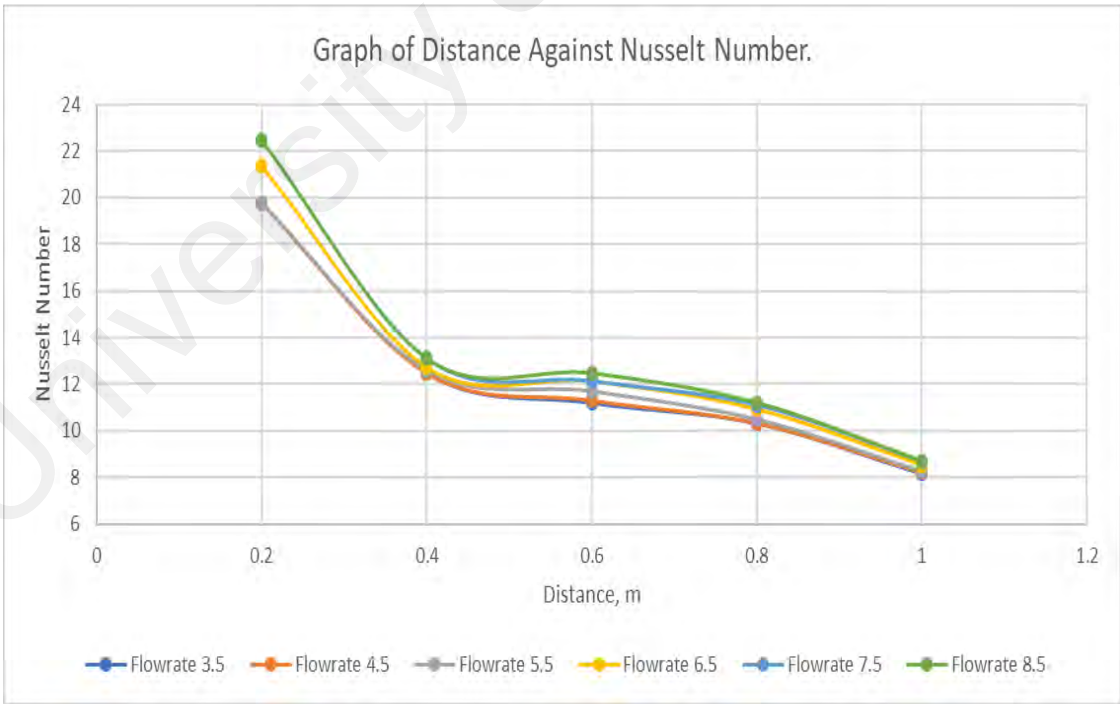


Figure 4-29: The Graph of Nusselt Number against distance for water run in a square tube.

From the graph, it can be observed that the Nusselt number for the flow rate of 8.5 L/m is the highest in comparison to the other flowrates. The highest Nusselt number is recorded at the 0.2 distance for the 8.5 L/m flowrate which is 22.44. The lowest Nusselt number is recorded by the 3.5 L/m flowrate at the distance of 1m which is 8.16.

From the graph, it can be observed that the Nusselt number for the flow rate of 8.5 L/m is the highest in comparison to the other flowrates. The highest Nusselt number is recorded at the 0.2 distance for the 8.5 L/m flowrate which is 1593.7 W/(m^2K). The lowest Nusselt number is recorded by the 3.5 L/m flowrate at the distance of 1m which is 579.3 W/(m^2K).

Besides that, the heat transfer coefficient also exhibits the same characteristic as Nusselt's number in which at a given point, provided that the flow rate is increased, the Nusselt number and heat transfer coefficient also increases. It is a directly proportional relationship.

GNP 0.05% - Circular Tube

Table 4-12: Data of Temperature to distance and flowrate for GNP 0.05% square tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	310.8	310.7	310.5	310.3	309.4	309
0.4	311.7	311.6	311.1	310.7	310.4	310.1
0.6	313.4	313.1	312.8	312.5	312.1	311.9
0.8	316.9	316.8	316.7	316.2	316	315.9
1	320.3	320.2	320.1	319.6	319.3	319.1

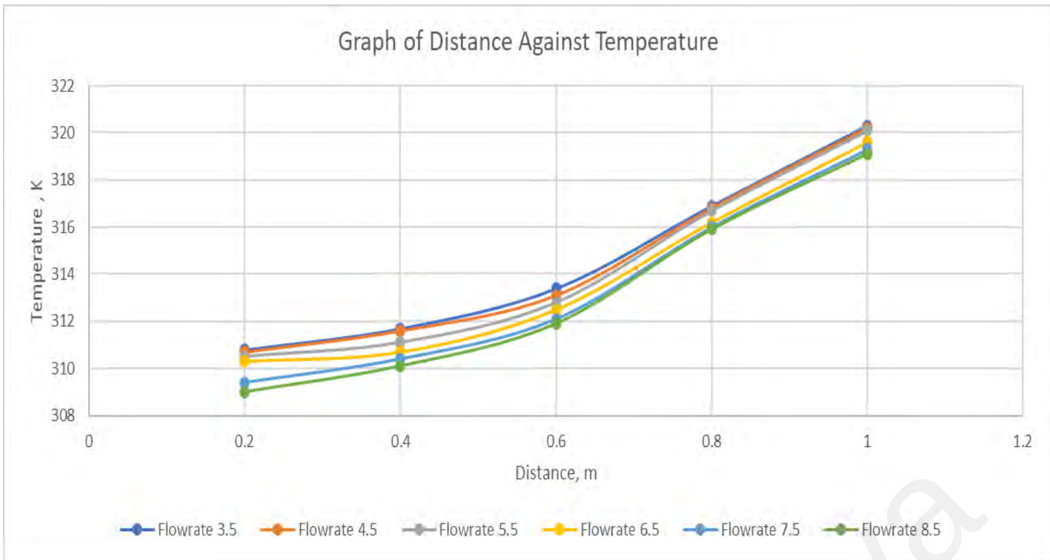


Figure 4-30: The Graph of Temperature against distance for GNP 0.05% run in a circular tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 320.3 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 319.1 K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 309 K and it travels through the tube the temperature increase to 310.1 K, 311.9 K, 315.9 K and 319.1 K.

GNP 0.05% - Square Tube

Table 4-13: Data of Temperature to distance and flowrate for GNP 0.05% square tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	309.8	309.8	309.6	309.7	309.7	309.6
0.4	311.5	311.5	311.5	311.5	311.5	311.3
0.6	314.4	314.1	313.9	313.6	313.2	313
0.8	315.1	315	314.8	314.8	314.3	314.2
1	319.5	319.5	319.4	319.4	319	318.8

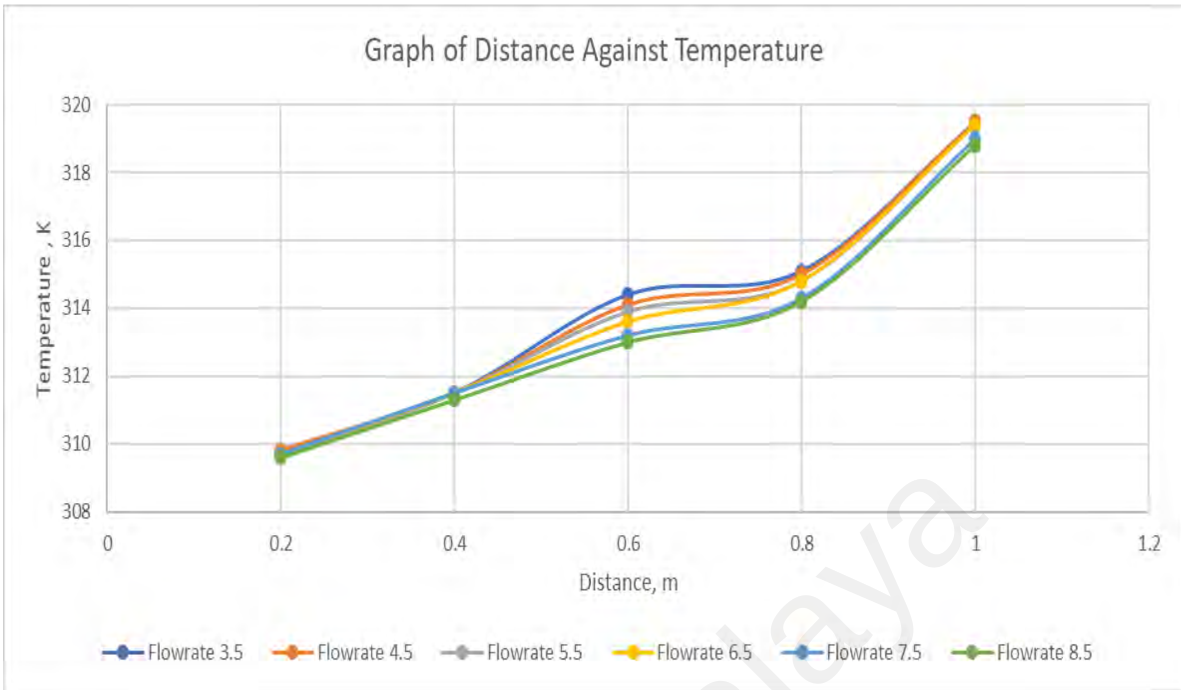


Figure 4-31: The Graph of Temperature against distance for GNP 0.05% run in a square tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 319.5 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 318.8 K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 309.6 K and it travels through the tube the temperature increase to 311.3 K, 313 K, 314.2 K and 318.8 K.

GNP 0.025% - Circular Tube

Table 4-14: Data of Temperature to distance and flowrate for GNP 0.025% circular tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	309.9	309.8	309.5	309.3	309.1	308.7
0.4	312.3	311.8	311.6	311.4	311.1	311
0.6	312.8	312.2	311.9	311.6	311.3	311.1
0.8	314.2	313.8	313.5	313.1	312.4	312
1	319.1	319	318.7	318.4	318.2	317.9

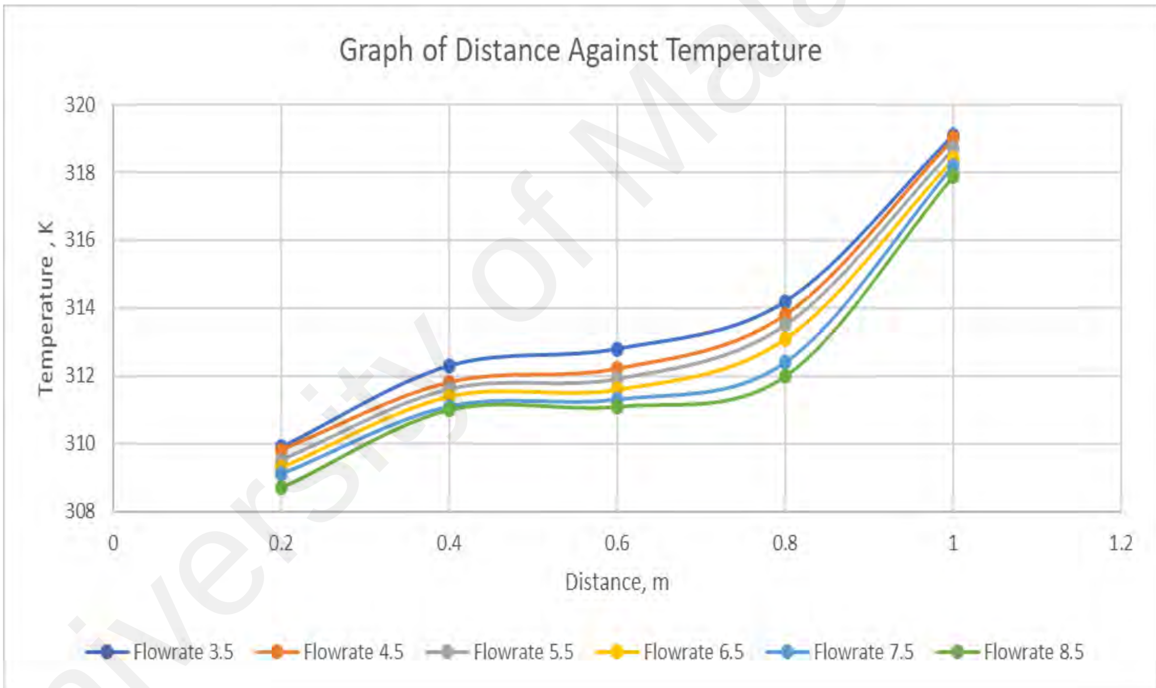


Figure 4-32: The Graph of Temperature against distance for GNP 0.025% run in a circular tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 319.1 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 317.9 K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 308.7 K and it travels through the tube the temperature increase to 311 K, 311.1 K, 312 K and 317.9 K.

GNP 0.025% - Square Tube

Table 4-15: Data of Temperature to distance and flowrate for GNP 0.025% square tube

	Temperature, K					
Position, m	Flowrate 3.5	Flowrate 4.5	Flowrate 5.5	Flowrate 6.5	Flowrate 7.5	Flowrate 8.5
0.2	310.7	310.4	310.3	310	309.7	309.6
0.4	312.5	312.1	312.1	311.8	311.5	311.3
0.6	314.4	314.1	313.9	313.6	313.2	313
0.8	315.5	315.2	315	314.8	314.3	314.2
1	320.5	320	319.9	319.4	319	318.8

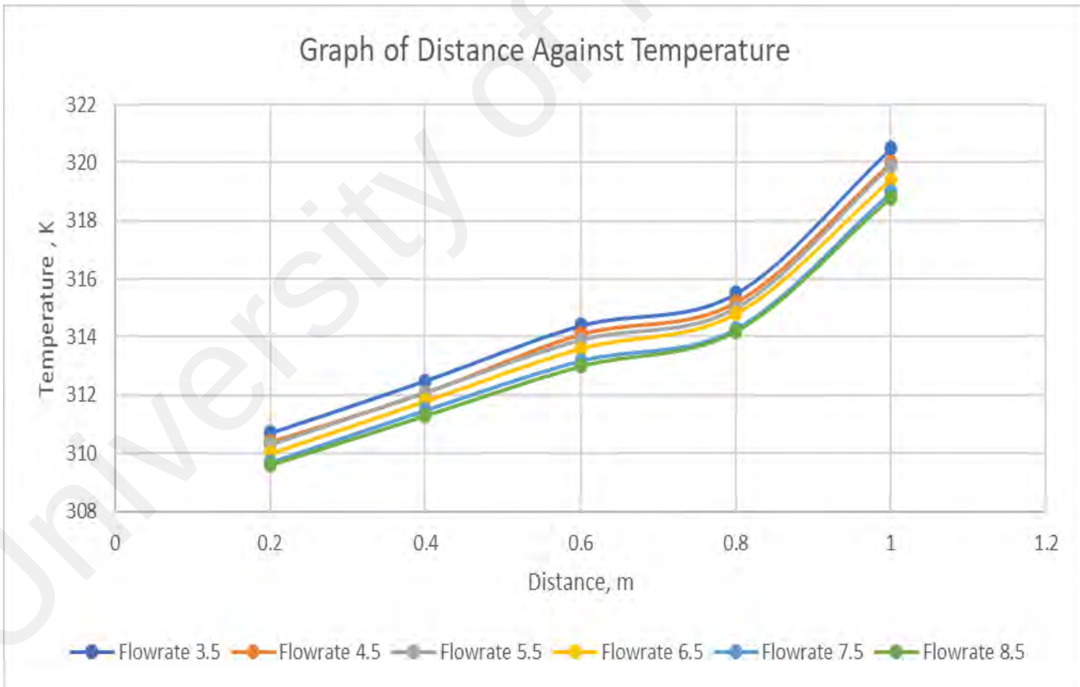


Figure 4-33: The Graph of Temperature against distance for GNP 0.025% run in a square tube.

From the graph, it can be seen that as the flowrate increase, the surface temperature of the tube decreases. The flowrate of 3.5 L/m has a surface temperature of 320.5 K at the 1m distance, meanwhile the flowrate of 8.5 L/m has a surface temperature of 318.8 K at the 1m distance. Besides that, it can be seen that the surface temperature increases as the water travel through the pipe from inlet to outlet as show by the graph. The temperature of the flowrate 8.5 L/m at the distance of 0.2 m is 309.6 K and it travels through the tube the temperature increase to 311.3 K, 313 K, 314.2 K and 318.8 K.

4.3 Comparison of Heat Transfer Coefficient and Nusselt Number for all Concentration against Velocity

4.3.1 Experimental

Circular Tube

Table 4-16: Data of Average Heat Transfer Coefficient and Average Nusselt Number to Velocity and Concentration for circular tube

Velocity (m/s)	0.743	0.955	1.167	1.379	1.592	1.804
H avg (water)	998.117	1029.548	1052.505	1106.643	1184.577	1217.317
H avg (0.1%)	1554.102	1707.798	1835.545	2045.893	2061.808	2947.237
H avg (0.05%)	1469.022	1503.554	1586.954	1685.746	1551.182	1649.320
H avg (0.025%)	1204.521	1207.359	1347.276	1422.064	1423.522	1494.896

Velocity (m/s)	0.743	0.955	1.167	1.379	1.592	1.804
Nu avg (Water)	16.363	16.878	17.254	18.142	19.419	19.956
Nu avg (0.1%)	21.889	24.053	25.853	28.815	29.040	41.510
Nu avg (0.05%)	22.998	23.539	24.845	26.391	24.285	25.821
Nu avg (0.025%)	19.330	19.376	21.621	22.821	22.845	23.990

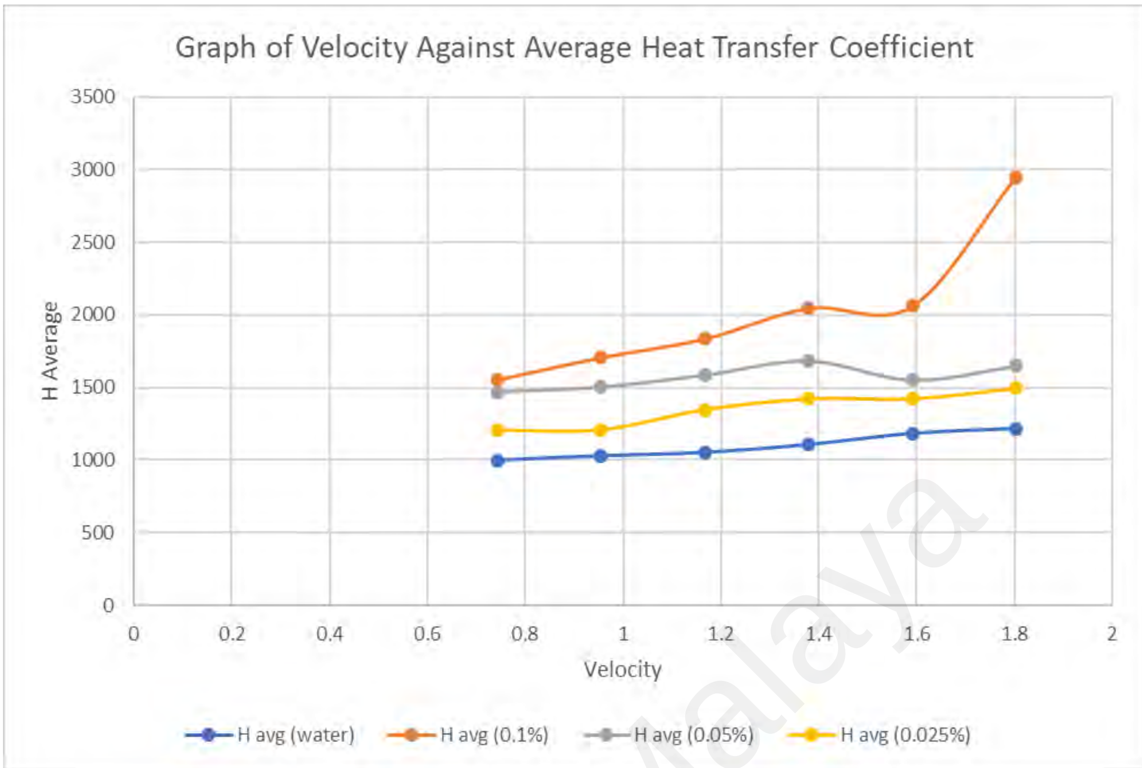


Figure 4-34: The Graph of Heat Transfer Coefficient against velocity for various concentration.

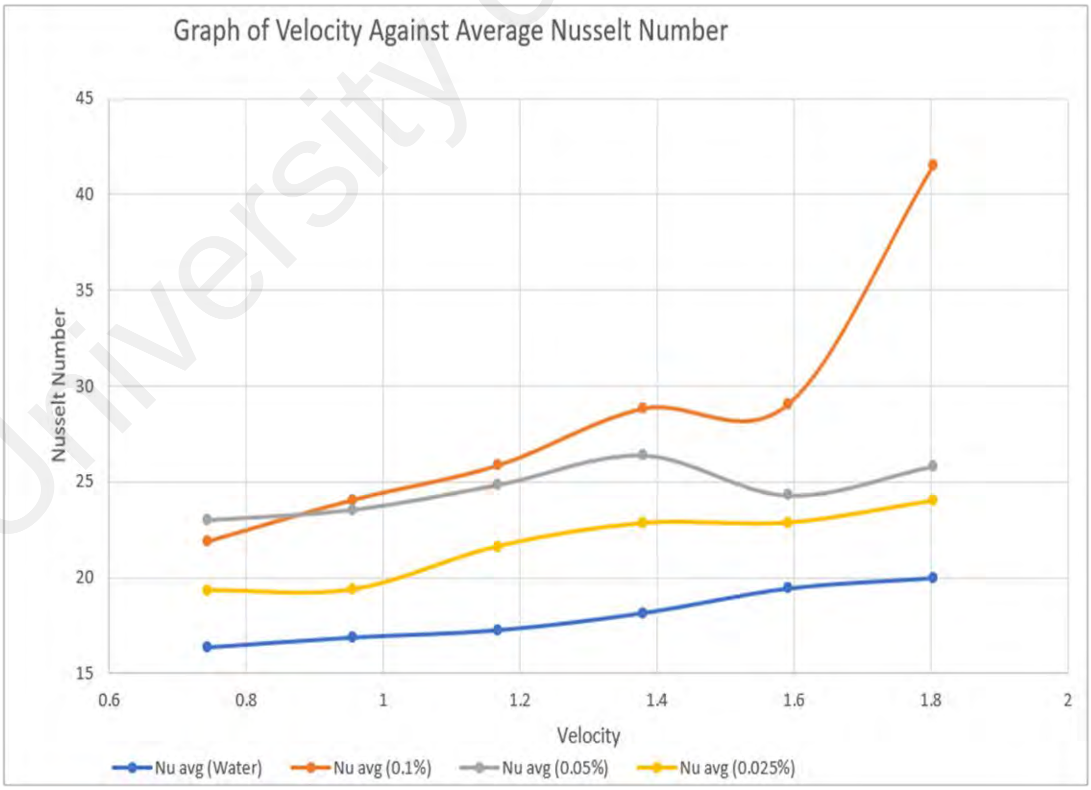


Figure 4-35: The Graph of Nusselt Number against velocity for various concentration.

Square Tube

Table 4-17: Data of Average Heat Transfer Coefficient and Average Nusselt Number to Velocity and Concentration for square tube

Velocity (m/s)	0.583	0.750	0.917	1.083	1.250	1.417
H avg (water)	605.404	604.638	605.058	612.648	643.871	661.671
H avg (0.1%)	732.873	734.609	743.310	777.042	798.579	803.766
H avg (0.05%)	649.549	653.116	661.484	662.272	672.787	682.101
H avg (0.025%)	611.344	629.028	634.864	651.712	672.787	682.101

Velocity (m/s)	0.583	0.750	0.917	1.083	1.250	1.417
Nu avg (Water)	9.925	9.912	9.919	10.043	10.555	10.847
Nu avg (0.1%)	10.322	10.347	10.469	10.944	11.248	11.321
Nu avg (0.05%)	10.169	10.225	10.356	10.368	10.533	10.679
Nu avg (0.025%)	9.811	10.095	10.188	10.459	10.797	10.946

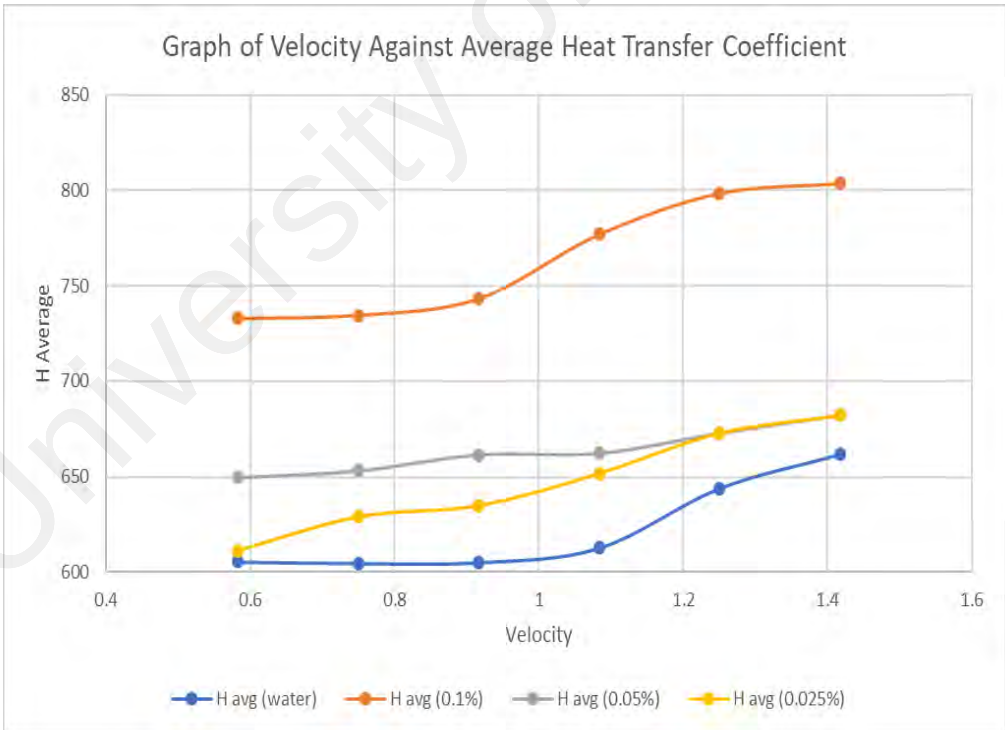


Figure 4-36: The Graph of Heat Transfer Coefficient against velocity for various concentration.

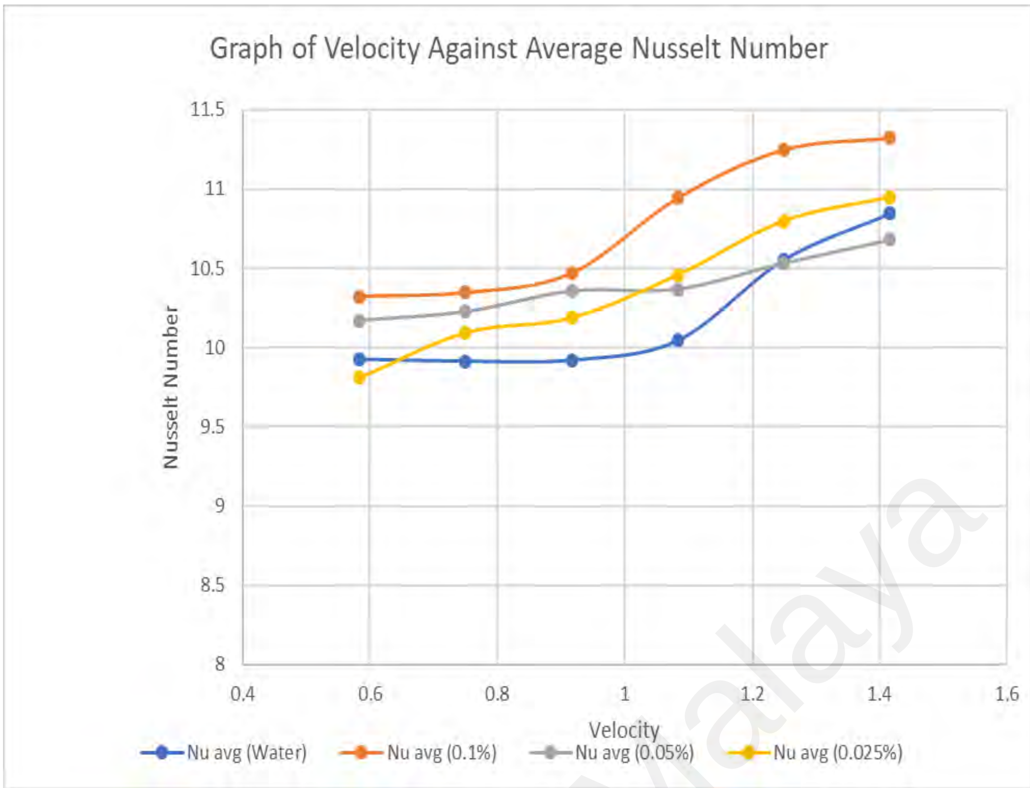


Figure 4-37: The Graph of Nusselt Number against velocity for various concentration.

4.3.2 Numerical Analysis

<u>Mesh Independence Study</u>

The optimum mesh size had to be determined to run the simulation with the ideal number of nodes thus saving time and obtaining an accurate result. The mesh independent study was conducted with the mesh size of 0.9m, 0.95m, 1m, 1.5m. Figure 4.38 show the results of the mesh independent study in which mesh size 0.9,0.95 and 1 m are acceptable with minimum fluctuation in their temperature.

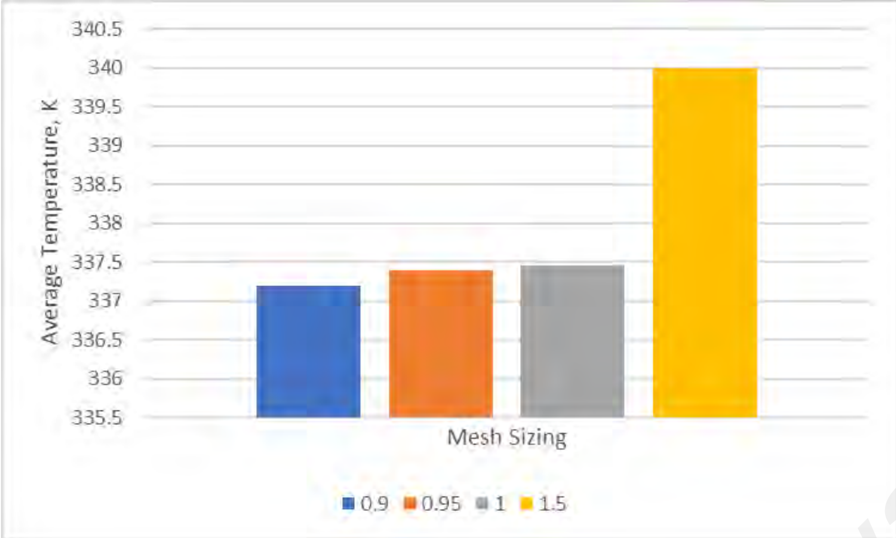


Figure 4-38: Mesh Independent Study

Circular

Table 4-18: Data of Average Heat Transfer Coefficient and Average Nusselt Number to Velocity and Concentration for circular tube

Velocity (m/s)	0.743	0.955	1.167	1.379	1.592	1.804
H avg (water)	708.478	746.896	773.880	793.584	808.490	820.045
H avg (0.1%)	1585.617	1777.910	1928.745	2049.669	2148.444	2230.163
H avg (0.05%)	1067.960	1154.381	1217.511	1265.229	1302.501	1332.153
H avg (0.025%)	856.217	912.596	952.534	982.192	1004.911	1022.569

Velocity (m/s)	0.743	0.955	1.167	1.379	1.592	1.804
Nu avg (Water)	11.614	12.244	12.687	13.010	13.254	13.443
Nu avg (0.1%)	22.333	25.041	27.165	28.869	30.260	31.411
Nu avg (0.05%)	16.720	18.072	19.061	19.808	20.391	20.856
Nu avg (0.025%)	13.741	14.645	15.286	15.762	16.127	16.410

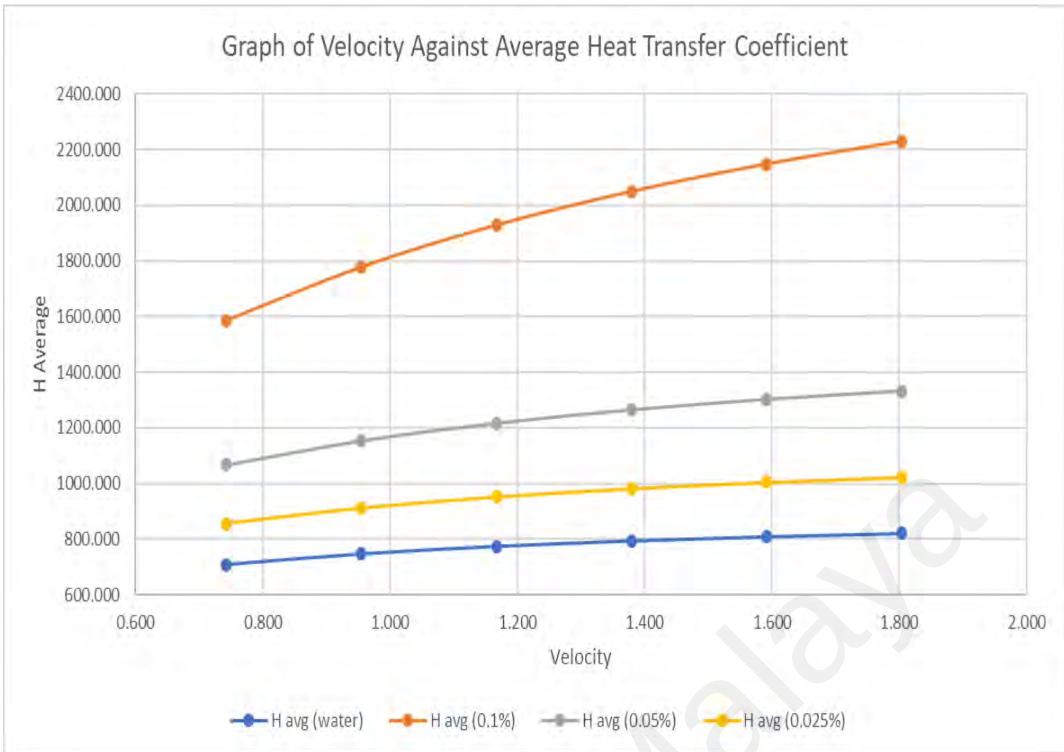


Figure 4-39: The Graph of Heat Transfer Coefficient against velocity for various concentration.

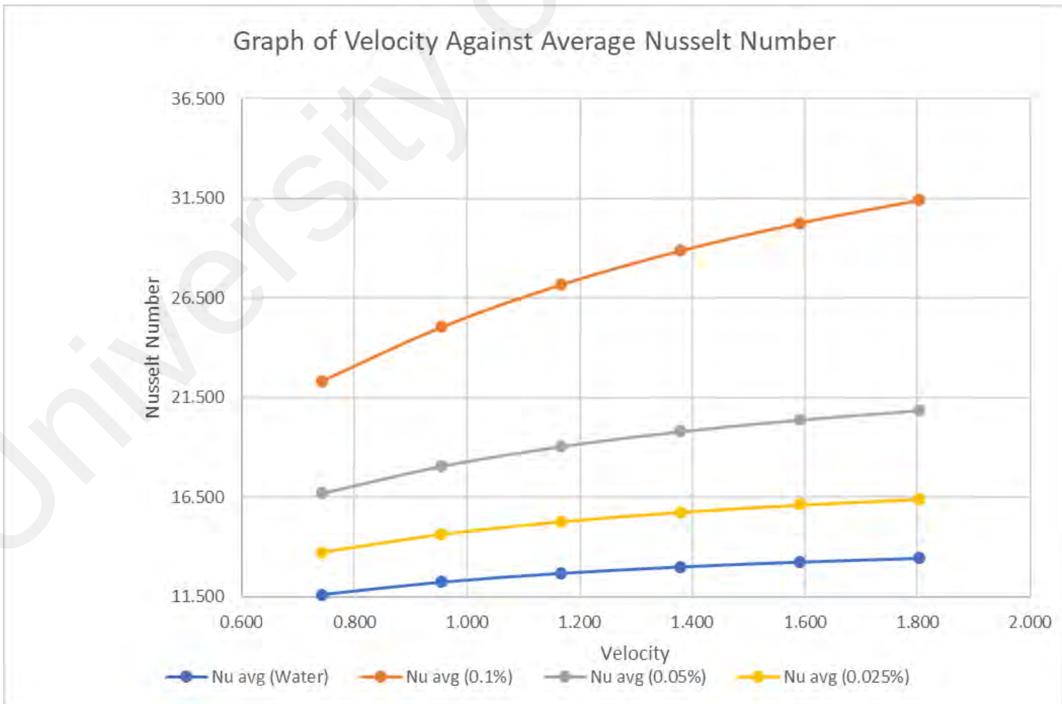


Figure 4-40: The Graph of Nusselt Number against velocity for various concentration.

Square

Table 4-19: Data of Average Heat Transfer Coefficient and Average Nusselt Number to Velocity and Concentration for square tube Square

Velocity (m/s)	0.583	0.750	0.917	1.083	1.250	1.417
H avg (water)	355.398	358.725	360.867	362.370	363.489	364.346
H avg (0.1%)	487.809	494.630	499.090	502.246	504.580	506.389
H avg (0.05%)	397.593	401.903	404.703	406.671	408.116	409.251
H avg (0.025%)	379.866	383.795	386.339	388.128	389.407	390.487

Velocity (m/s)	0.583	0.750	0.917	1.083	1.250	1.417
Nu avg (Water)	5.826	5.881	5.916	5.940	5.959	5.973
Nu avg (0.1%)	6.871	6.967	7.029	7.074	7.107	7.132
Nu avg (0.05%)	6.225	6.292	6.336	6.367	6.389	6.407
Nu avg (0.025%)	6.096	6.159	6.200	6.229	6.249	6.267

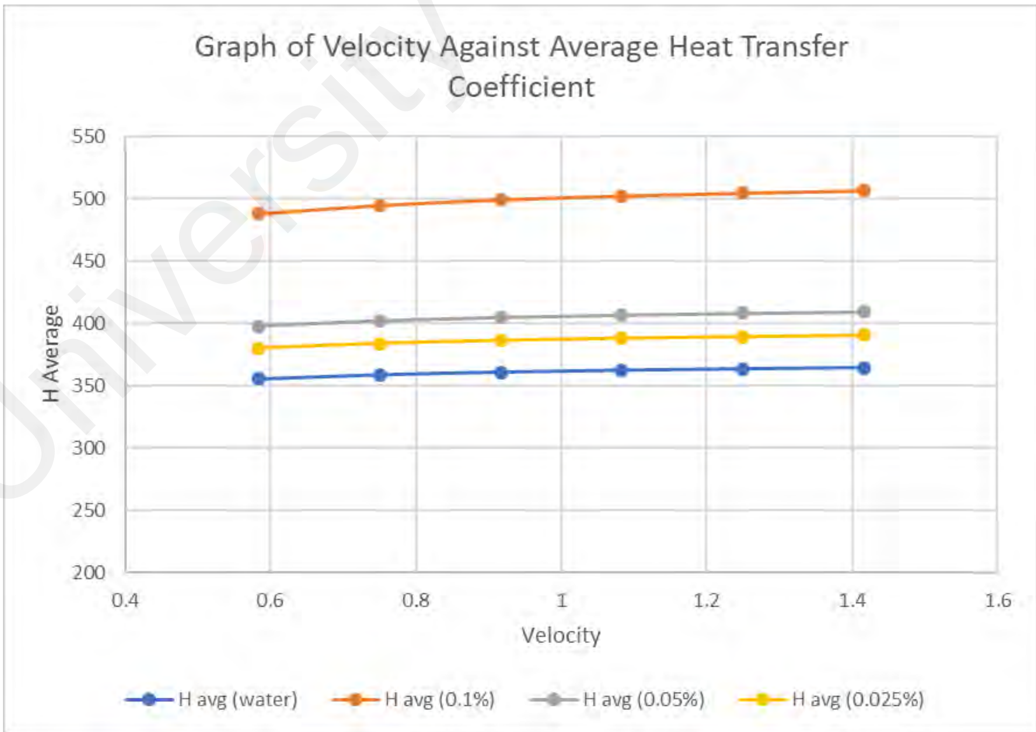


Figure 4-41: The Graph of Heat Transfer Coefficient against velocity for various concentration.

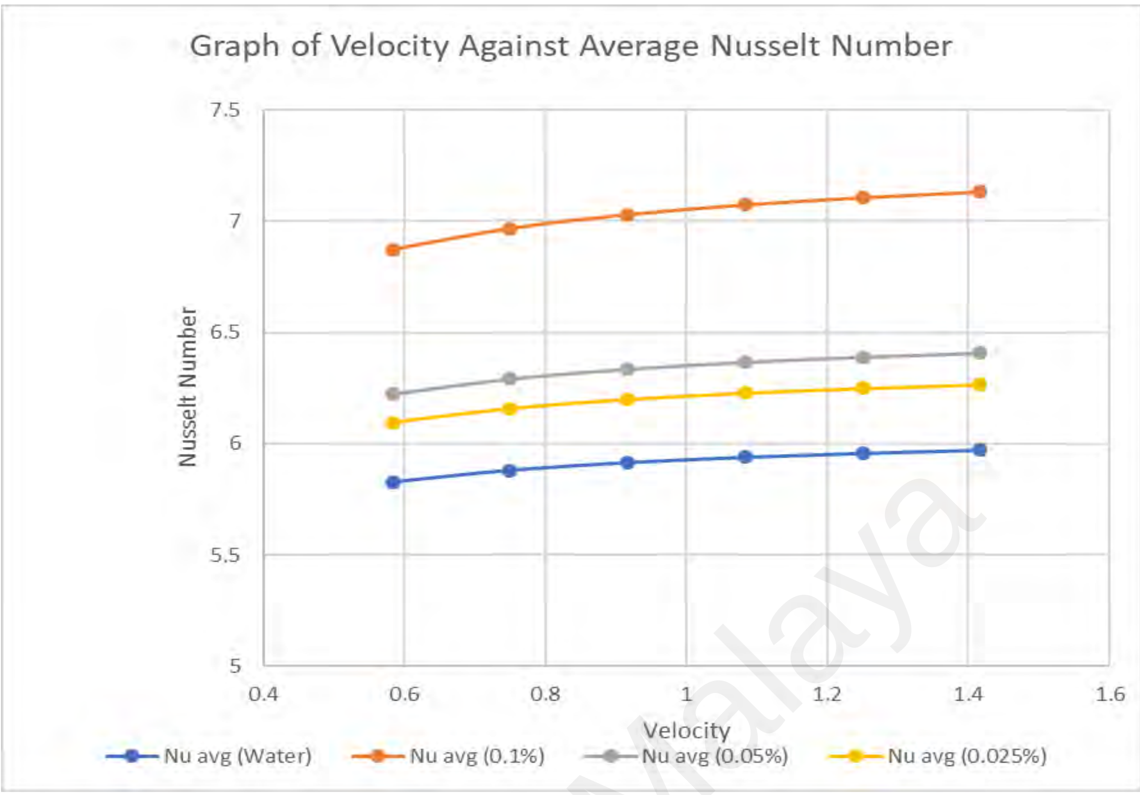


Figure 4-42: The Graph of Nusselt Number against velocity for various concentration.

From the graphs above for both the circular and square shaped tubes, it can be observed that the highest heat transfer coefficient and Nusselt Number is represented by the GNP with 0.1% concentration. This is due to the presence of nanoparticles in the nanofluid which increases the thermal conductivity the fluid.

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

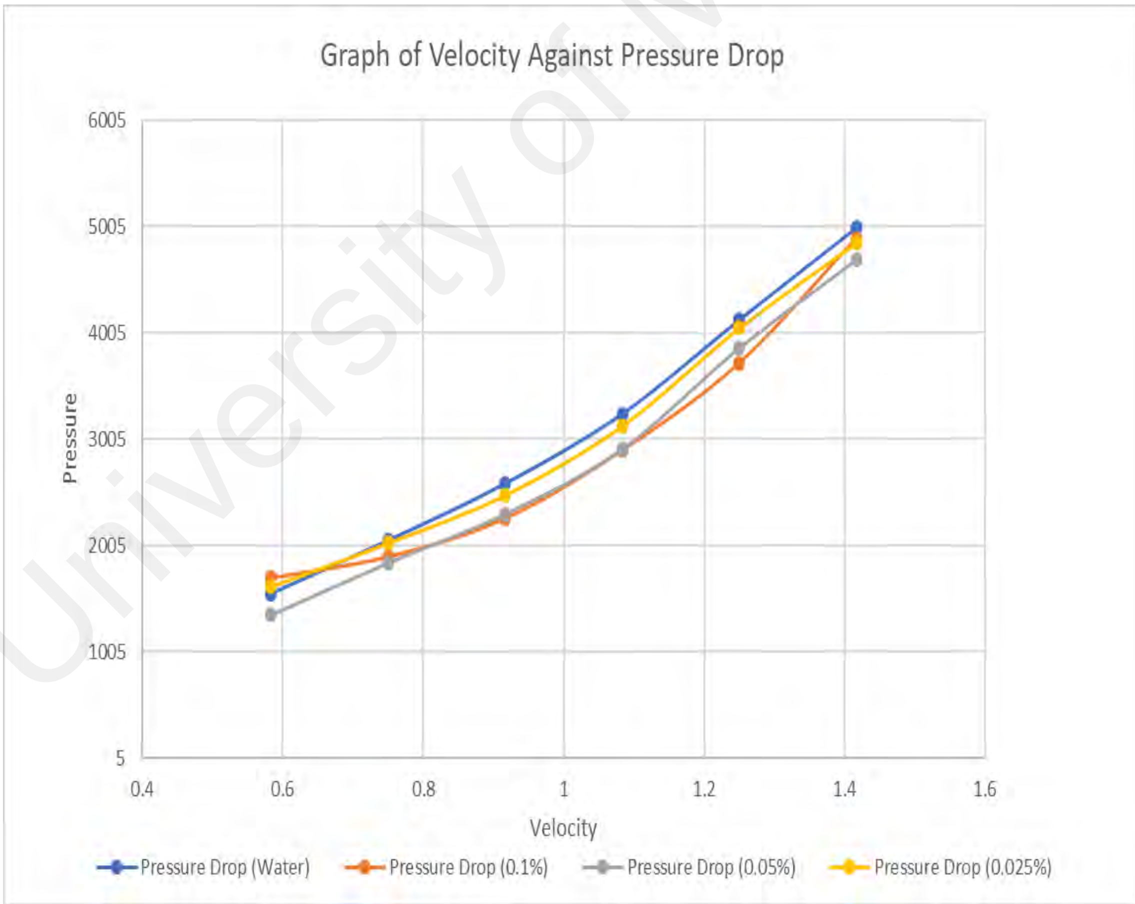
When comparison is done between different concentration of GNP nanofluid, the highest concentration exhibits the best heat transfer capability with the highest Nusselt number. This is evident when the gradient for the 0.1% is the highest, then followed by 0.05% and 0.025%.

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

4.4 Pressure Drop

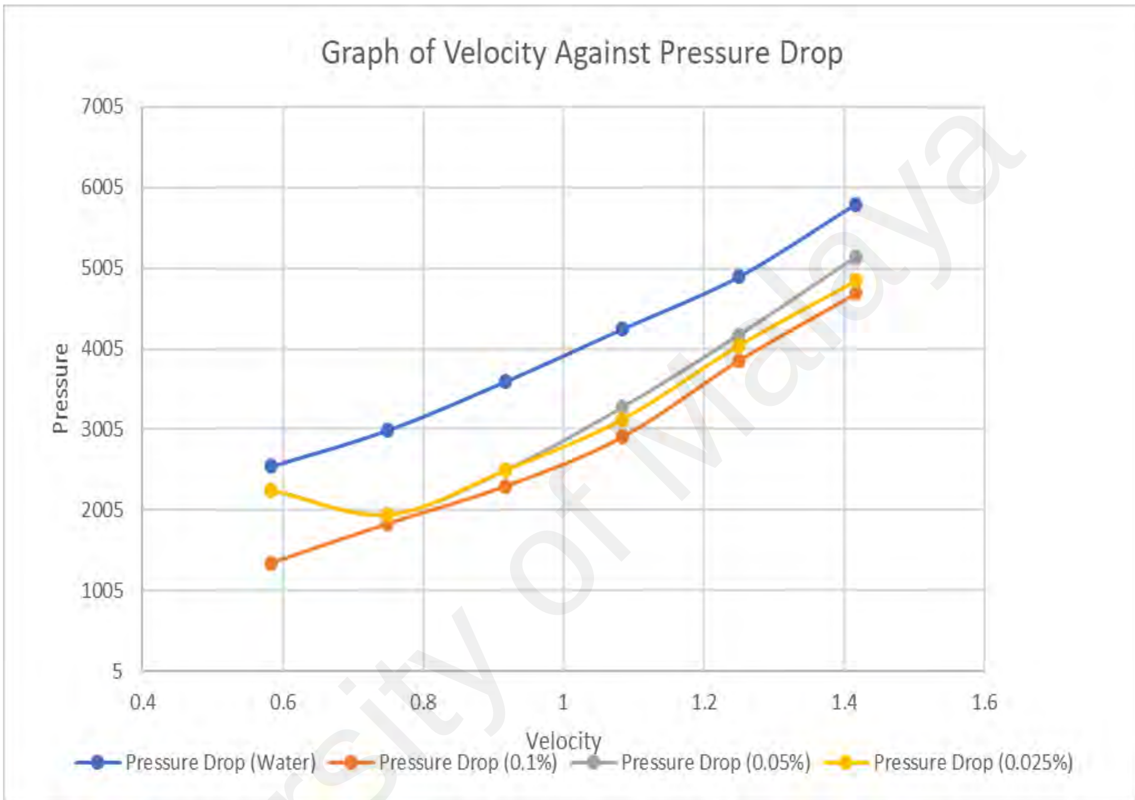
<u>Circular Tube</u>

Velocity (m/s)	0.58333333	0.75	0.916666667	1.083333333	1.25	1.416667
Pressure Drop (Water)	1550	2050	2585	3240	4125	4990
Pressure Drop (0.1%)	1700	1900	2260	2900	3720	4890
Pressure Drop (0.05%)	1350	1840	2300	2910	3860	4690
Pressure Drop (0.025%)	1620	2030	2480	3130	4050	4850



Square Tube

Velocity (m/s)	0.58333333	0.75	0.916666667	1.083333333	1.25	1.416667
Pressure Drop (Water)	2550	3000	3600	4250	4900	5800
Pressure Drop (0.1%)	1350	1840	2300	2910	3860	4690
Pressure Drop (0.05%)	2250	1950	2500	3280	4180	5150
Pressure Drop (0.025%)	2250	1950	2500	3130	4050	4850



From the graph, it can be observed that as the velocity or flow rate increase, the pressure drop increases. This is shown in the graph as both the circular and square tube exhibits the same result.

CHAPTER 5: CONCLUSION

All the objectives of this study were addressed in the Results and discussion with the outcome analyzed.

As per conclusion, it can be said that the circular shape tube exhibits better heat transfer capability in comparison to the square tube as the Nusselt number is higher in the circular conduit. The heat transfer coefficient is also found to be higher in the circular tube.

From the study, we can also conclude that the concentration of GNP does have effect to the heat transfer capability of the working fluid. The higher the concentration, the better the heat transfer capability. This is proven through the Nusselt Number and Heat Transfer coefficient of GNP 0.1% which was higher than the other concentrations.

Besides that, this is also confirmed by the numerical analysis done using ANSYS Fluent software where the GNP 0,1% had the highest Nusselt number. All the GNP concentrations also exhibits better heat transfer capability in comparison to water.

Finally, the analytical equations were analyzed to identify the thermal conductivity, specific heat capacity, density and viscosity. This equation proves that there is indeed an increase in the thermal conductivity when graphene nanoplatelets are present in water.

5.1 Future Work

Current work focused on the improvement of working fluid only meanwhile, the future works could explore the combination of both the enhancement of working fluid and betterment of heat exchanger shape to a more complex design such as S-shapes. Combination can be done also in terms of flow where step flow in involved to enhance the heat transfer growth.

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