STUDY OF HEAT TRANSFER AND FRICTION LOSS ANALYSIS OF FLOWING FLUID IN DIFFERENT CONFIGURATION OF CLOSED CONDUIT FLOW

FACULTY OF MECHANICAL ENGINEERING
UNIVERSITY OF MALAYA
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STUDY OF HEAT TRANSFER AND FRICTION LOSS ANALYSIS OF FLOWING FLUID IN DIFFERENT CONFIGURAYION OF CLOSED CONDUIT FLOW

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.

Field of Study: Heat Exchanger

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ABSTRACT

The heat exchanger available on market satisfies the elementary conditions. However, there are very few research on difference shape and its efficiency on heat exchanger. With new design of shape of this study is intend to improve the efficiency of heat exchanger. A CFD package (ANSYS FLUENT) will be use for the numerical study of heat transfer and flow characteristics of a single pipe heat exchanger for annular flow, with 2 shape of pipe and the results then will be compared. The simulation will be carry out for water to water heat transfer characteristics and for same length and same diameter of tube and annulus and for same input temperature. Consequently this study concerned on nano fluid with different parameter which has the best heat transfer in circular and square tube. The heat transfer coefficient will be measured and has compared

Keywords:Heat Exchanger:Heat transfer;Characteristics;Ansys; Shape

ABSTRAK

Penukar haba yang terdapat di pasaran memenuhi syarat asas. Walau bagaimanapun, terdapat sedikit kajian mengenai perbezaan bentuk dan kecekapannya pada penukar haba. Dengan reka bentuk bentuk baru kajian ini bertujuan untuk meningkatkan kecekapan penukar haba. Pakej CFD (ANSYS FLUENT) akan digunakan untuk kajian berangka ciri pemindahan haba dan cir aliran penukar haba paip tunggal untuk aliran anulus, dengan 2 bentuk paip dan hasilnya kemudian akan dibandingkan. Simulasi akan dilakukan untuk ciri pemindahan haba air ke air dan panjang dan diameter tiub dan anulus yang sama dan untuk suhu input yang sama. Oleh itu, kajian ini memusatkan perhatian pada cecair nano dengan parameter berbeza yang mempunyai pemindahan haba terbaik dalam tiub bulat dan persegi. Pekali pemindahan haba akan diukur dan telah dibandingkan

Keywords: Penukar Haba: Pemindahan haba; Ciri aliran; Ansys; Bentuk

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LIST OF SYMBOLS AND ABBREVIATIONS

Di	:	Outer Diameter
Do	:	Outer Diameter
L	:	Length
D	:	Diameter
Re	:	Reynold Number
Nu	:	Nusselt Number

INTRODUCTION

1.1 Introduction

Constant and fast mechanical advances in modern handling necessitate that plan and activity issues be settled as fast as conceivable so as to keep organizations serious, especially as far as vitality productivity and low expenses. For a long time, tests and experimental investigation have been the favored arrangement devices for mechanical examination. Notwithstanding the hearty and solid nature of test technique, certain elements limit its appropriateness scope. For instance, streams in process establishments are typically extremely perplexing; the utilization of test technique in related examination may request critical rearrangements or countless analyses to accomplish a worthy arrangement, showing both expense and time limitations. Therefore it has become a need to utilize propelled demonstrating and reproduction devices in industry, and the quantity of ventures profiting by these items keeps on growing. Computational liquid elements (CFD) is a PC reenactment procedure utilized for liquid stream and warmth move demonstrating. In light of progressively ground-breaking PC assets, CFD can be applied to illuminate modern stream and complex marvel issues. Be that as it may, there still exists an absence of information for CFD applications in various modern territories empowering the improvement of general rules in explicit numerical warmth and stream considers. This proposition endeavors to give CFD usage techniques and information suitable for those shifted mechanical applications.

To portray the conduct of stream elements, administering scientific conditions are settled numerically. This is what is known as computational reenactment. After effects of this reenactment incorporate the approximated speed field and appropriation of temperature and weight in the whole stream area. Related physical properties (e.g., temperature profiles and thickness) can be separated effectively from the displaying. The goal of much ebb and flow investigates is to improve the warmth and mass exchange models and to expand the scope of compound and physical models in CFD codes for application in modern issues. Liquid streams and warmth move assume basic jobs in mechanical preparing. For instance, air or water streams are normally utilized for cooling purposes. Improving the cooling execution requires knowledge into the cooling stream profile. Ordinarily, stream data is gained by estimating in trial test offices or directing stream representation examines. The two strategies have impediments, and it isn't generally a simple occupation to get all stream boundaries. Numerical strategies went with new current and fast PCs have as of late created methods to expel these impediments. There are heap cases in industry that can be considered and advanced utilizing numerical recreations. Numerous procedures contain liquid streams having various stages or part blends, which must all be remembered for the recreation. For instance, movement of air pockets or beads in a liquid, blending vessels, heat exchangers, heaters, or HVAC hardware are run of the mill cases that can be concentrated all the more effectively by computational recreation. In turbines, fans or whatever other applications that contain moving parts, the numerical recreation can be actualized effectively, if right conditions like time-variety of stream calculations are thought of. In such cases, generally what is essential to be determined is transient stream field. In this theory, numerical techniques are applied in various mechanical applications including: Power transformers cooling framework and CO2/H2O condenser in an oxy-fuel process.

1.2 Overview

This study highlight the enhancement of heat transfer using nanofluids and with different type of configuration.

1.3 Problem Statement

The heat exchanger available on market satisfies the elementary conditions. However, there are very few research on difference shape and its efficiency on heat exchanger. With new design of shape of this study is intend to improve the efficiency of heat exchanger.

1.4 Research Objective

The objective of this project is to:

1. To explore study different configuration of low passage and explore the all and find out highest heat transfer combination.
2. To evaluate the flow characteristics and compare with the heat transfer enhance.
3. To study and recommend which design have the best heat transfer.

1.5 Research Scope

This project is intertwined with the heat exchanger design. As a result, it required research on the fundamentals and characteristics of each type of heat exchanger. The design selection tool was created based on an interpretation of the concept of designing for different types of heat exchangers. In the first stage of the project, all of the properties and equations related to developing the heat exchanger were defined. The thermal characteristics of the fluids, as well as the physical qualities that contribute to the heat exchanger's performance, have been determined for all of the key parameters for the heat exchanger. The heat transfer coefficient, pressure drop, and effectiveness of the heat exchanger determine the heat exchanger's performance. The heat exchanger design tool has been developed in the project's second stage. The tool was put to the test with a case study after it was finished. The heat exchanger had to cool high-temperature air using cooled water for the case study. The tool was created to cater to three different types of heat exchangers: plate fin heat exchangers, finned tube heat exchangers, and shelved tube heat exchangers.

LITERATURE REVIEW

There are many different types of heat exchangers on the market. It is critical to choose the best appropriate heat exchanger for the system. The efficiency of the system will be affected by the heat exchanger compatibility. In every system, it is always better to aim for the system's maximum performance, as this will not only extend the system's life but also lower the cost of operation and maintenance. When it comes to selecting the right heat exchanger, there are numerous aspects to consider. It is critical to decide on the type of heat exchanger to utilize in the system early on in the design process.

2.1 Fundamentals of Heat Transfer

The total energy balance and the equation are considered when calculating any heat transfer.

$$Q = \dot{m}_{hot} C_{p,hot} \left(T_{hot,in} - T_{hot,out}\right) = \dot{m}_{cold} C_{p,cold} \left(T_{cold,o}\right.$$

$$Q = UAF\Delta T_{lm}$$

Where $F = Correction\ Factor$

$\Delta T_{lm} = Log\ Mean\ Temperature\ Differe$

$A = Total\ heat\ transfer\ area$

Figure 2-1: Heat Transfer Calculation

2.2 Shell and Tube Heat Exchanger

There are several factors which will affect the heat transfer coefficient of the shell sid e, which in turn will decide the heat transfer rate on the shell side. The fluid flow of the shell would be diverted from axial flow to top-to bottom flow or side to side flow in the present of baffles. Such changes in direction will increase the coefficientof heat transfer compared to the continuous flow along the axes of the pipes.Tube shape patterns affect turbulence and thus the coefficient of heat transfer e.g triangular pitch gives greater turbulence than square pitch. The narrower the distance between the baffle would also increase the amount of times the shellfluid changes its direction, resulting in greater turbulence. Tube size, clearance and fluid-flow characteristics will also affect the shell side coefficient.There is no real field of shell side flow where the shell fluid's mass velocity can be measured.It is due to the varying flow area around the diameter of the bundle, with different tube clearances in each longitudinal tube row. Obviously, the correlation obtained for fluids flowing in tubes is not applicable to fluids flowing through the tube.Particularly several terms are used in heat exchanger s pecification issue and one of the terms is"Rating". In particular, there are many terms used in specifications for heatexchangers and one of the terms is "cost." The term "ratin g" describes the computational process in which the inlet flow rate and temperature, the fluid properties and the parameters of the heat exchanger are taken as input and the outlet temperature and thermal duty or the necessary heat exchanger length are measured as output.

In the first step the initial conditions were determined which are the thermal properties of the heat exchanger. Such initial conditions include fluid flow rate, fluid temperature range, and tube length and arrangement. Basically the next stage involved in calculation of physical properties of the heat exchanger. First, is the total number of tubes measured. The next calculation is U-Tube heat load measurement and test. There are two sets of calculations for this component, namely calculation of the tube side heat transfer coefficient and calculation of the shell side heat transfer coefficient. Last but not least is the calculation and checking of pressure drop. A heat exchanger's efficiency can be calculated by four properties, namely number oftubes and shell diameter, heat transfe r rate, total heat transfer coefficient, and decrease in tube and shell side pressure.. Reynolds Number in tube and Heat Transfer Coefficient in tube vs. Number of Tubes. Reynolds Number and Heat Transfer Coefficient are gradually decreased corresponding to a high number of Tubes. This is because the fluid has a high velocity with a steady mass flow rate.

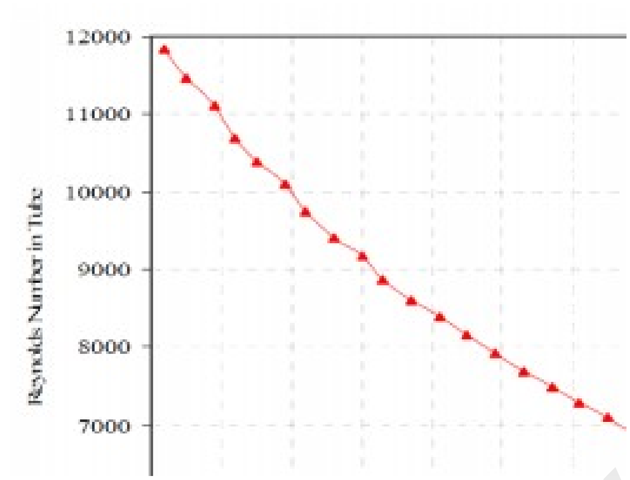

Figure 2-2: Effect of Reynolds Number on Number of Tubes

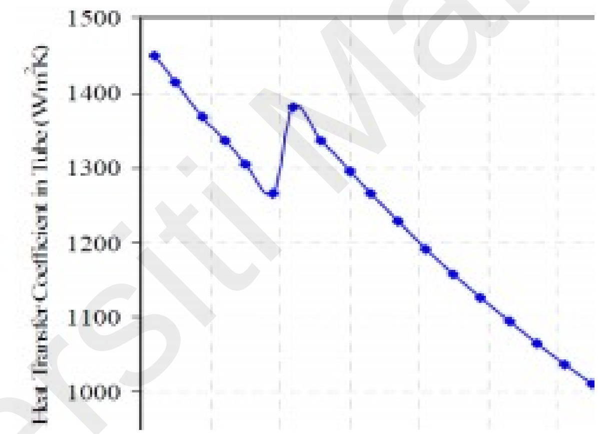

Figure 2-3: Effect of Heat Transfer Coefficient on Number of Tubes

There is a small increase in the heat transfer coefficient between the total number of tubes 220 and 240, due to the change from turbulent flow to transition flow. Reynolds Number in Shell and Heat Transfer Coefficient for tube versus Pipe Size. The increasing trend of Reynolds Number (Re) curves and the heat transfer coefficient (h) shown in the graph shows a steady decrease in both Re and h As high as Tube Total Length (L). This graph also shows, however, an increase in Reynolds Number due to the increase in Baffles number.

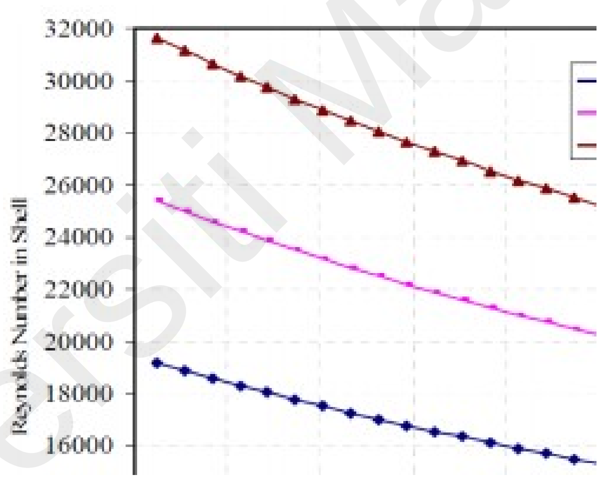

Figure 2-4: A fact of Reynolds Number on Number of Baffles and Length of Tube

2.3 Nanofluid

A nanofluid is a fluid, called nanoparticles, containing particles of a nanometer size. These fluids are colloidal clusters of nanoparticles found in a base fluid. The nanoparticles used in nanofluids are typically made of nanotubes made from metal, oxides, carbides, or carbon.

The nanoparticles we going to use is silica dioxide (SiO2) or known as silica. It is made up of two element which is silica and two oxygen bond. It is widely use in food industry, pharmaceutical industry, and nowadays use as medium for heat transfer enhance. Besides that, silica dioxide may found naturally.

2.4 Thermo-physical properties of nanofluids with varied concentrations

Heat Transfer Fluids	Thermo-physical Properties			
	k (W/m.K)	μ (Pa. s)	Specific Heat Cρ	ρ (m^3/kg)
DI-water (25 C)	0.607	0.000891		997.1
	SiO2-water Nanofluids (% vol.)			
SiO2	Yu and Choi	Einstien	Pak and Choi	Pak and Choi
SiO2 0.025%	0.60718	0.0008915	4178.142	997.3058
SiO2 0.05%	0.60737	0.0008921	4177.283	997.6115
SiO2 0.075%	0.60755	0.0008926	4176.425	997.9173
SiO2 0.1%	0.60774	0.0008932	4175.566	998.223

Table 2-1: Nanofluids with varied concentration

Table 1
Physical properties of metal oxide nanomaterials.

Nanoparticle	Thermal conductivity, W/m K	Density, kg/m^3	Specific heat, J/kg K	Reference
SiO_2	1.4	2220	745	Vajjha et al. [29]
Al_2O_3	36.0	3880	773	Pak and Cho [10]
TiO_2	8.4	4175	692	Pak and Cho [10]
Fe_3O_4	80.4	5180	670	Sundar et al. [30]
ZrO_2	1.7	5500	502	Kothandaraman and Subramanyam [31]
ZnO	29.0	5600	514	Vajjha and Das [32], Hong et al. [33]
CuO	69.0	6350	535	Fotukian and Nasr Esfahany [34]

Table 2-2: Physical Properties of nanomaterials

METHODOLOGY

3.1 Methodology

The goal of this project's research is to gather information in the field of heat exchangers. The goal of the study is to identify key characteristics and equations related to heat exchanger design. As a result, the research was concentrated on the heat exchanger design stage, as it is where the design considerations and consequences of design were studied. The physical design of a heat exchanger has an impact on its performance. The heat exchanger's size, number of tubes, and heat transfer area all affect the heat exchanger's performance. As a result, critical information and equations were acquired from reference books, journals, and other online sources. As previously stated, the project's next phase concentrated on the tool's development. All of the attributes and characteristics were gathered using Ansys Fluent to build the tool.

3.1.1. Research Scope

Two varieties of the most typical heat exchanger have been chosen for this project. The tool created for this project is based on understanding of the two types of heat exchanger configurations: circular and square. The operation of each type of heat exchanger is tailored to a specific goal, such as cooling or heating a fluid using nanofluid. The instrument was built and tested for this project to determine the system's heat transfer rate and flow characteristics.

3.2 Tool Required

Ansys Fluent was used to create the design tool since it is more convenient and user pleasant.

Model Data

		Symbol		Units
Pipe	Inner Dia	Di	0.037	m
	Outer Dia	Do	0.04	m
	Length	L	1.38	m
	Thickness	(Do-Di)	0.0015	m
Rod	Dia	D	0.0127	m
	Length	L	1.40	m

Table 3-1 : Model Set up

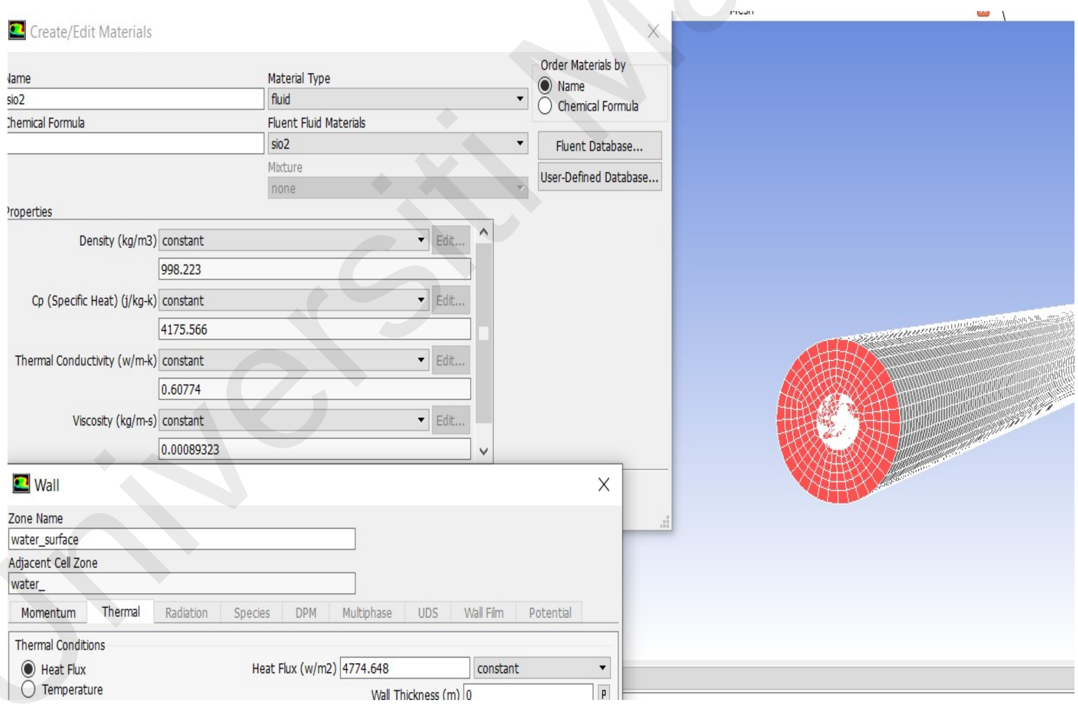

Figure 3-1: Circular Tube Set up

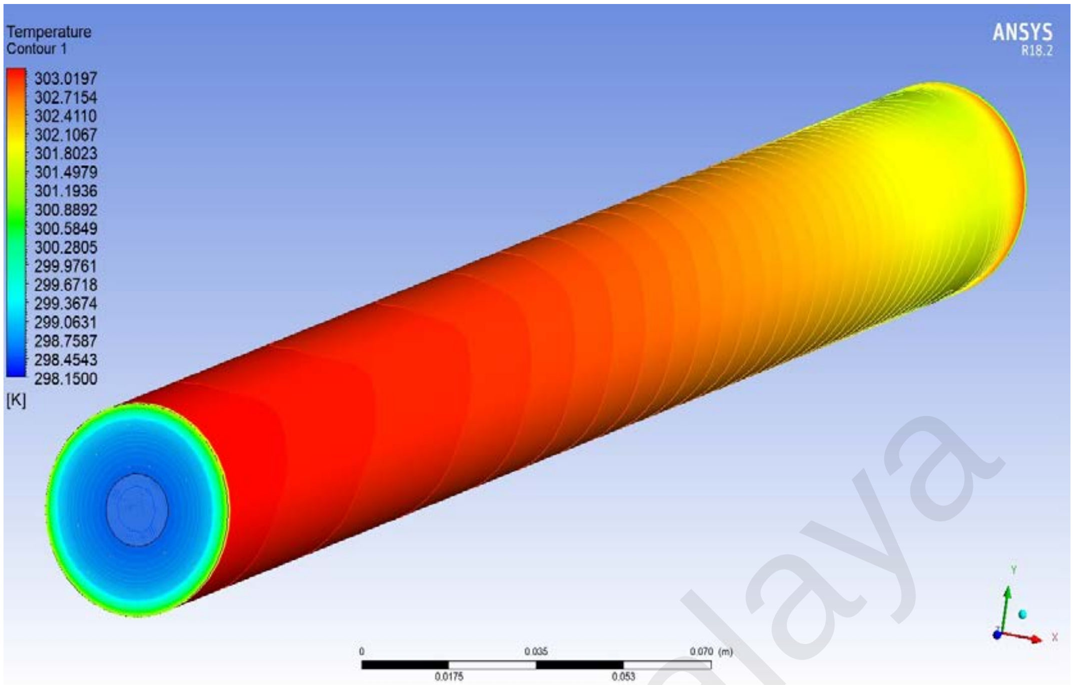

Figure 3-2 : Circular Tube Temperature Contour

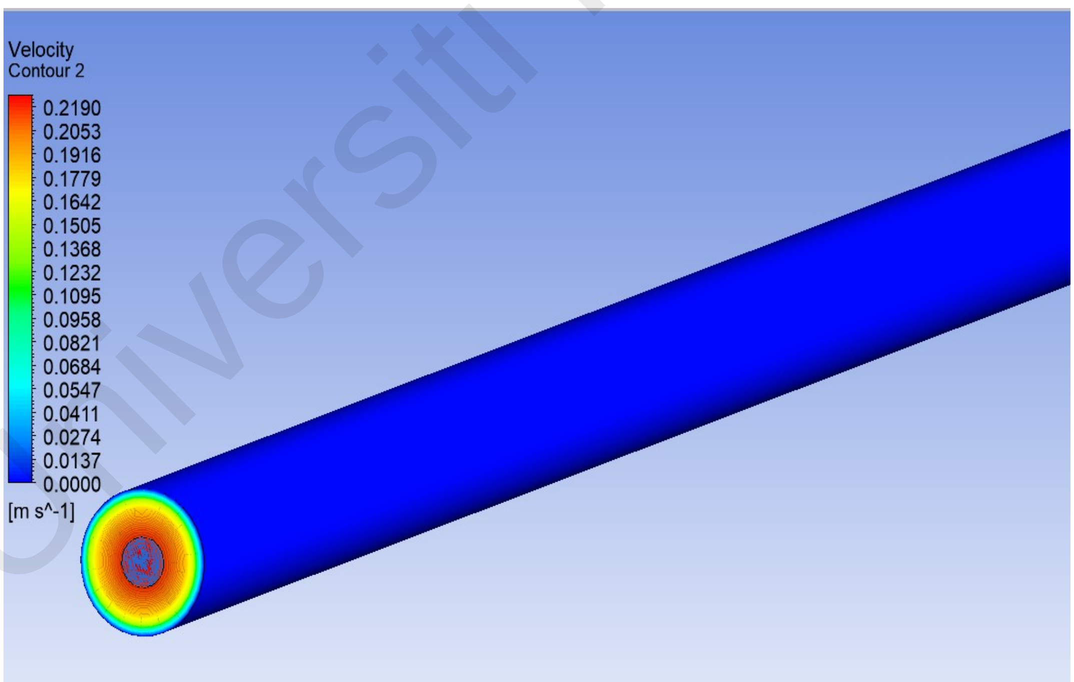

Figure 3-3 : Circular Tube Velocity Contour

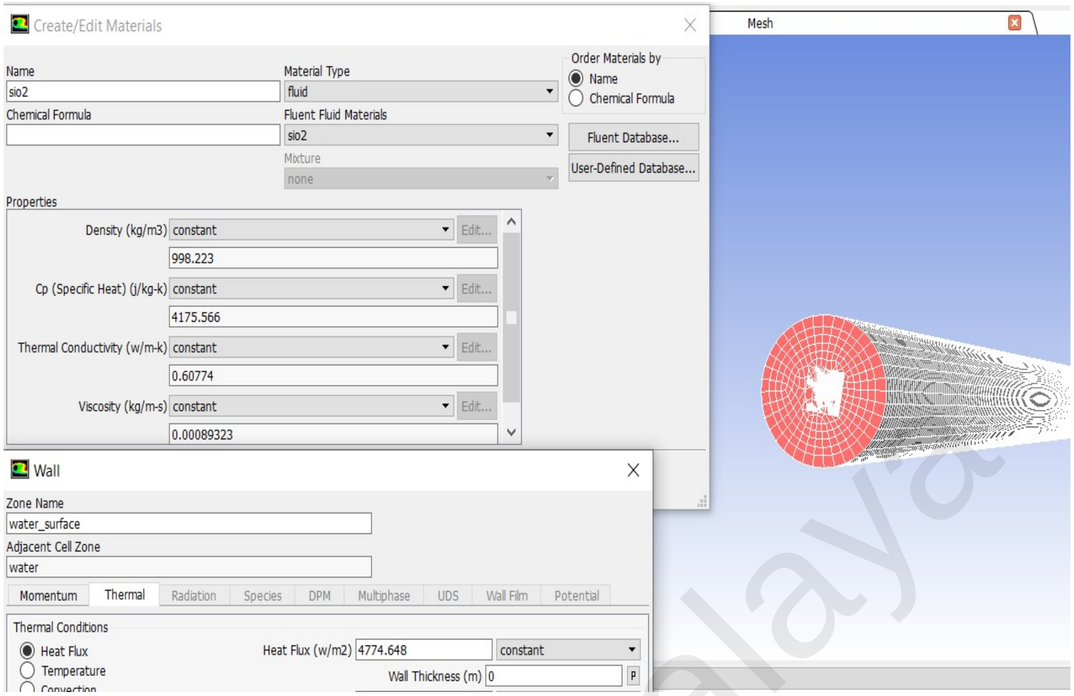

Figure 3-4 : Square Tube Set up

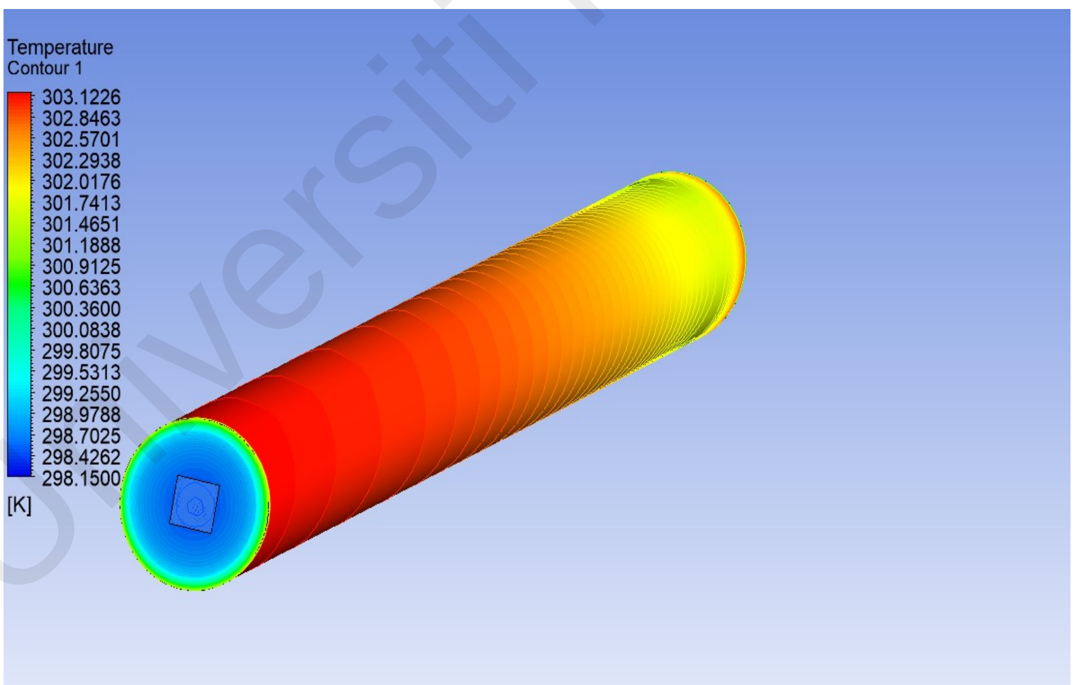

Figure 3-5: Square Tube Temperature Contour

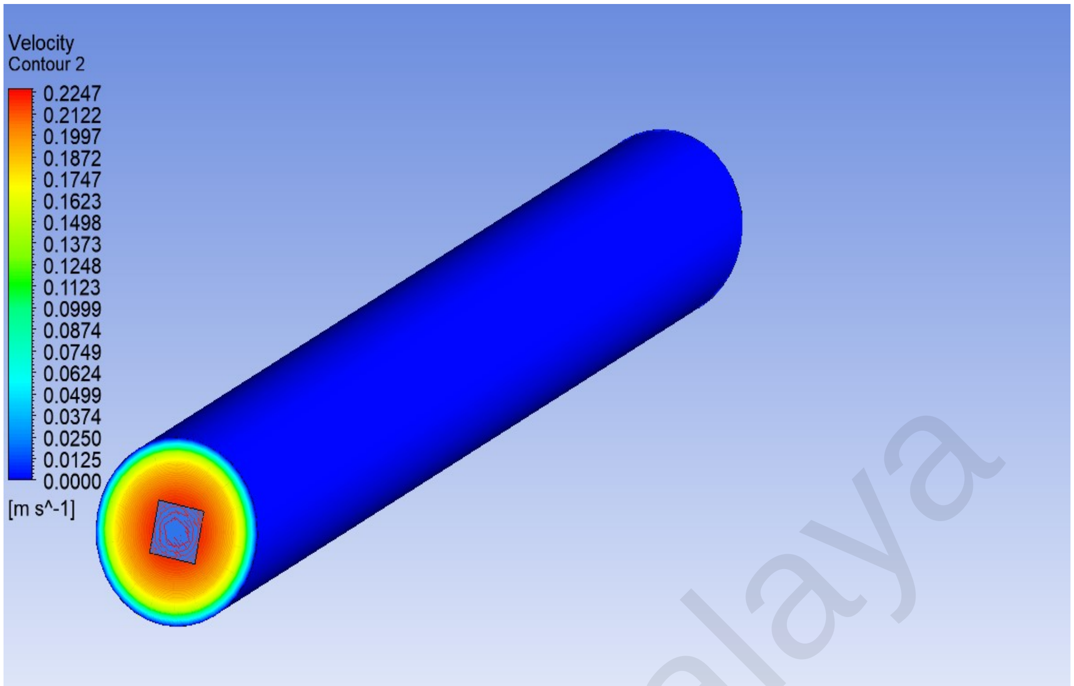

Figure 3-6: Square Tube Velocity Contour

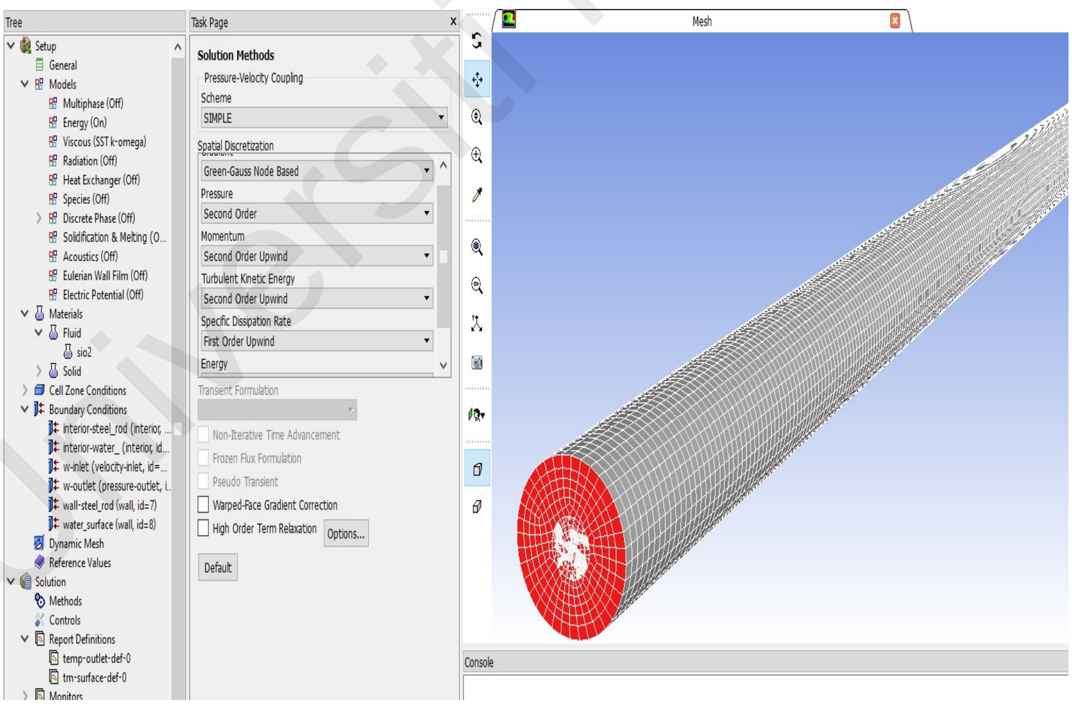

Figure 3-7: Model Method Set up

3.3 Project Flowchart and Gantt Chart

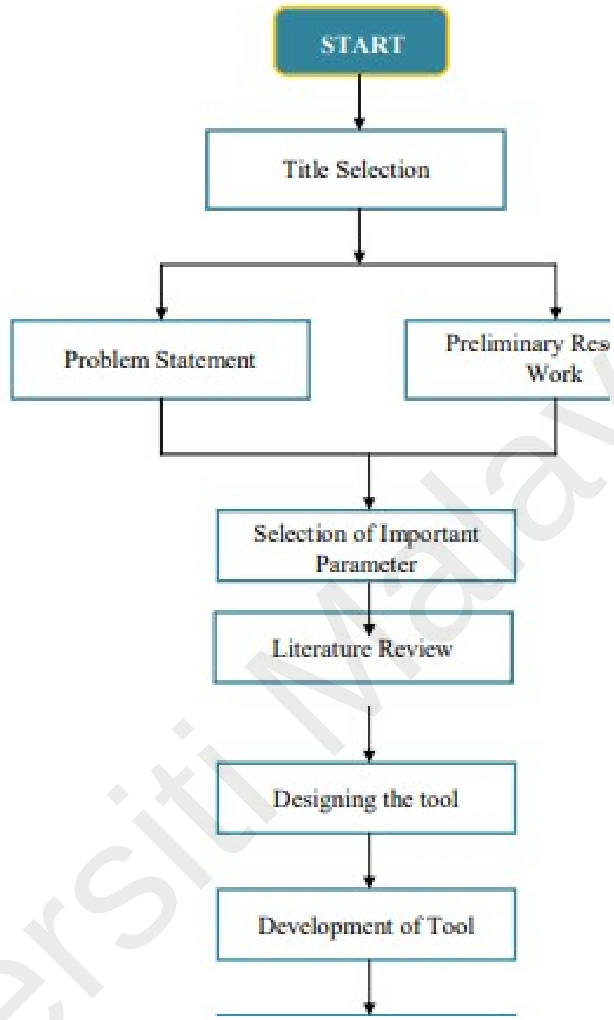

Figure 3-8: Project Flow Chart

TASK / WEEK	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P1																									
Supervisor and Title Selection	■	■	■																						
Literature Review			■	■	■	■																			
Methodology							■	■	■																
Progress Report										■															
P2																									
Project Writing											■	■	■	■	■	■	■	■	■	■					
Report Progress																				■	■	■	■	■	
Oral Presentation																									■

Table 3-2: Project Gantt Chart

RESULTS AND DISCUSSION

The comparison between the shapes and its effect on heat transfer, pressure, temperature and velocity is studied. The data from water run, with nanoparticles 0.1%, 0.075, 0.05% and 0.025% of circular shape is compared with square shape.

4.1 Heat Transfer Coefficient Against Distance

4.1.1 Heat Transfer Coefficient, 600W

4.1.1.1 Concentration [0.025] SiO2, 600W

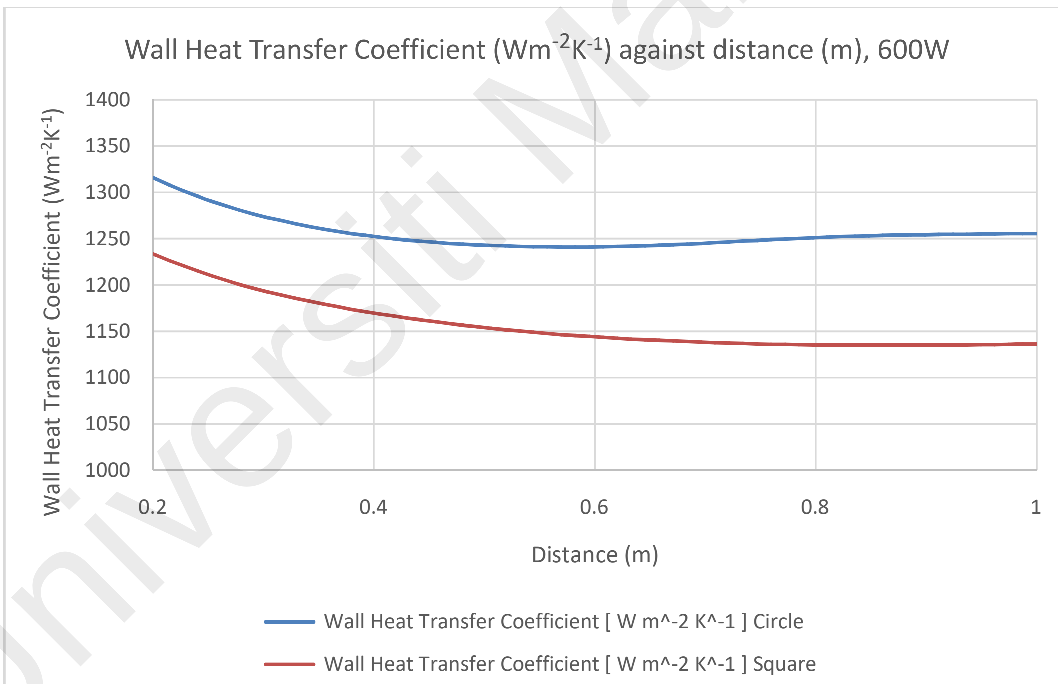

Figure 4-1 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for [0.025] SiO2, 600W

4.1.1.2 Concentration [0.050] SiO2, 600W

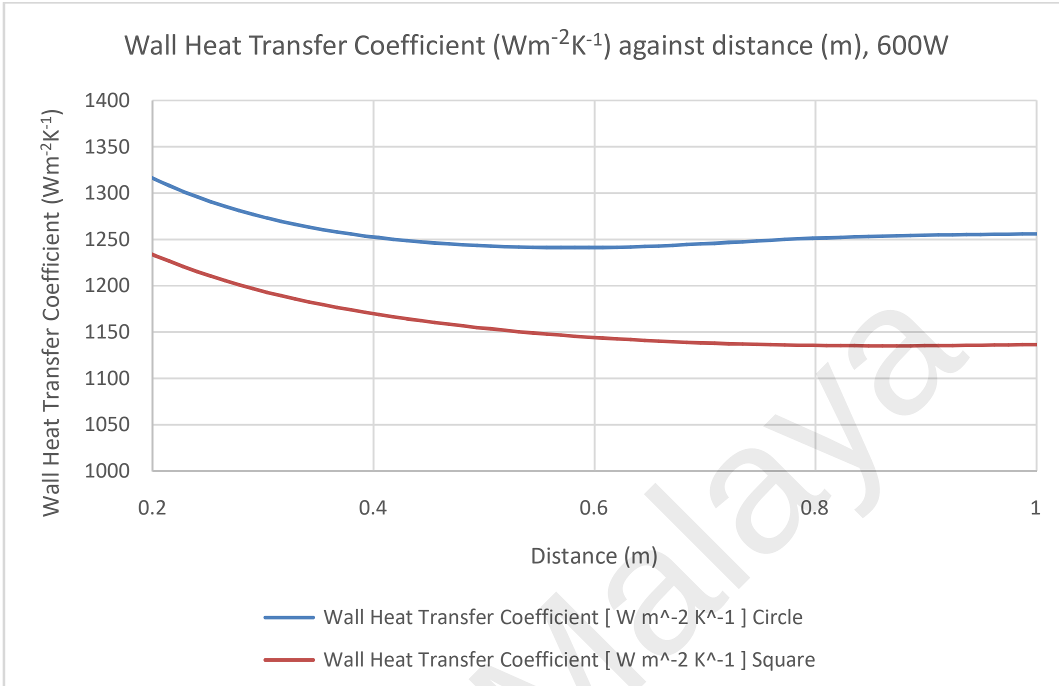

Figure 4-2 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for [0.050] SiO2, 600W

4.1.1.3 Concentration [0.075] SiO2, 600W

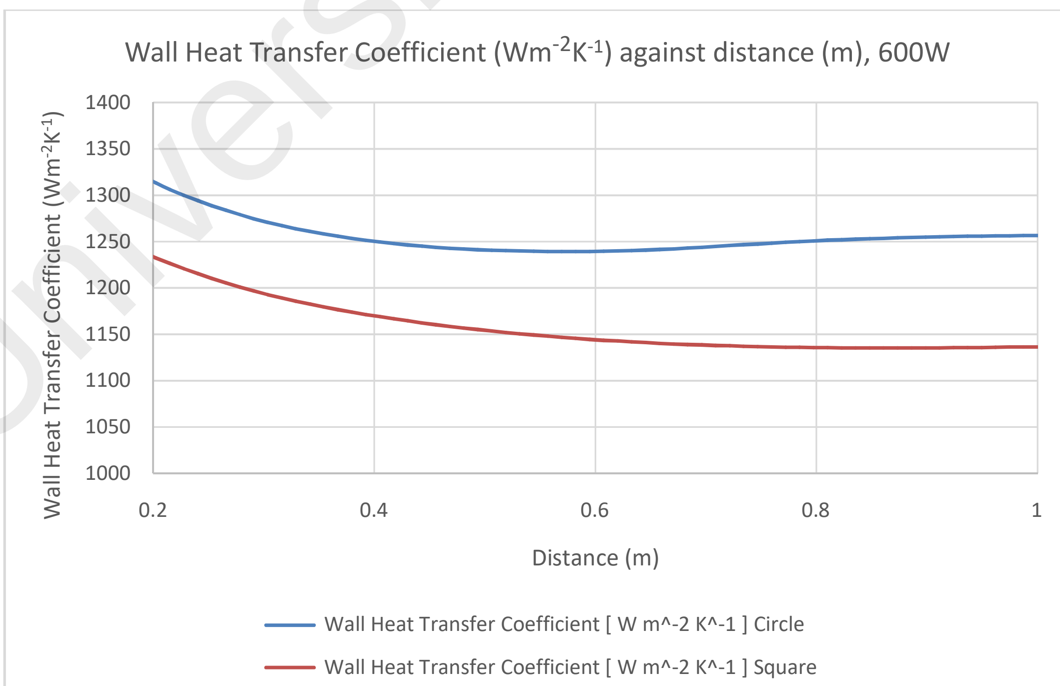

Figure 4-3 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for [0.075] SiO2, 600W

4.1.1.4 Concentration [0.100] SiO2, 600W

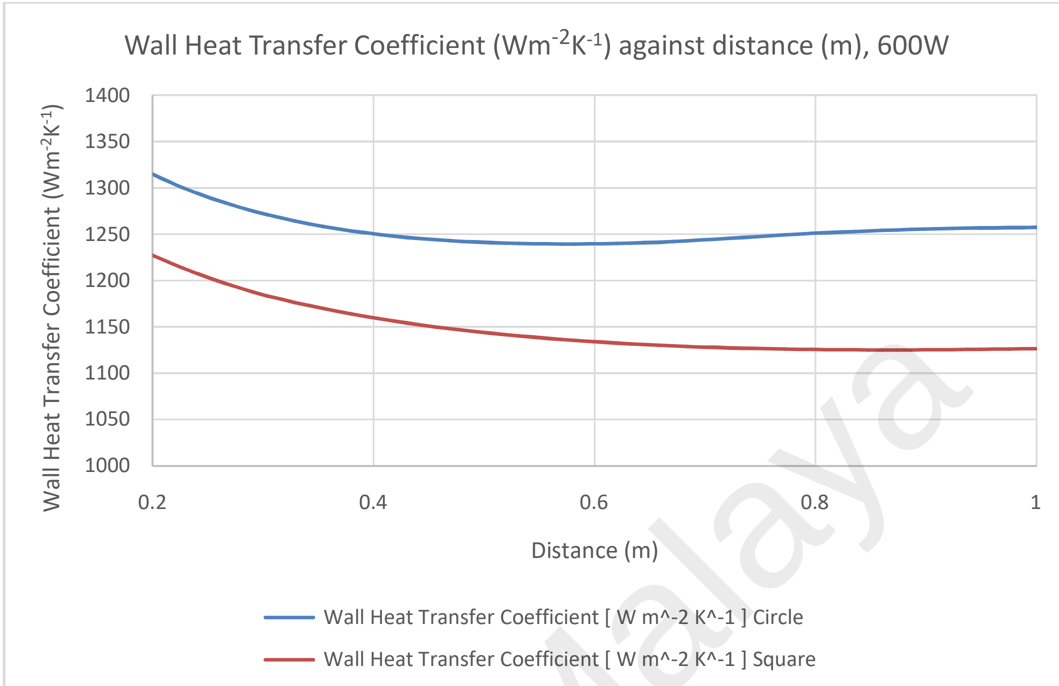

Figure 4-4 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for [0.100] SiO2, 600W

4.1.1.5 Water, 600W

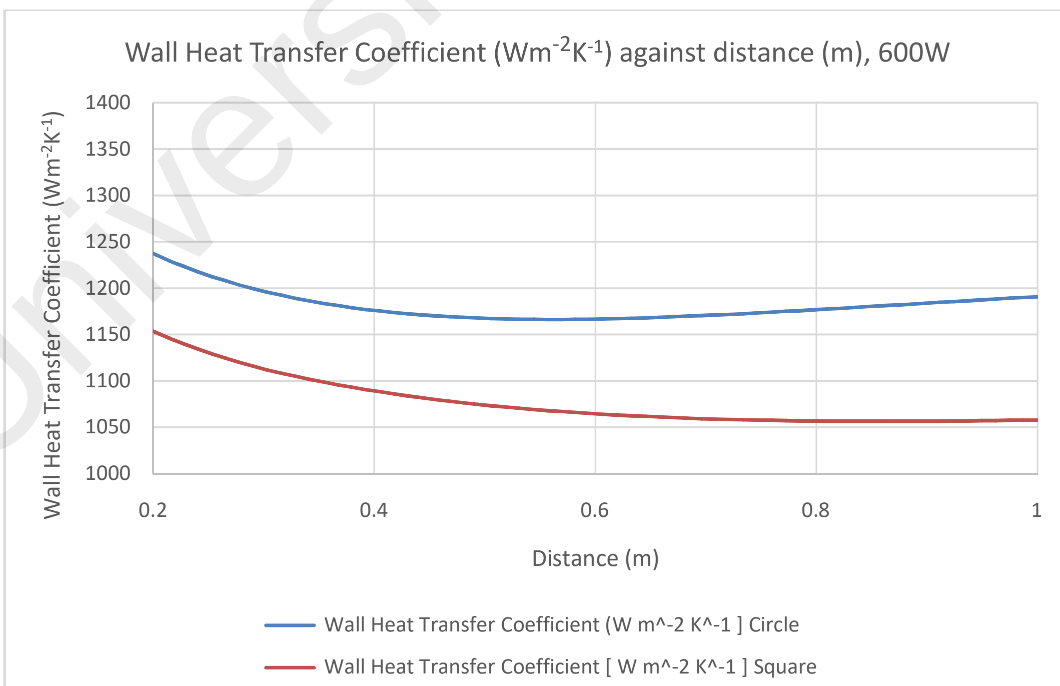

Figure 4-5 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for water, 600W

4.1.2 Heat Transfer Coefficient, 800W

4.1.2.1 Concentration [0.025] SiO2, 800W

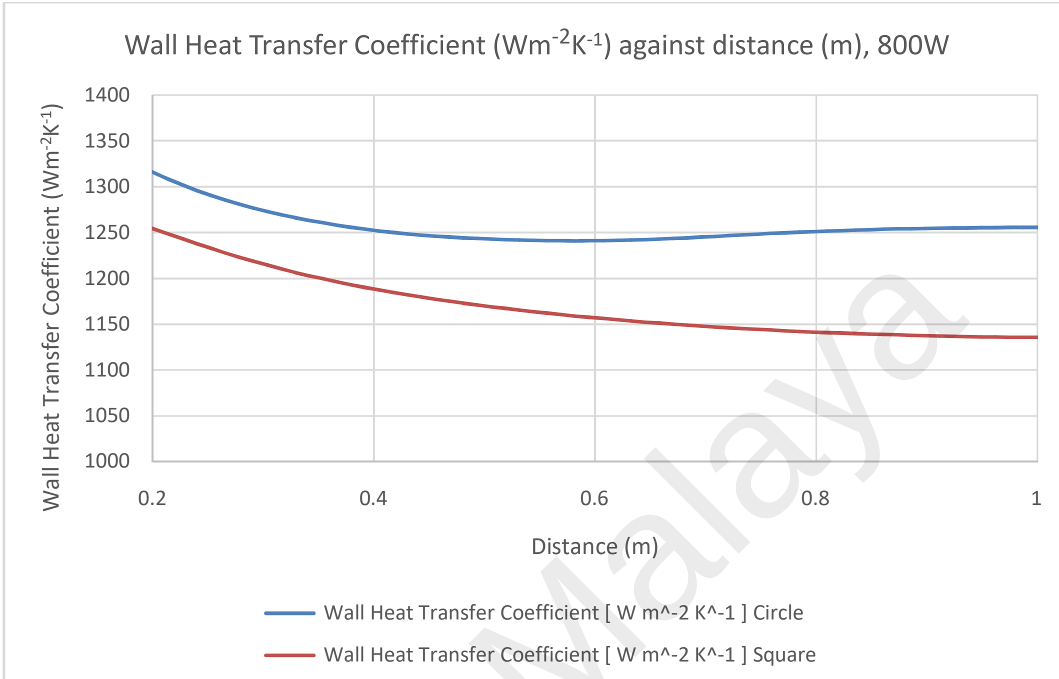

Figure 4-6 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for [0.025] SiO2, 800W

4.1.2.2 Concentration [0.050] SiO2, 800W

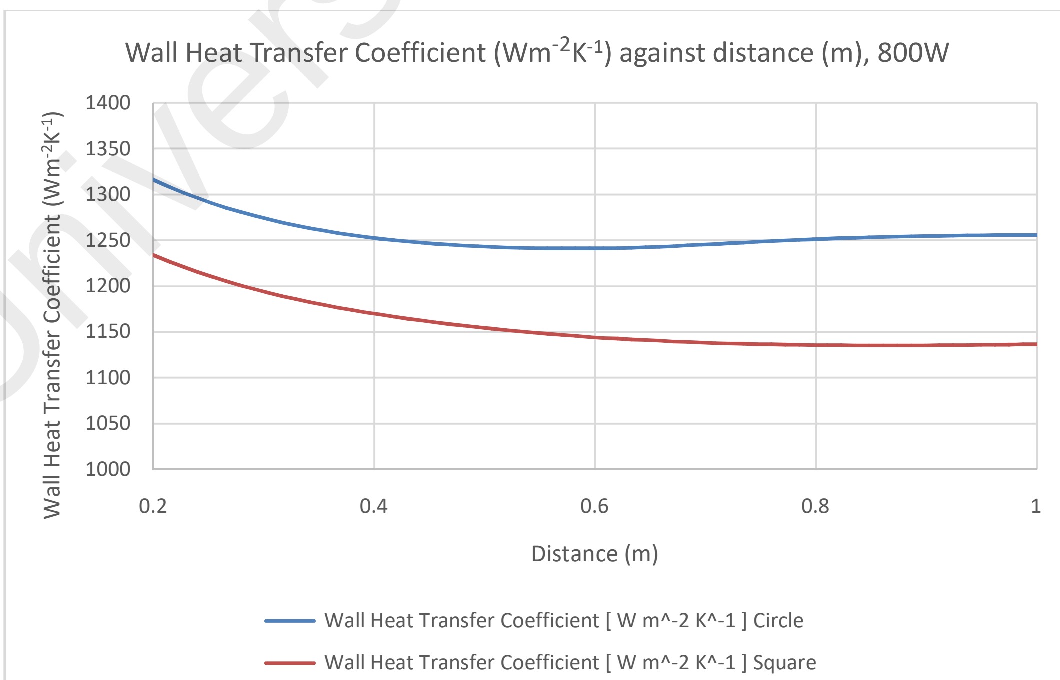

Figure 4-7 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for [0.050] SiO2, 800W

4.1.2.3 Concentration [0.075] SiO2, 800W

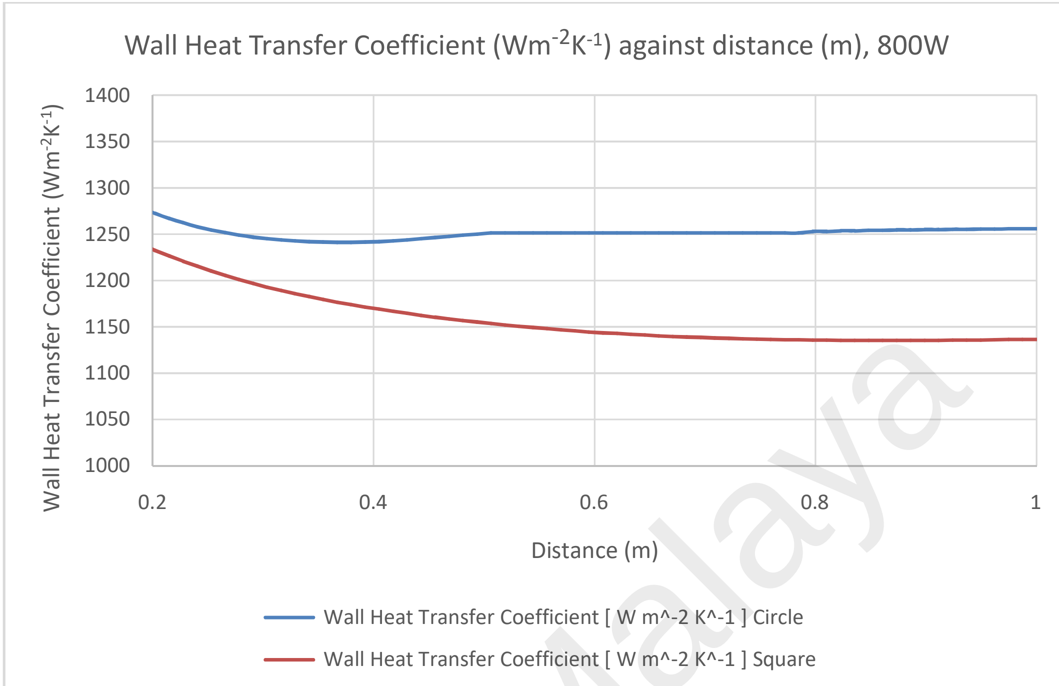

Figure 4-8 Wall heat transfer coefficient (Wm^{-2}K$^{=1}$) against distance (m) for [0.075] **SiO2, 800W**

4.1.2.4 Concentration [0.100] SiO2, 800W

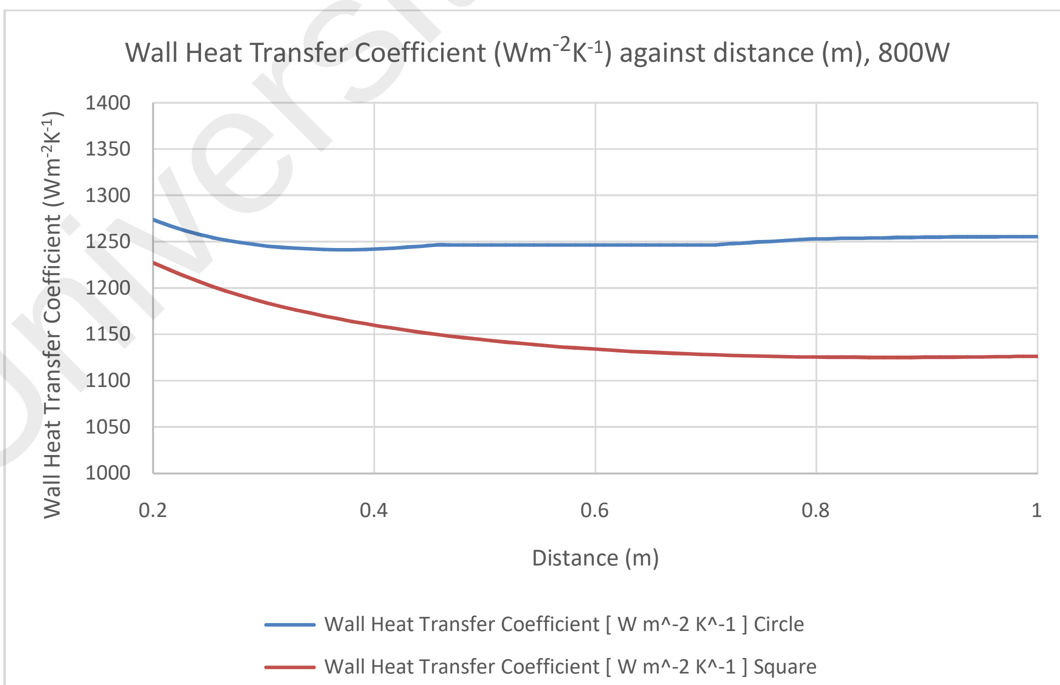

Figure 4-9 Wall heat transfer coefficient (Wm^{-2}K$^{=1}$) against distance (m) for [0.100] SiO2, 800W

4.1.2.5 Water, 800W

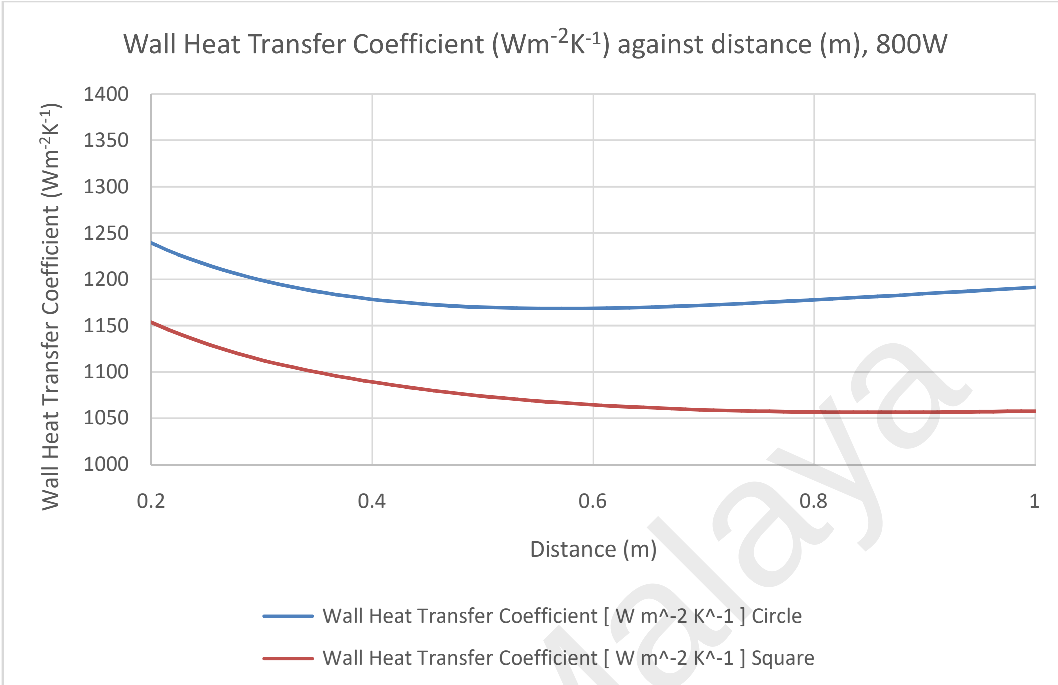

Figure 4-10 Wall heat transfer coefficient ($Wm^{-2}K^{=1}$) against distance (m) for water, 800W

The wall heat transfer coefficient for all concentrations of SiO2 nanofluid and water exhibit similar graphical trends for both the circle and square design. The wall heat transfer coefficient is the highest at 0.2m for each case and decreases until the 0.4m point where the heat transfer coefficient starts to normalize and produces a constant and average wall heat transfer coefficient.

When comparing between the circle and square design, the circle design exhibited a higher heat transfer coefficient than the square design in all cases of SiO2 concentration and water. The disparity in heat transfer coefficient for the circle and square design of [0.025], [0.050],[0.075], and [0.100] SiO2 was the highest with a position of 0.6m having the highest difference. However, as the fluid changes to water, the disparity between the heat transfer coefficient for the two designs decreases. Past research has also strongly suggested the improved effectiveness and efficiency of a circular tube compared to a rectangular tube for heat transfer, indicating that a circular design has a higher heat transfer coefficient and Nusselt Number than a rectangular design (Bisht, Joshi, & Gupta, 2014).

4.2 Pressure Against Distance

4.2.1 Pressure, 600W

4.2.1.1 Concentration [0.025] SiO2, 600W

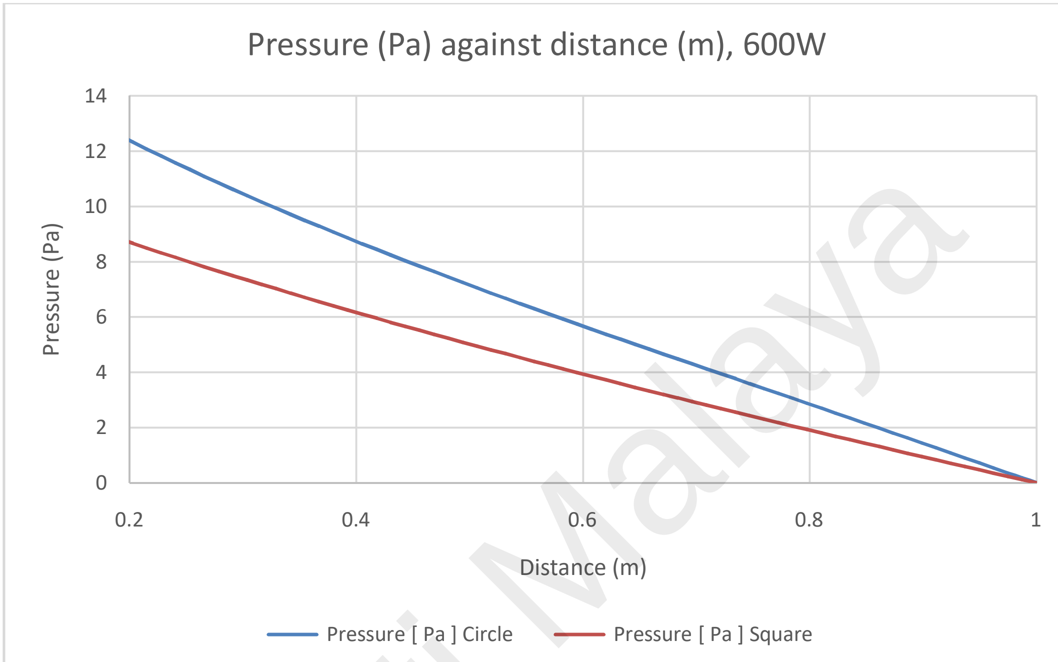

Figure 4-11 Pressure (Pa) against distance (m) for [0.025] SiO2, 600W

4.2.1.2 Concentration [0.050] SiO2, 600W

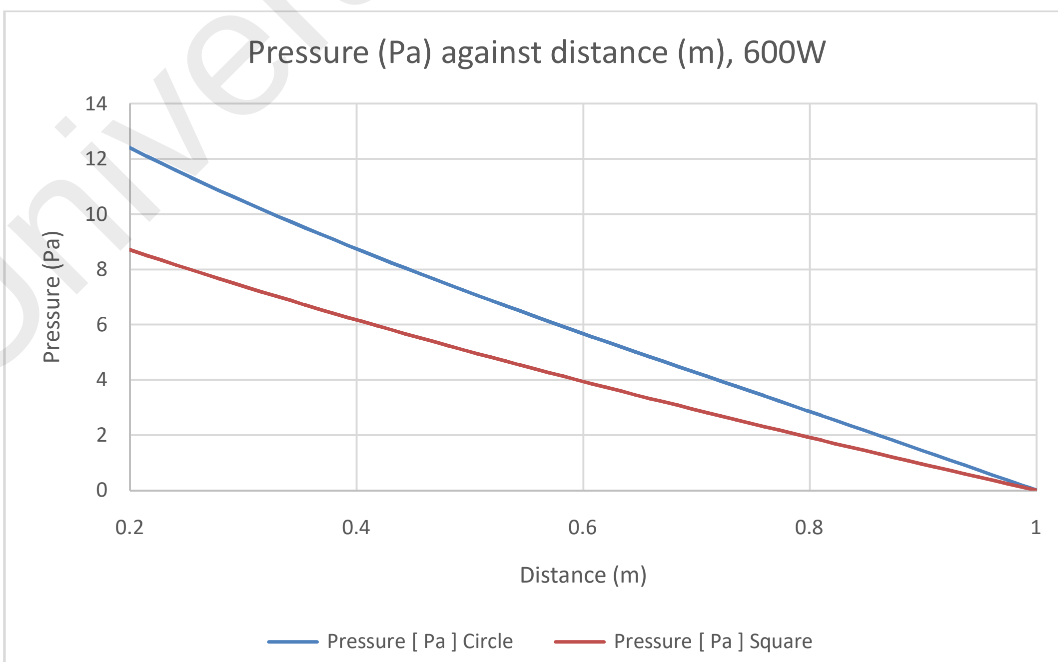

Figure 4-12 Pressure (Pa) against distance (m) for [0.050] SiO2, 600W

4.2.1.3 Concentration [0.075] SiO2, 600W

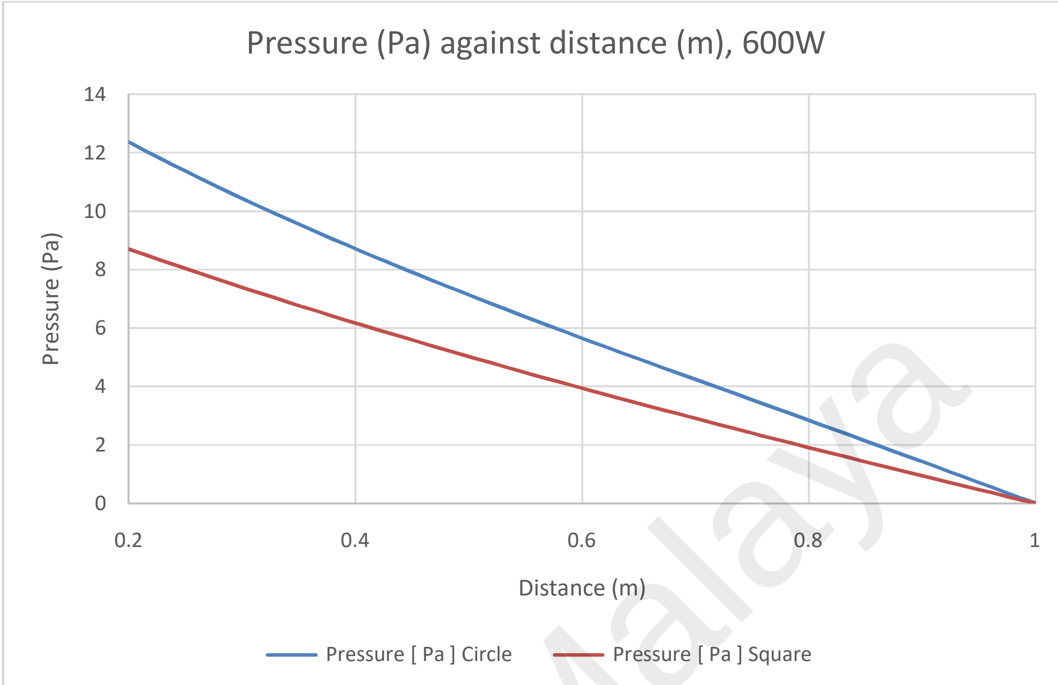

Figure 4-13 Pressure (Pa) against distance (m) for [0.075] SiO2, 600W

4.2.1.4 Concentration [0.100] SiO2, 600W

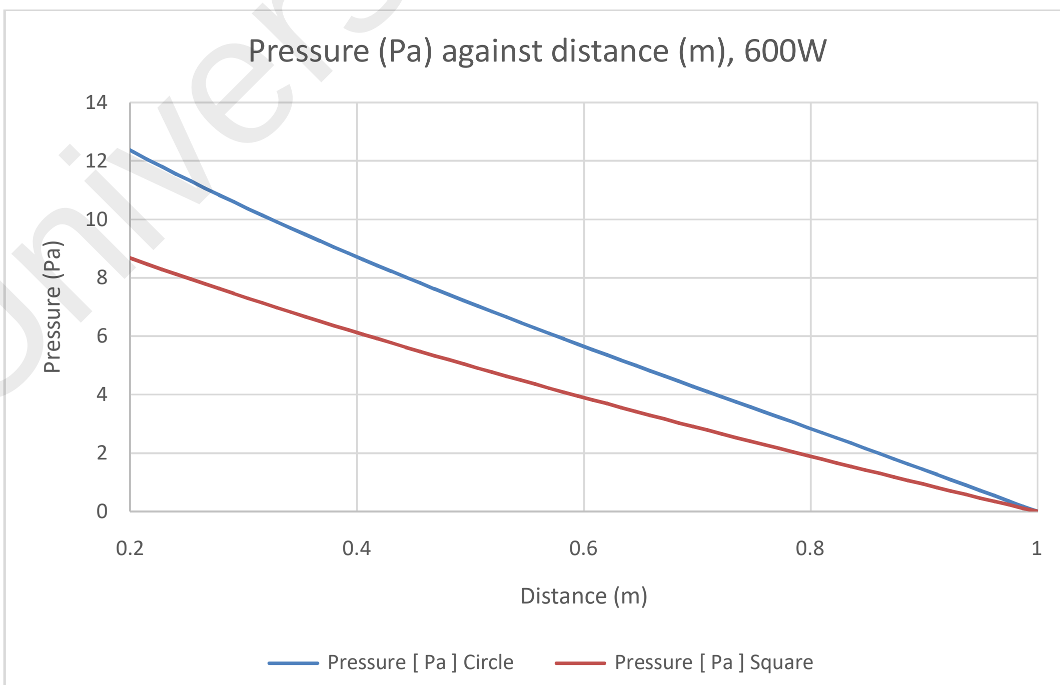

Figure 4-14 Pressure (Pa) against distance (m) for [0.100] SiO2, 600W

4.2.1.5 Water, 600W

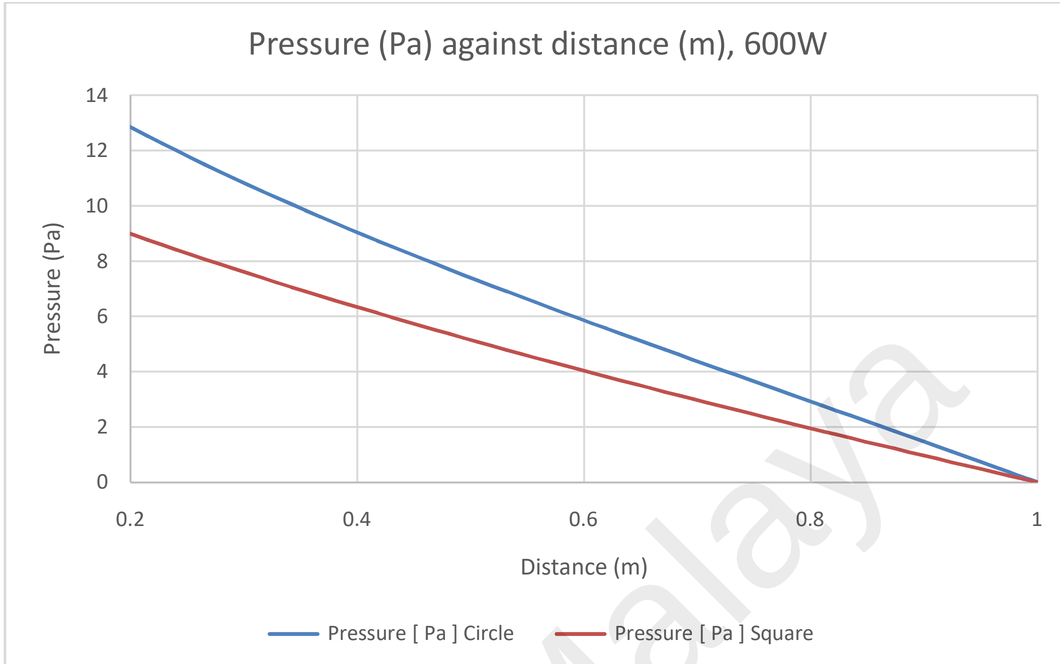

Figure 4-15 Pressure (Pa) against distance (m) for water, 600W

4.2.2 Pressure, 800W

4.2.2.1 Concentration [0.025] SiO2, 800W

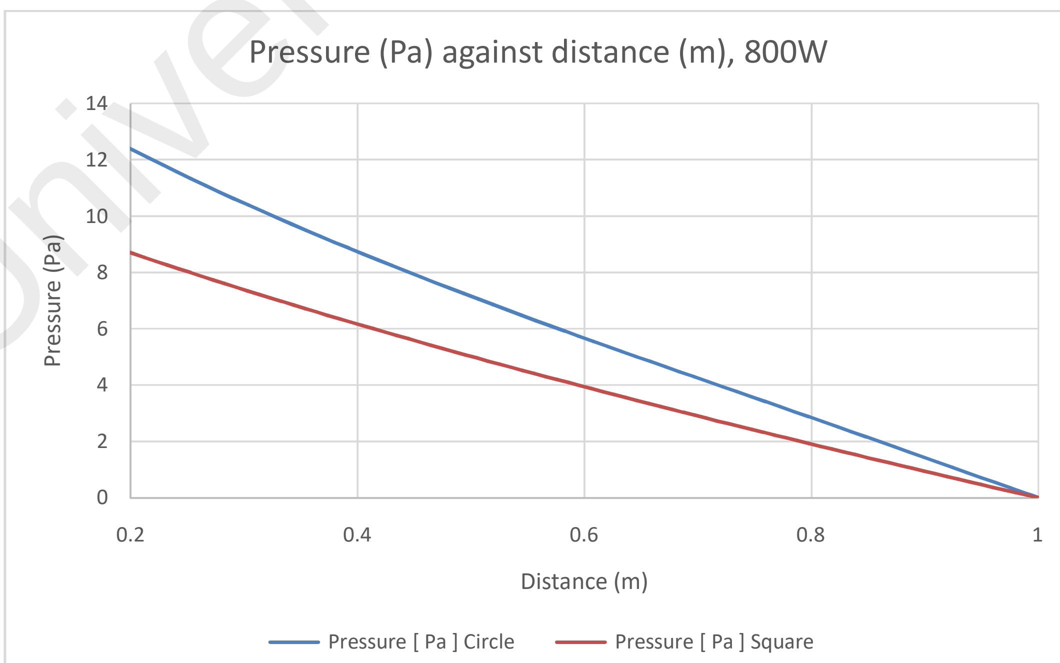

Figure 4-16 Pressure (Pa) against distance (m) for [0.025] SiO2, 800W

4.2.2.2 Concentration [0.050] SiO2, 800W

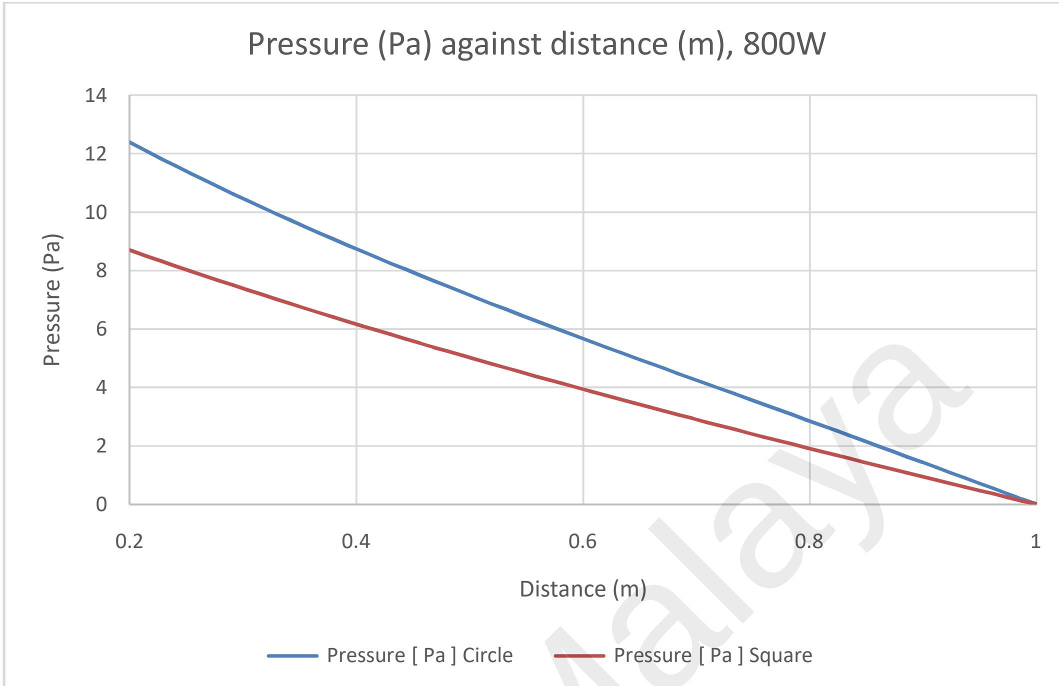

Figure 4-17 Pressure (Pa) against distance (m) for [0.050] SiO2, 800W

4.2.2.3 Concentration [0.075] SiO2, 800W

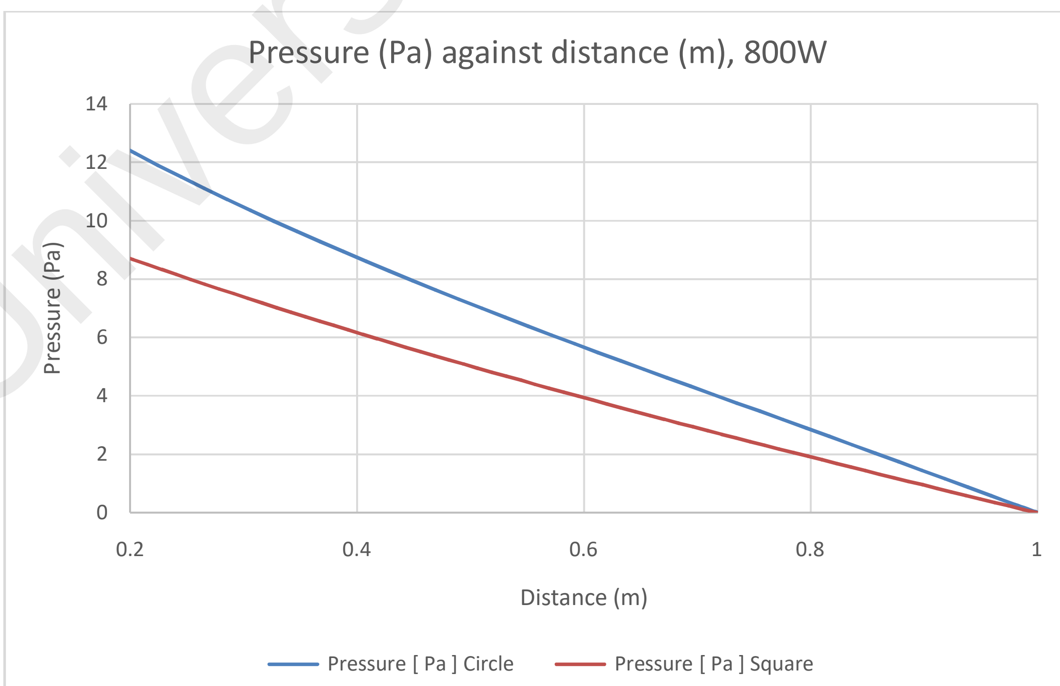

Figure 4-18 Pressure (Pa) against distance (m) for [0.075] SiO2, 800W

4.2.2.4 Concentration [0.100] SiO2, 800W

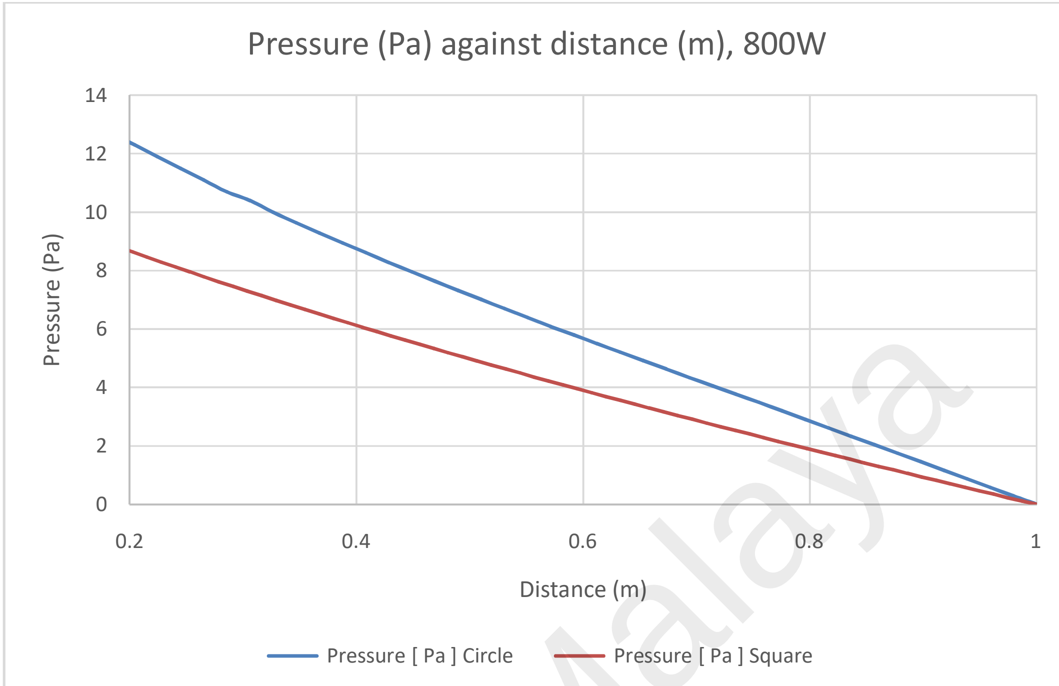

Figure 4-19 Pressure (Pa) against distance (m) for [0.100] SiO2, 800W

4.2.2.5 Water, 800W

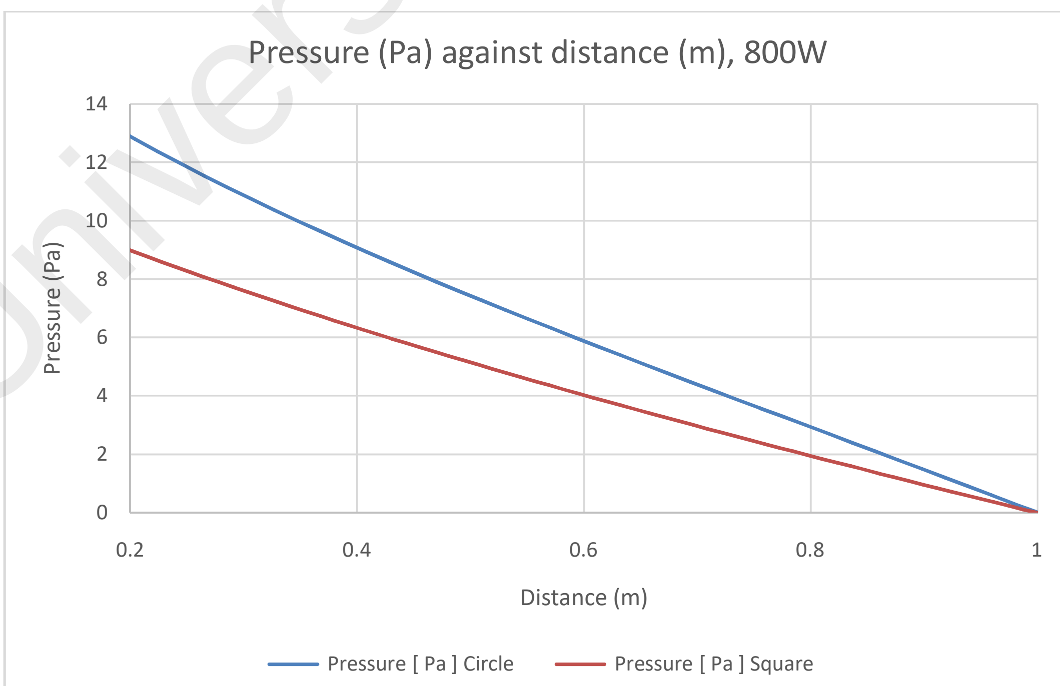

Figure 4-20 Pressure (Pa) against distance (m) for water, 800W

The pressure for all concentration of SiO2 nanofluid and water have similar proportional graphical trends for both the circle and square design. The pressure is the highest at 0.2m for each case and decreases proportionally. The pressure starting at 0.2m for the circle is higher than that of the square design for all fluid concentrations. The graphical gradient for the circle to higher than that for the square, which indicates a higher pressure loss.

When comparing between the circle and square design, the circle design displayed a higher overall pressure throughout the entire distance than the square design. Although so, the pressure loss for the circle design is higher than that of the square design. The difference between the two overall pressure is similar to 0.2m. However, as the distance increases, the difference between the two overall pressure decreases until the pressure is the same (0Pa) at 1m. Even though the circle design started with higher pressure, due to the higher pressure loss as seen from the graphical gradient, the graph intersects the square design at 1m.

4.3 Temperature Against Distance

4.3.1 Temperature, 600W

4.3.1.1 Concentration [0.025] SiO2, 600W

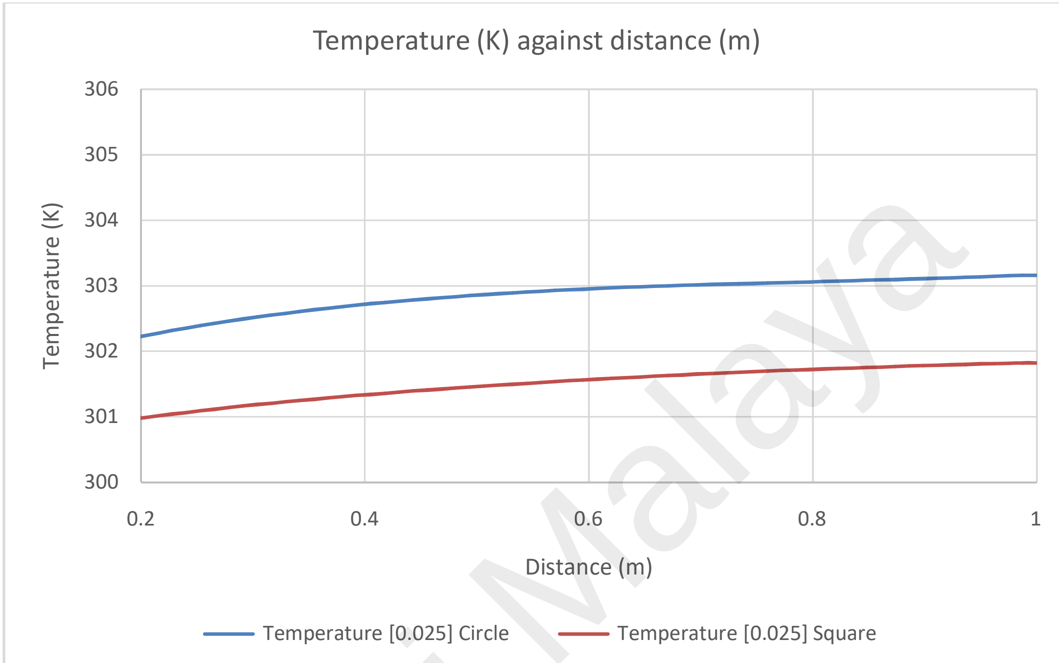

Figure 4-21 Temperature (K) against distance (m) for [0.025] SiO2, 600W

4.3.1.2 Concentration [0.050] SiO2, 600W

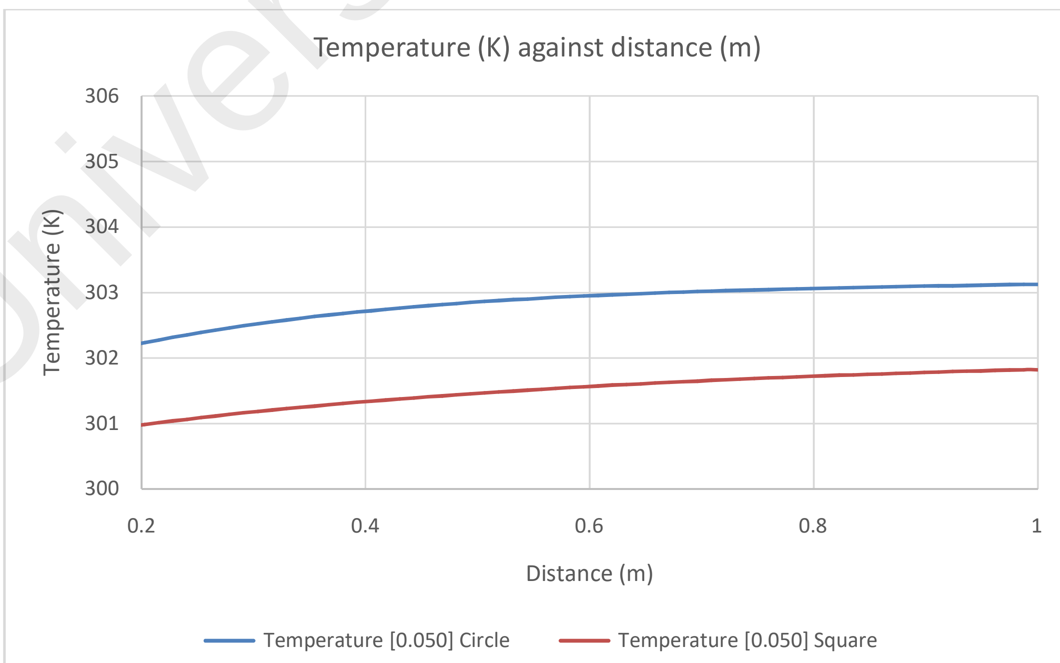

Figure 4-22 Temperature (K) against distance (m) for [0.050] SiO2, 600W

4.3.1.3 Concentration [0.075] SiO2, 600W

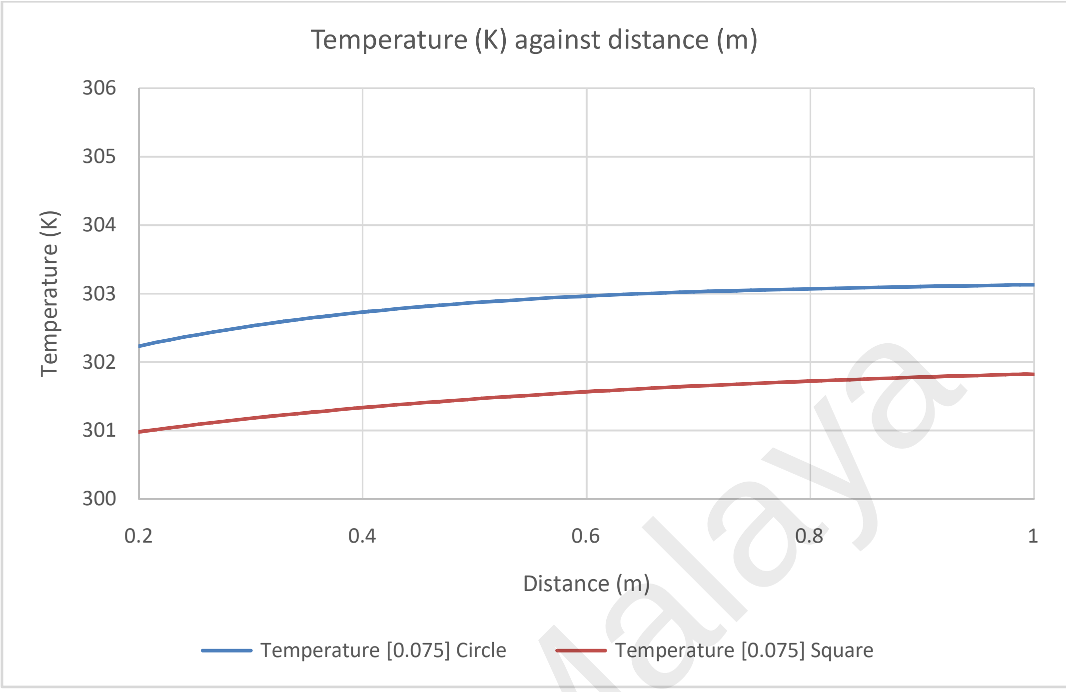

Figure 4-23 Temperature (K) against distance (m) for [0.075] SiO2, 600W

4.3.1.4 Concentration [0.100] SiO2, 600W

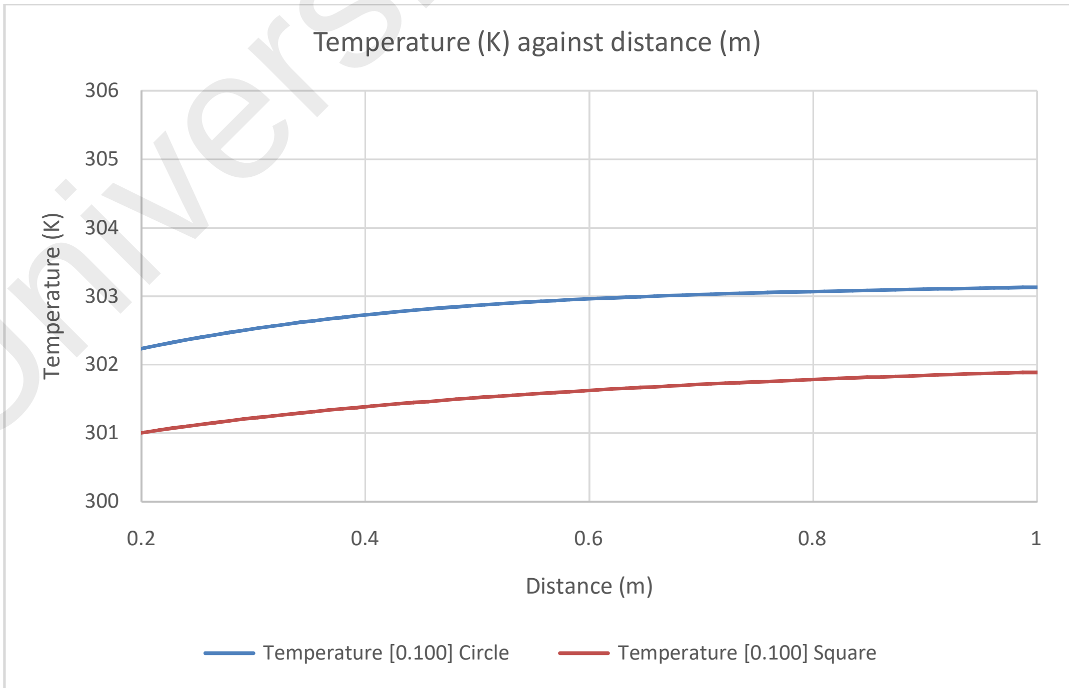

Figure 4-24 Temperature (K) against distance (m) for [0.100] SiO2, 600W

4.3.1.5 Water, 600W

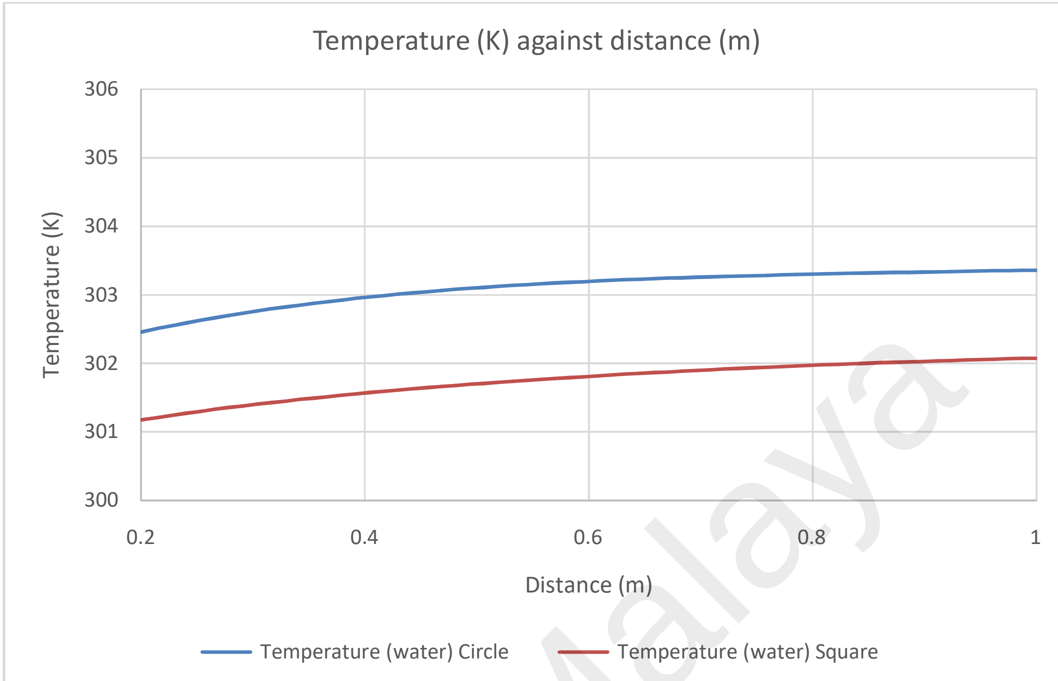

Figure 4-25 Temperature (K) against distance (m) for water, 600W

4.3.2 Temperature, 800W

4.3.2.1 Concentration [0.025] SiO2, 800W

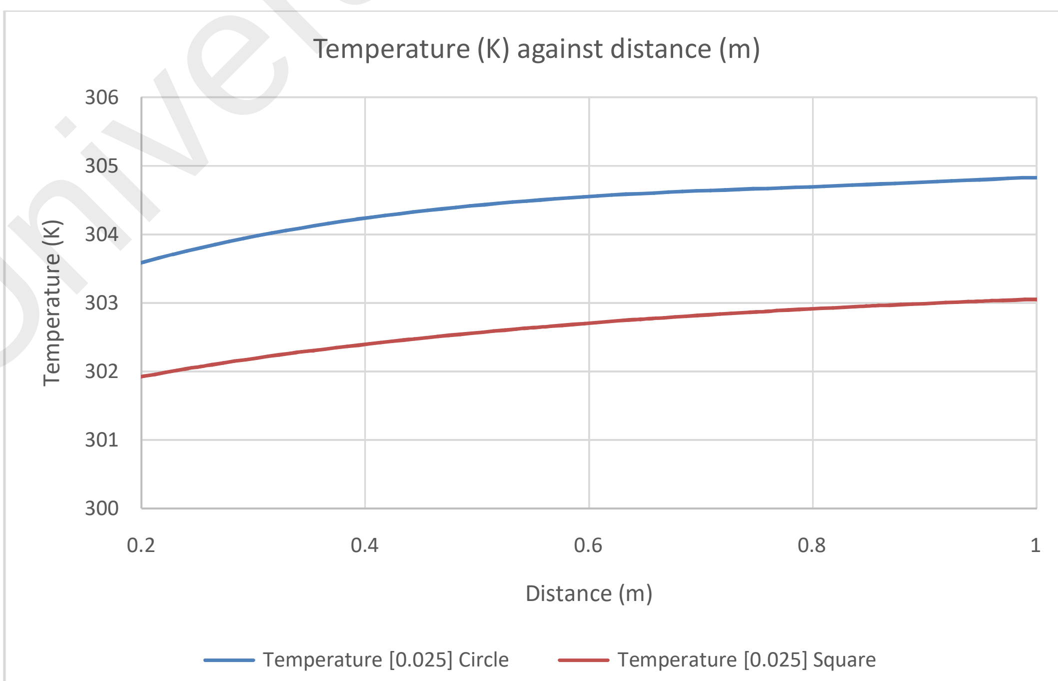

Figure 4-26 Temperature (K) against distance (m) for [0.025] SiO2, 800W

4.3.2.2 Concentration [0.050] SiO2, 800W

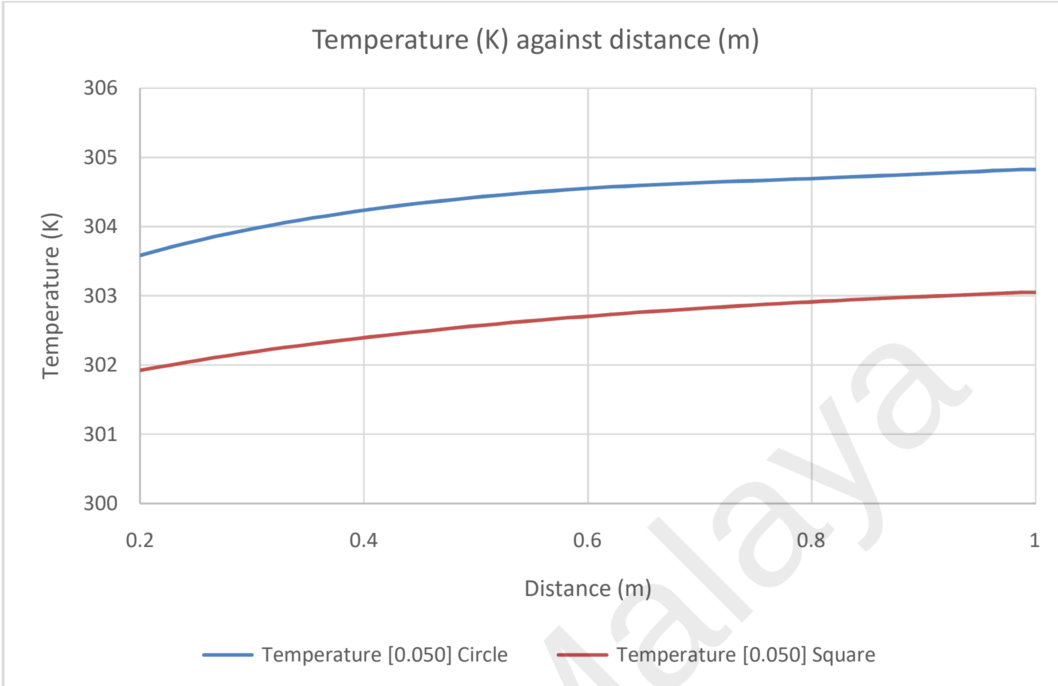

Figure 4-27 Temperature (K) against distance (m) for [0.050] SiO2, 800W

4.3.2.3 Concentration [0.075] SiO2, 800W

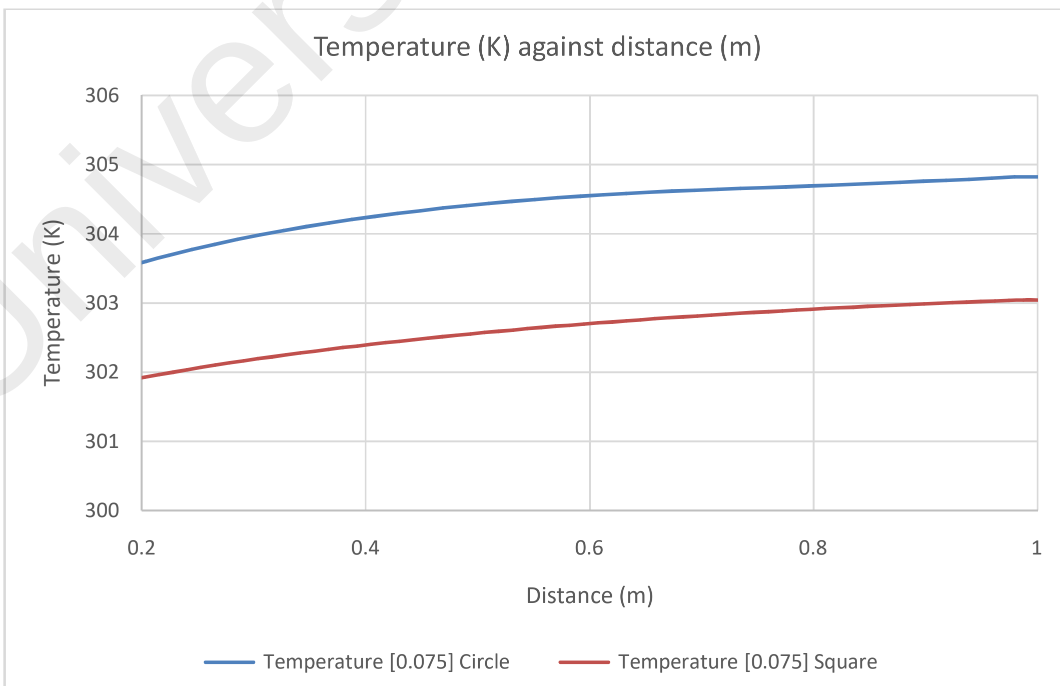

Figure 4-28 Temperature (K) against distance (m) for [0.075] SiO2, 800W

4.3.2.4 Concentration [0.100] SiO2, 800W

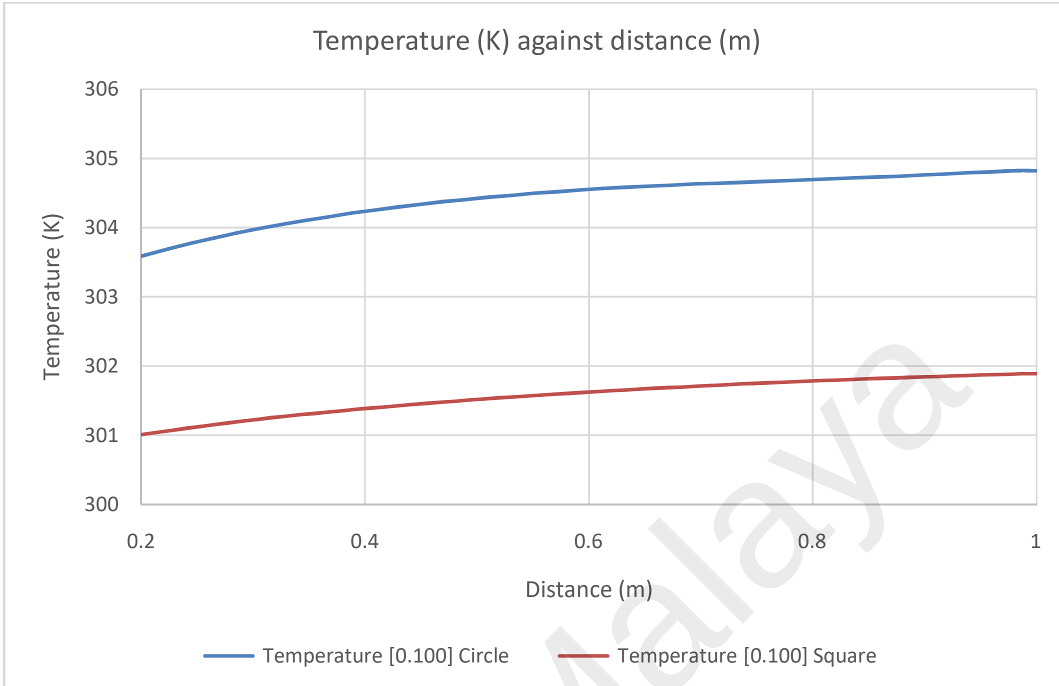

Figure 4-29 Temperature (K) against distance (m) for [0.100] SiO2, 800W

4.3.2.5 Water, 800W

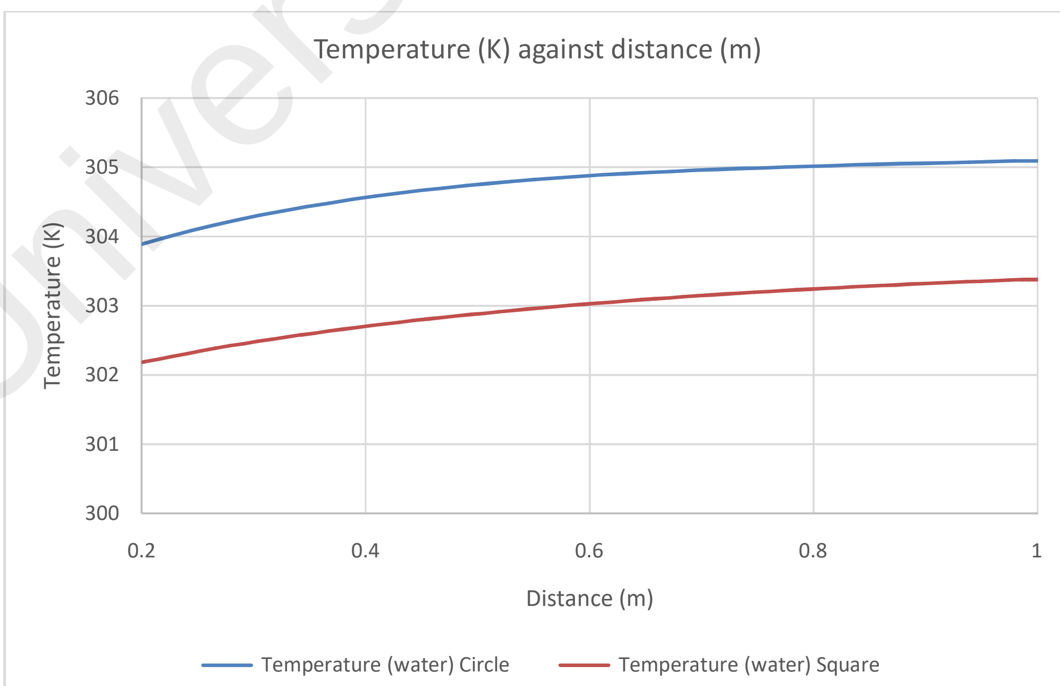

Figure 4-30 Temperature (K) against distance (m) for water, 800W

The temperature for all concentrations of SiO_2 nanofluid and water display similar graphical trends for both the circle and square design. The temperature increases as the fluid flow through the enclosure. When comparing, the 600W simulations demonstrated a lower overall temperature than that of the 800W simulations. As the position increases, the temperature increases.

When comparing between the circle and square design, the circle design exhibited a higher overall temperature than the square design in all cases of SiO_2 concentration and water. The difference in temperature for the circle and square design was between 1K and 3K. The difference is maintained at a constant level throughout the distance of the enclosure.

4.4 Velocity Against Distance

4.4.1 Velocity, 600W

4.4.1.1 Concentration [0.025] SiO2, 600W

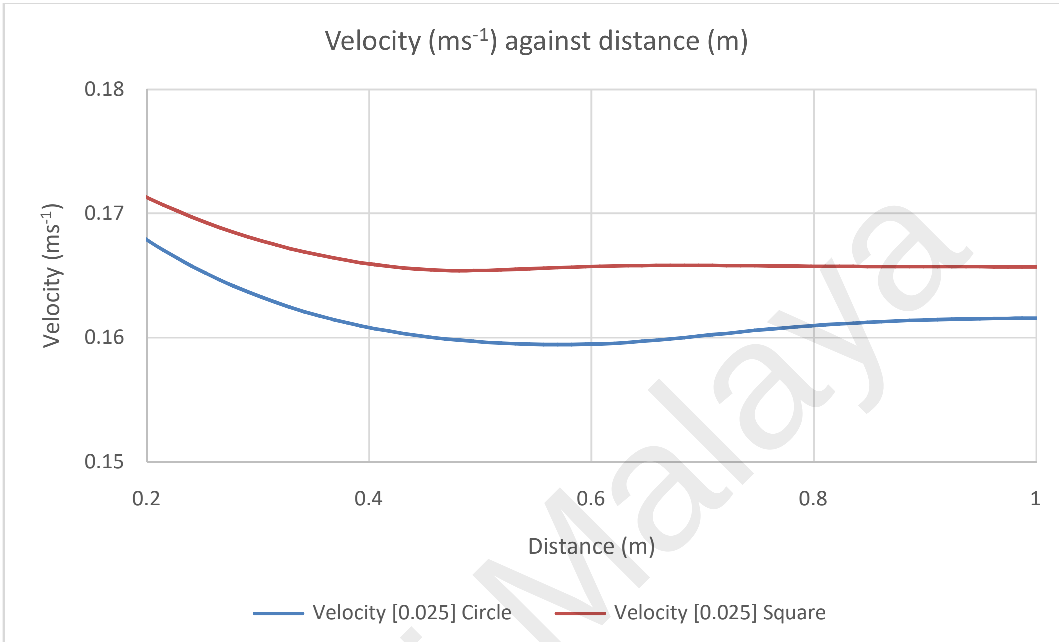

Figure 4-31 Velocity (ms^{-1}) against distance (m) for [0.025] SiO2, 600W

4.4.1.2 Concentration [0.050] SiO2, 600W

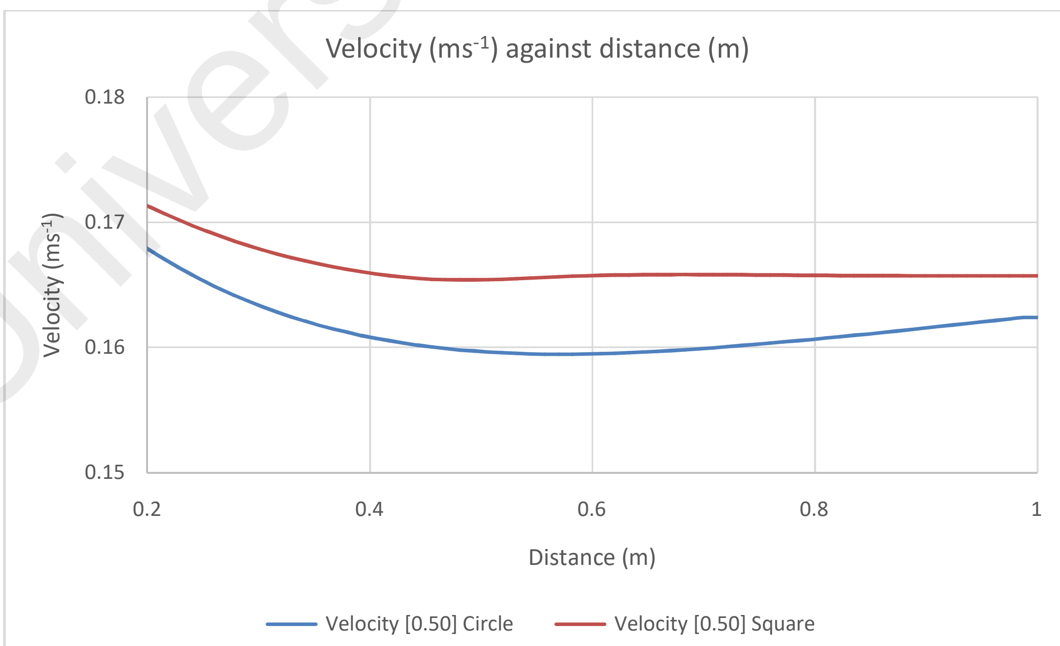

Figure 4-32 Velocity (ms^{-1}) against distance (m) for [0.050] SiO2, 600W

4.4.1.3 **Concentration [0.075] SiO2, 600W**

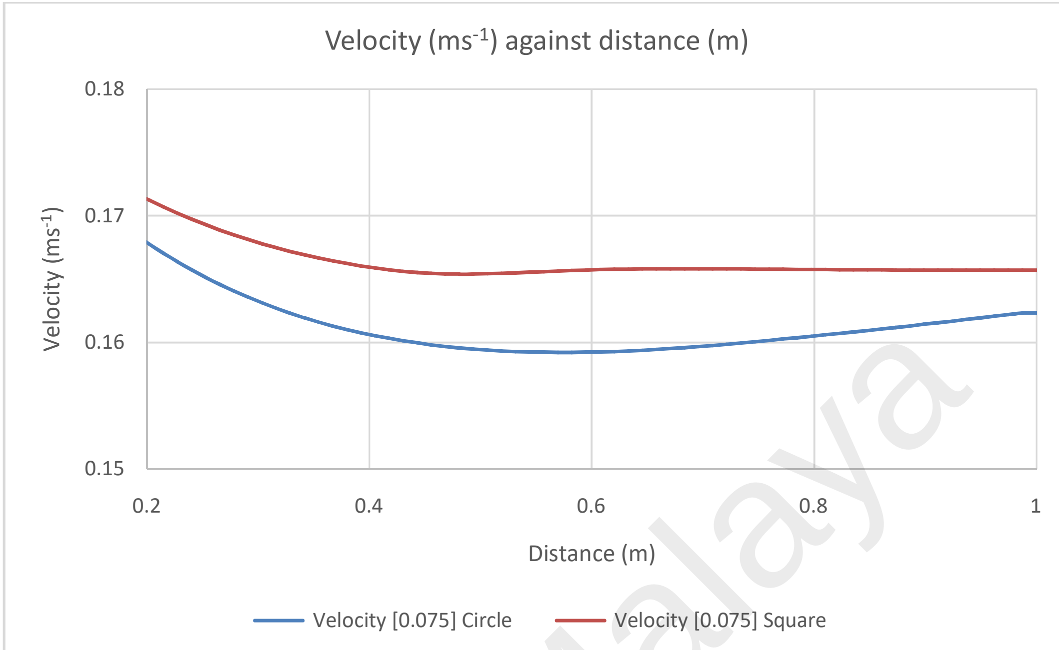

Figure 4-33 Velocity (ms^{-1}) against distance (m) for [0.075] SiO2, 600W

4.4.1.4 **Concentration [0.100] SiO2, 600W**

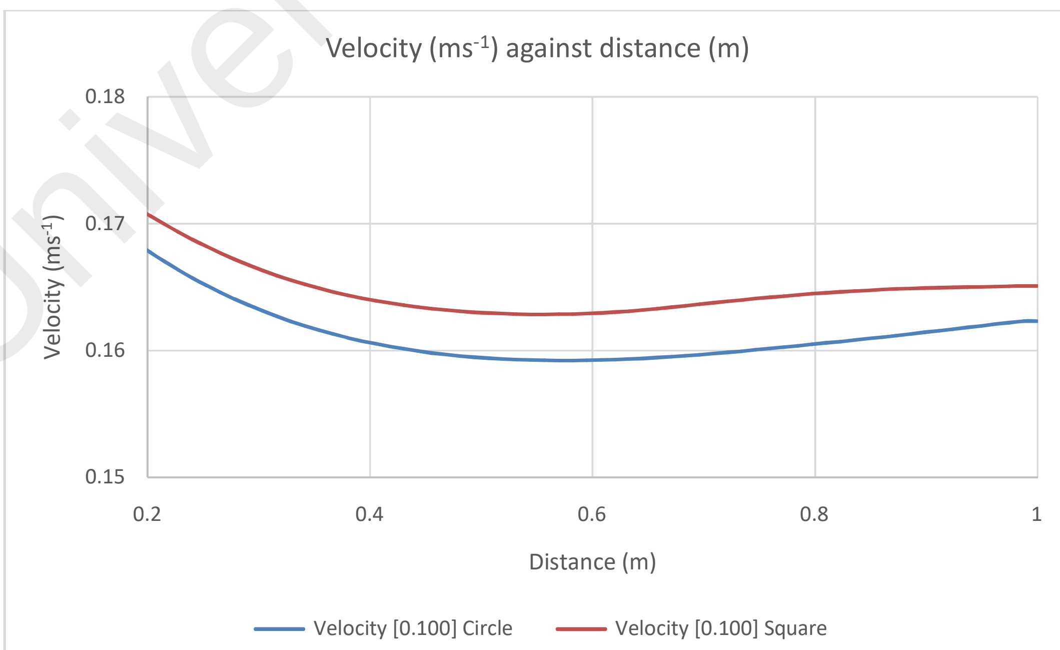

Figure 4-34 Velocity (ms^{-1}) against distance (m) for [0.100] SiO2, 600W

4.4.1.5 Water, 600W

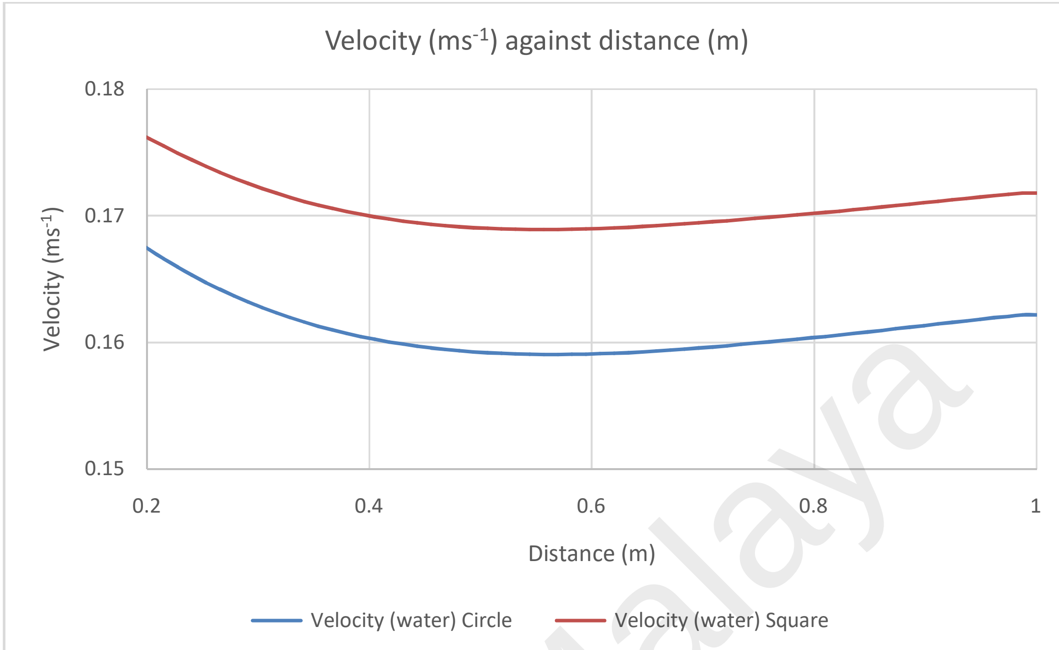

Figure 4-35 Velocity (ms^{-1}) against distance (m) for water, 600W

4.4.2 Velocity, 800W

4.4.2.1 Concentration [0.025] SiO2, 800W

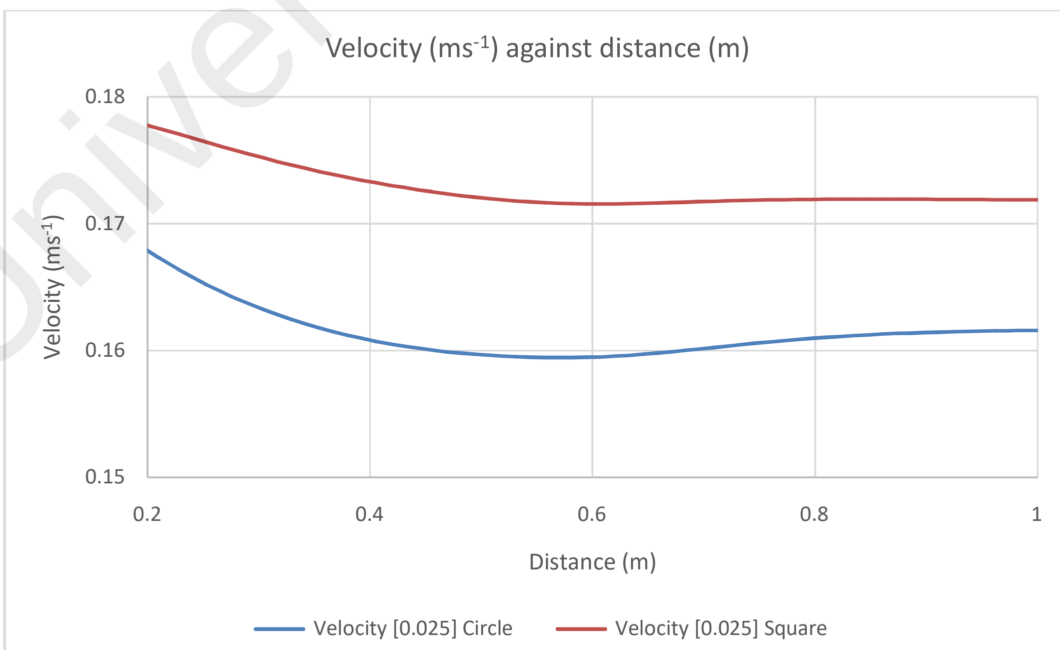

Figure 4-36 Velocity (ms^{-1}) against distance (m) for [0.025] SiO2, 800W

4.4.2.2 Concentration [0.050] SiO2, 800W

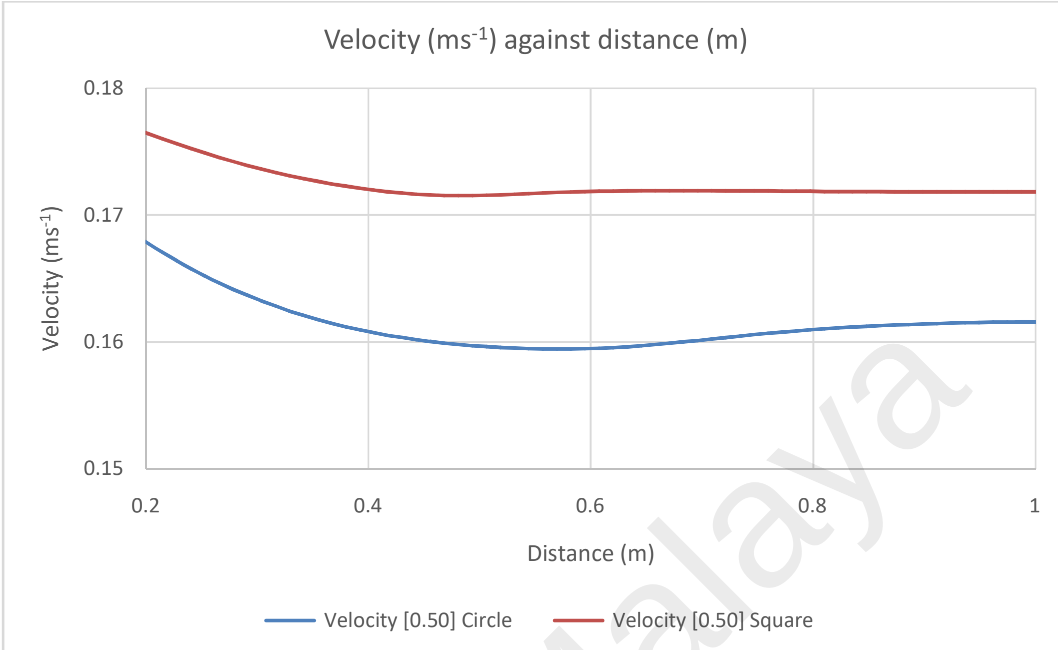

Figure 4-37 Velocity (ms^{-1}) against distance (m) for [0.050] SiO2, 800W

4.4.2.3 Concentration [0.075] SiO2, 800W

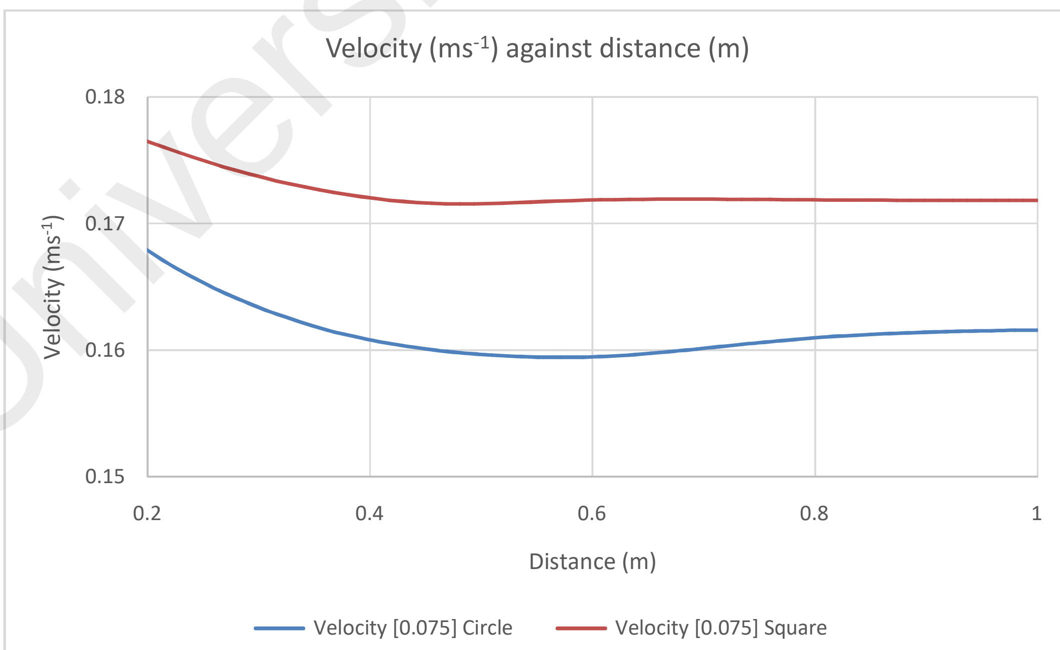

Figure 4-38 Velocity (ms^{-1}) against distance (m) for [0.075] SiO2, 800W

4.4.2.4 Concentration [0.100] SiO2, 800W

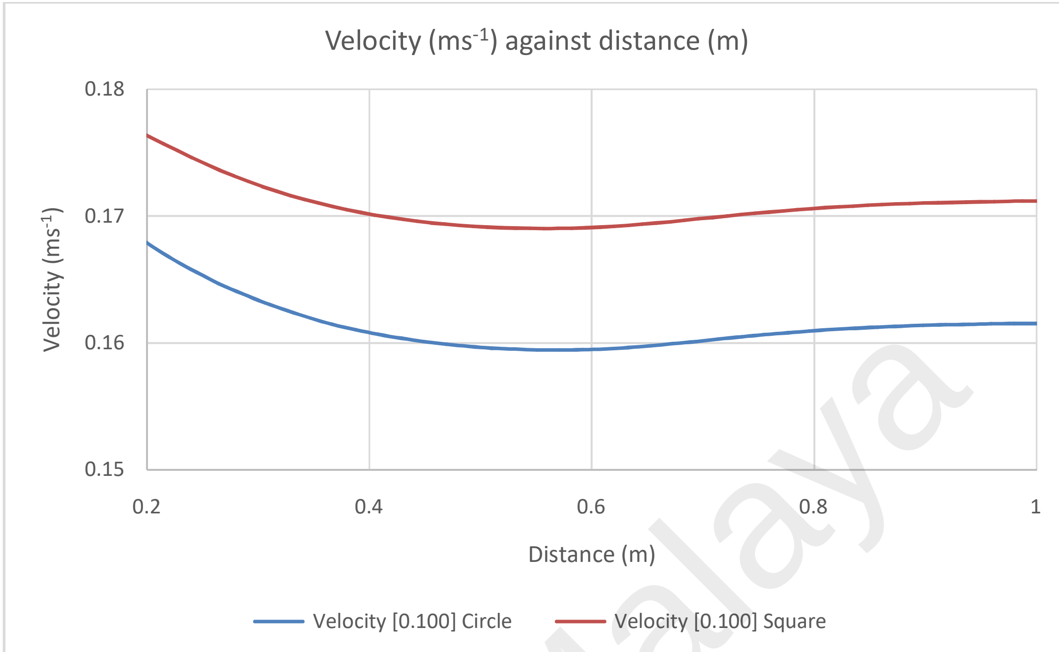

Figure 4-39 Velocity (ms^{-1}) against distance (m) for [0.100] SiO2, 800W

4.4.2.5 Water, 800W

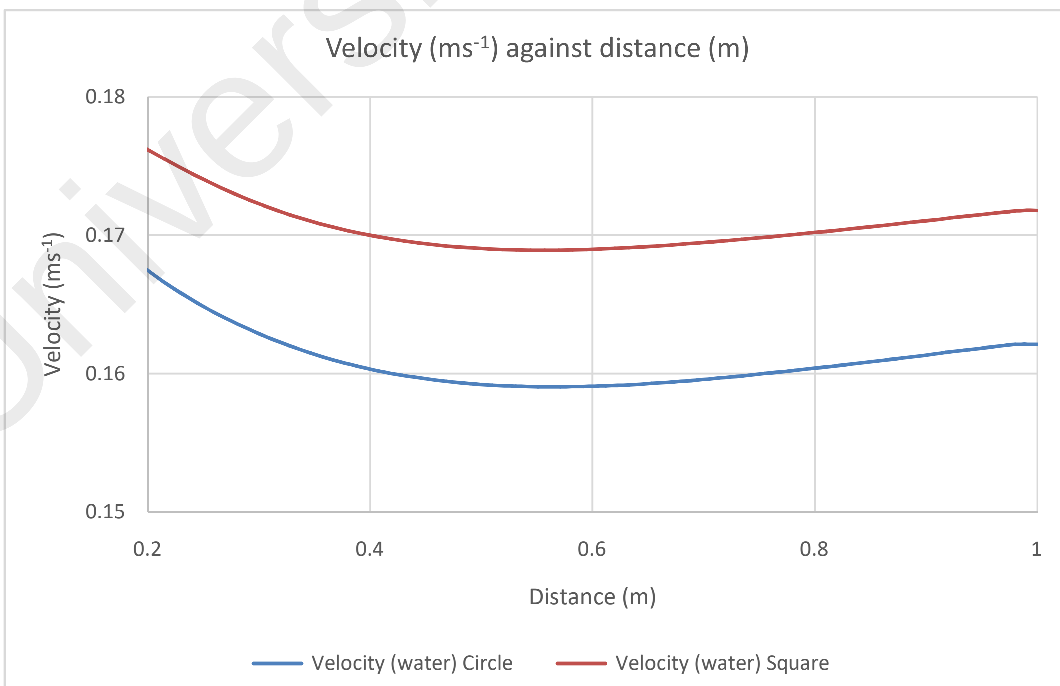

Figure 4-40 Velocity (ms^{-1}) against distance (m) for water, 800W

The overall velocity for all concentration of SiO_2 nanofluid and water have similar downward graphical trends for both the circle and square designs. The velocity is the highest at 0.2m and dips at 0.6m position and increases up until the 1m position.

When comparing between the circle and square design, the squaredesign displayed a higher overall velocity throughout the entire distance than the circle design. The difference throughout the positions of the enclosure between the two designs remains similarly constant.

4.5 Comparison Of Flow Characteristic

4.5.1 Heat Transfer Coefficient

4.5.1.1 Circle design, 600W

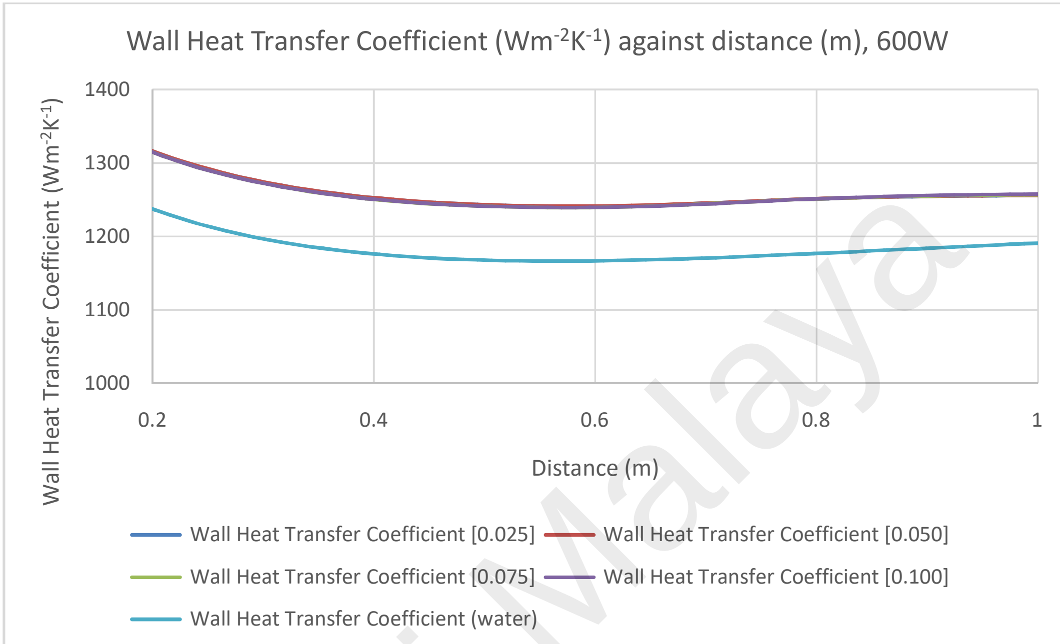

Figure 4-41 Comparison of wall heat transfer coefficient ($Wm^{-2}K^{-1}$) against distance (m) for circle design, 600W

4.5.1.2 Square design, 600W

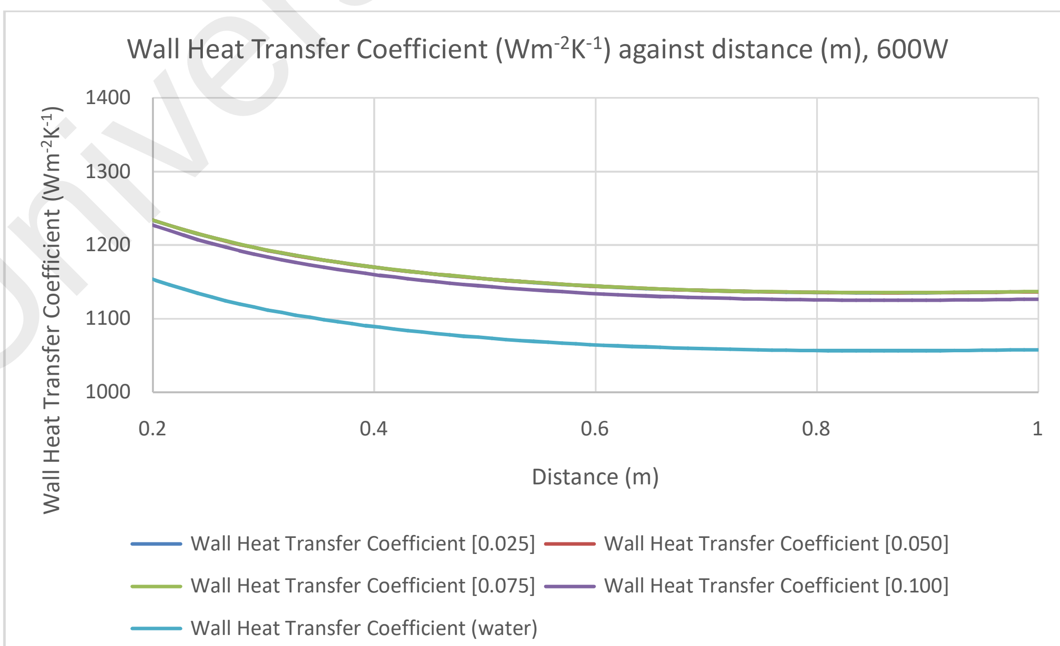

Figure 4-42 Comparison of wall heat transfer coefficient ($Wm^{-2}K^{-1}$) against distance (m) for square design, 600W

Table 4-1 Comparison of Wall Heat Transfer Coefficient for circle design, 600W

Distance (m)	Wall heat Transfer Coefficient ($Wm^{-2}K^{-1}$)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	1315.984	1316.106	1314.564	1314.665	1237.316
0.4	1252.410	1252.524	1250.319	1250.413	1175.318
0.6	1241.066	1241.182	1239.413	1239.519	1166.693
0.8	1251.113	1251.232	1250.908	1251.019	1176.776
1.0	1255.587	1255.713	1256.545	1257.387	1190.711

Table 4-2 Comparison of Wall Heat Transfer Coefficient for square design, 600W

Distance (m)	Wall heat Transfer Coefficient ($Wm^{-2}K^{-1}$)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	1233.595	1233.699	1233.853	1227.197	1153.414
0.4	1169.780	1169.876	1170.019	1159.823	1089.084
0.6	1143.964	1144.056	1144.195	1133.912	1063.881
0.8	1135.452	1135.544	1135.683	1125.534	1056.653
1.0	919.570	919.645	919.758	911.561	856.050

Table 4-3 Percentage increase in wall heat transfer coefficient for circle and square design, 600W

Distance (m)	Percentage increase (%)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	6.679	6.680	6.541	7.127	7.274
0.4	7.064	7.065	6.863	7.811	7.918
0.6	8.488	8.490	8.3212	9.314	9.664
0.8	10.186	10.188	10.146	11.149	11.368
1.0	36.541	36.543	36.617	39.938	39.094

4.5.1.3 Circle design, 800W

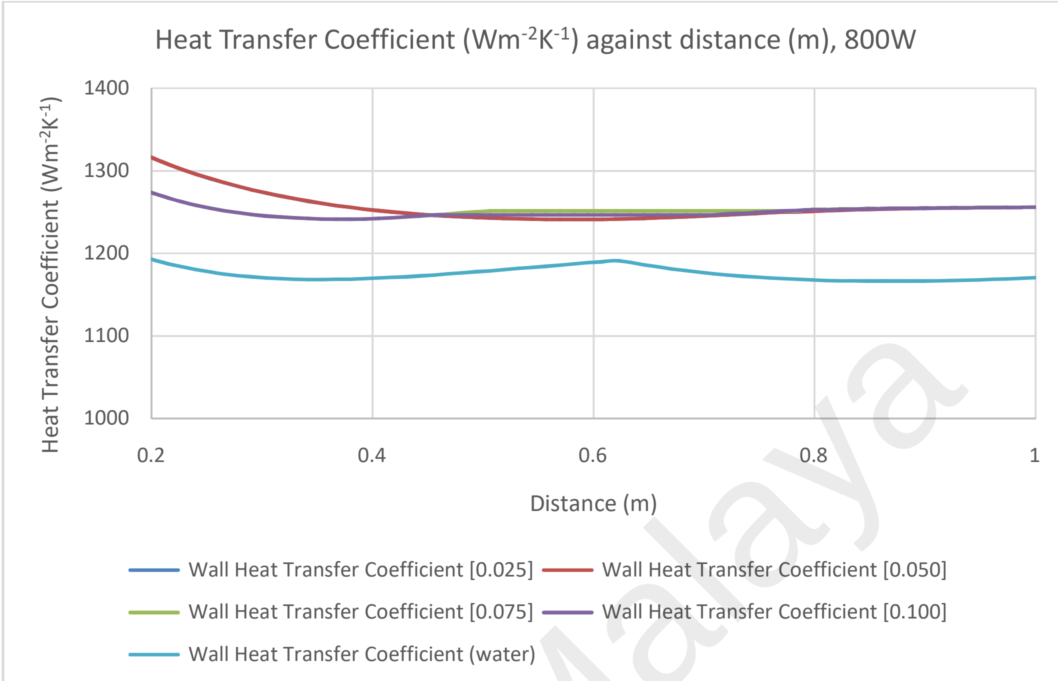

Figure 4-43 Comparison of wall heat transfer coefficient ($Wm^{-2}K^{-}$) against distance (m) for circle design, 800W

4.5.1.4 Square design, 800W

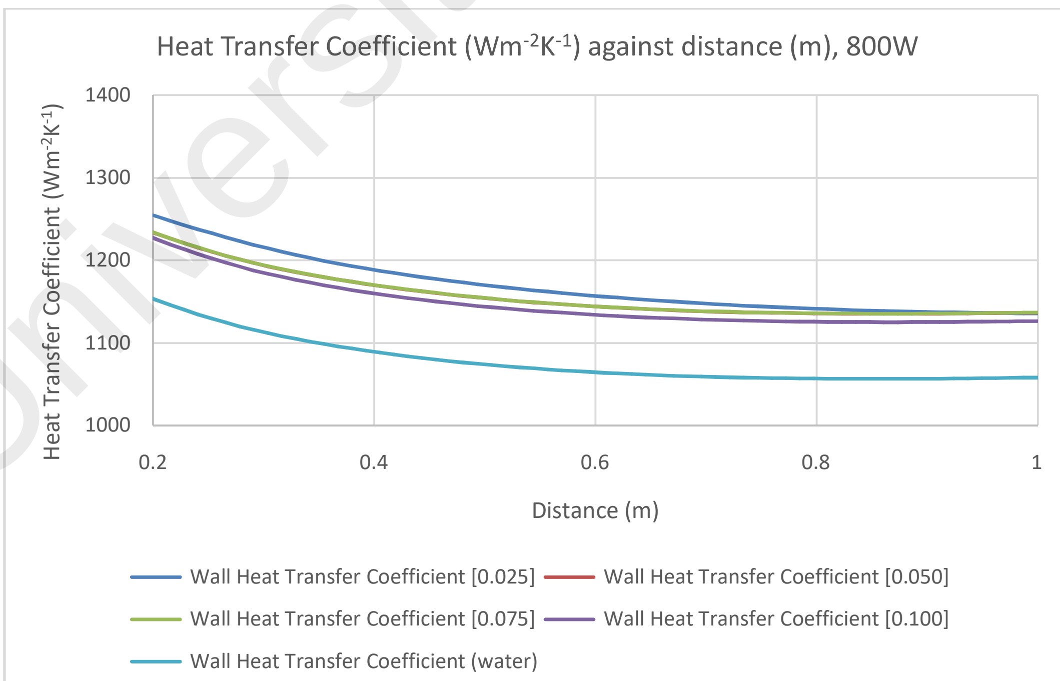

Figure 4-44 Comparison of wall heat transfer coefficient ($Wm^{-2}K^{-}$) against distance (m) for square design, 800W

Table 4-4 Comparison of Wall Heat Transfer Coefficient for circle design, 800W

Distance (m)	Wall heat Transfer Coefficient ($Wm^{-2}K^{-1}$)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	1315.984	1316.106	1273.592	1273.688	1192.791
0.4	1252.410	1252.524	1241.819	1241.954	1169.932
0.6	1241.066	1241.182	1251.201	1246.575	1189.074
0.8	1251.113	1251.232	1252.948	1252.884	1167.750
1.0	1255.587	1255.713	1255.869	1255.600	1170.303

Table 4-5 Comparison of Wall Heat Transfer Coefficient for square design, 800W

Distance (m)	Wall heat Transfer Coefficient ($Wm^{-2}K^{-1}$)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	1254.409	1233.699	1233.853	1227.197	1153.414
0.4	1188.267	1169.876	1170.019	1159.823	1089.084
0.6	1156.878	1144.056	1144.195	1133.912	1064.409
0.8	1141.269	1135.544	1135.683	1125.534	1056.653
1.0	919.570	919.645	919.758	911.561	856.050

Table 4-6 Percentage increase in wall heat transfer coefficient for circle and square design, 800W

Distance (m)	Percentage increase (%)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	4.909	6.680	3.221	3.788	3.414
0.4	5.398	7.065	6.137	7.081	7.424
0.6	7.277	8.490	9.352	9.938	11.712
0.8	9.625	10.188	10.326	11.315	10.514
1.0	36.541	36.543	36.543	37.742	36.710

For the circle and square design, the heat transfer coefficient for the different concentrations of SiO2 is similar while the value for water is the lowest. The [0.025] SiO2 exhibits the best performance in the heat transfer coefficient when compared to the other concentrations.

When comparing to the square design, the circle design showed an improvement in the heat transfer coefficient with percentages increases between 6.541% and 39.938% for the 600W simulation and between 3.221% and 37.742% for the 800W simulation. The Nusselt Number is a clear reflection of this improvement with identical numerical improvements in each case corresponding to the concentration and position. The percentage increase in Nusselt number is identical to the percentage increase in the wall heat transfer coefficient since the Nusselt Number is proportional to the wall heat transfer coefficient. At a position of 1m, the highest improvement produced by the implementation of circle design in the 600W simulation was with the [0.100] SiO2 fluid with a 39.938% increase in wall heat transfer coefficient, while the lowest improvement was the use of [0.025] SiO2 with 36.541%. Meanwhile, for the same 1m position, the highest improvement produced in the 800W simulation was also the [0.100] SiO2 with a 37.742% increase in wall heat transfer coefficient, while the lowest improvement was the use of [0.025] SiO2 with 36.541%.

The improvement obtained was a result of the increase in the contact surface area between the design and the fluid. From the heat transfer coefficient equation (Bockh& Wetzel, 2012):

$$U = Q / (A * dT)$$

where:

U = heat transfer coefficient ($Wm^{-2}K^{-1}$)

Q = heat transfer (W)

A = contact area (m^2)

dT = temperature difference (K)

From the equation, the heat transfer coefficient is proportional to the heat transfer while inversely proportional to the contact area and the temperature difference. However, in this study, the variable concerned is the contact area which is expressed by the circle and square design. The higher the contact area, the lower the heat transfer coefficient, and vice versa. To determine the contact area of each design, the cross-sectional area of the two designs were determined.

Table 4-7 Difference in surface area contact for circle and square design.

Design	**Area (mm^2)**
Circle	126.68
Square	111.95

Given the same length of the rod, the contact surface area can be represented by the perimeter of the design. Since the square design has a higher perimeter, the surface area contact between the rod and the running fluid is higher. This results in the lower wall heat transfer coefficient for the square design compared to the circle design.Circular designs are more efficient due to the lower wastage due to the equal distribution of heat transfer since the heat is radiating outwards in an equal manner. For square designs, the edges of the square act as areas of concentration, whereby heat transfer will not be as effective as it will take a longer time to absorb the heat from those concentrated areas. The usage of circle rods in industrial applications especially in the field of heat transfer and thermodynamics, namely air-conditioning, mechanical ventilation, and industrial heat transfer systems.

Past research has also strongly suggested the improved effectiveness and efficiency of a circular tube compared to a rectangular tube for heat transfer, indicating that a circular design has a higher heat transfer coefficient and Nusselt Number than a rectangular design (Bisht, Joshi, & Gupta, 2014).

4.5.2 Pressure

4.5.2.1 Circle design, 600W

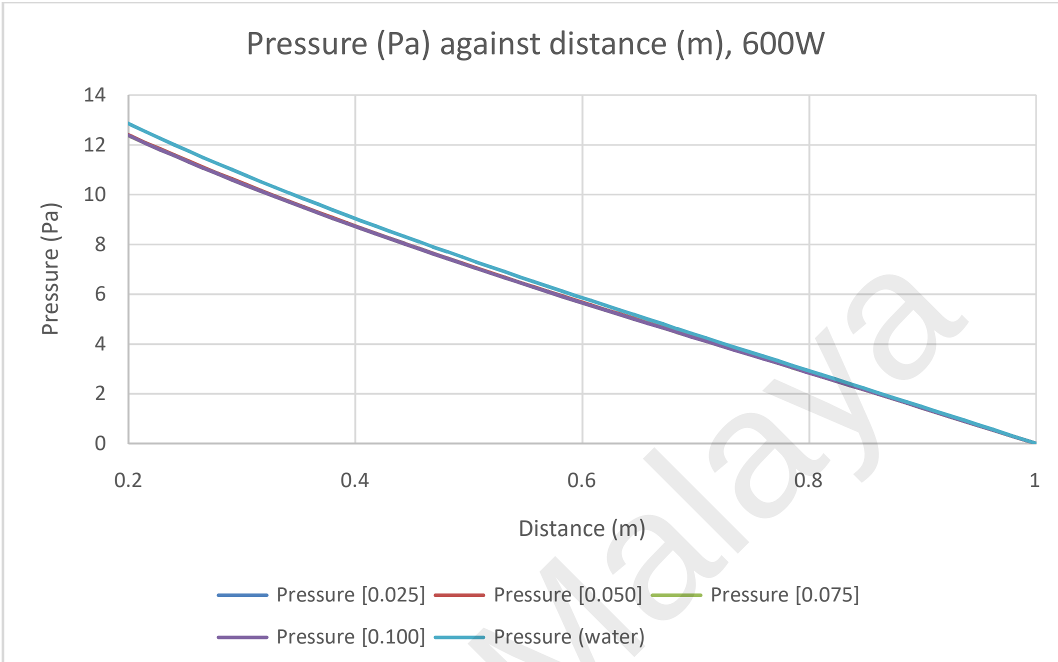

Figure 4-45 Comparison of pressure (Pa) against distance (m) for circle design, 600W

4.5.2.2 Square design, 600W

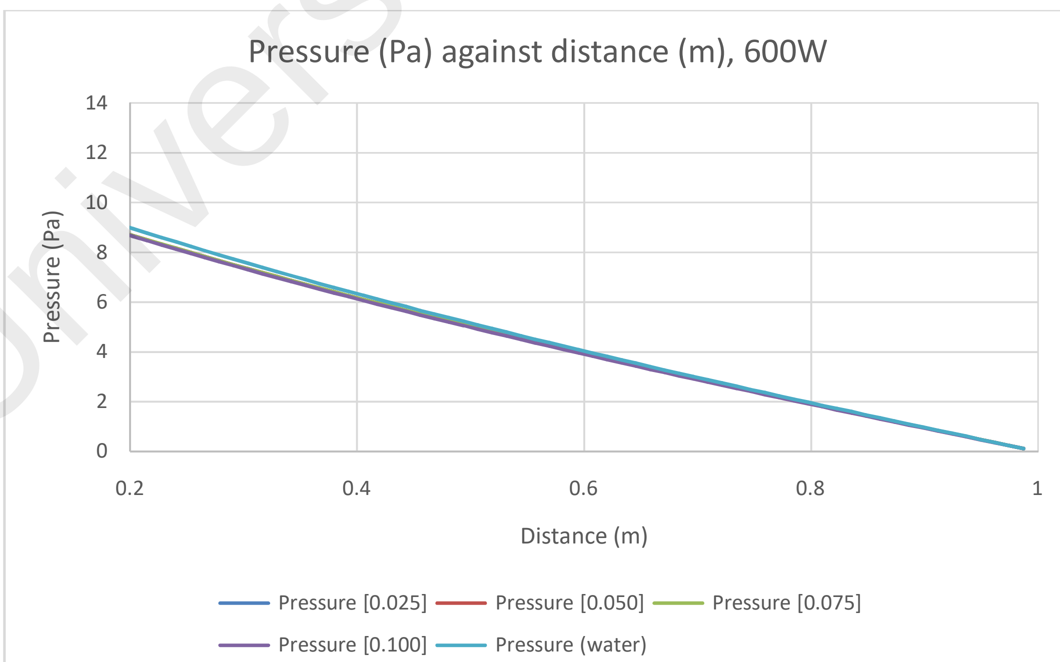

Figure 4-46 Comparison of pressure (Pa) against distance (m) for square design, 600W

4.5.2.3 Circle design, 800W

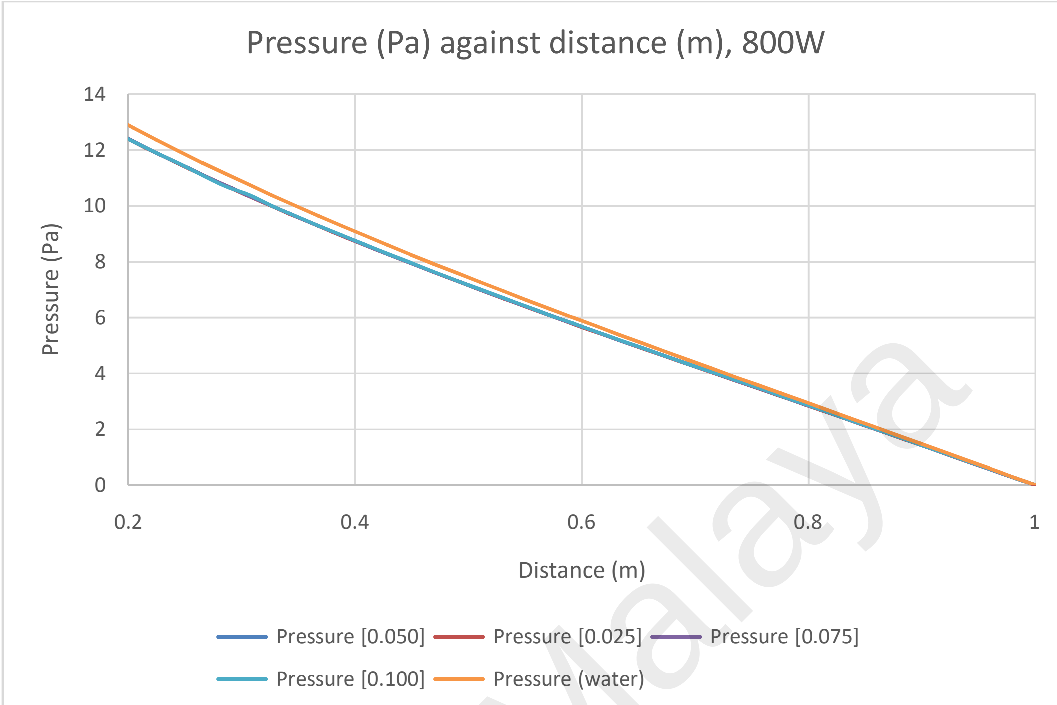

Figure 4-47 Comparison of pressure (Pa) against distance (m) for circle design, 800W

4.5.2.4 Square design, 800W

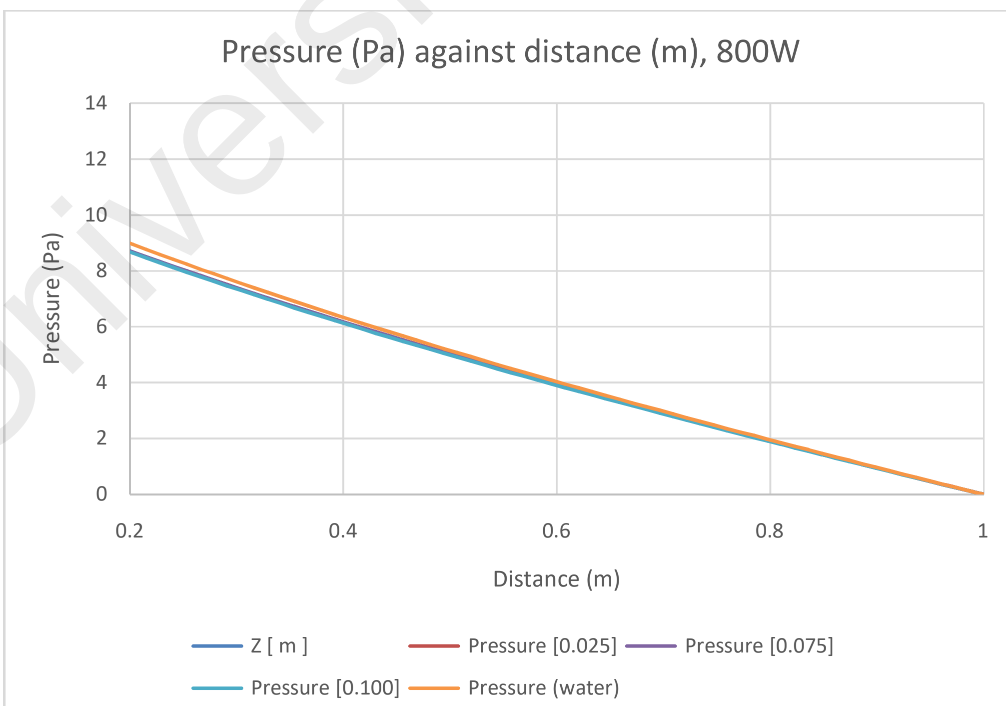

Figure 4-48 Comparison of pressure (Pa) against distance (m) for square design, 800W

The pressure loss of a fluid can be represented by the gradient of the plot. The higher the gradient, the higher the pressure loss, and vice versa. Water has the highest pressure loss out of all the other concentrations of SiO2. However, the difference is minimal and is negligible in almost all situations.

Pressure loss is caused by five factors (Sellens, n.d.), friction between fluid and pipe wall, fitting losses, friction within adjacent layers of fluid, pressure loss due to elevation, and pressure gain due to external power (pump). In this study, the factors of fitting losses, pressure loss due to elevation, and pressure gain from the pump can all be disregarded as there are no fitting components, no elevation, and no pump in the simulation. The two main factors that affect the pressure loss in this study are friction between fluid and pipe wall and the friction within adjacent layers of fluids.

Friction losses between fluid and pipe wall can be represented using the Darcy-Weisbach equation, which factors include friction factor, pipe length, hydraulic diameter, fluid density, and fluid velocity (Brown, 2003). Since the pipe length, hydraulic diameter, and fluid velocity is the same for the SiO2 and water simulations, the difference in pressure loss is caused by the friction factor and fluid density. Also, since friction factor is obtained from the Moody Chart using Reynolds' Number (which is inversely proportional to viscosity), the two main factors causing a difference in pressure for SiO2 and water are fluid density and viscosity.

Table 4-8 Density of viscosity of different SiO2 fluid and water

Fluid concentration	Density (kg/m^3)	Viscosity (kg/ms)
[0.025] SiO2	997.306	0.0008915
[0.050] SiO2	997.612	0.0008921
[0.075] SiO2	997.917	0.0008926
[0.100] SiO2	998.223	0.0008932
Water	998.200	0.0010030

As seen from the table above, as the concentration of SiO2 increases, the density and viscosity increase until water which has the highest of both factors. According to the Darcy-Weisbach equation, the pressure loss is inversely proportional to fluid viscosity (proportional to friction factor) and proportional to fluid density. The similarities in pressure loss for the SiO2 is mainly due to the similarities in the values of viscosity which are between 0.0000001 difference, which is minimal. However, when water is used, the viscosity increases dramatically, thus causing a higher pressure loss when compared to the other fluids. Although so, the difference in pressure loss between the SiO2 and water is minimal due to the small absolute value of the viscosity, thus the difference in pressure loss is negligible.

Meanwhile, when comparing the overall pressure and pressure loss for both circle and square design, the circle design has a higher overall pressure when compared to the square design. Since pressure is a function of force and normal surface area, while the force is constant for both designs, the normal surface area of the fluid flow is lower for the circle design than that of square design. From Table 13, the circle design has a higher cross-sectional area, which translates to a lower fluid flow area, and vice versa for the square design.

4.5.3 Temperature

4.5.3.1 Circle design, 600W

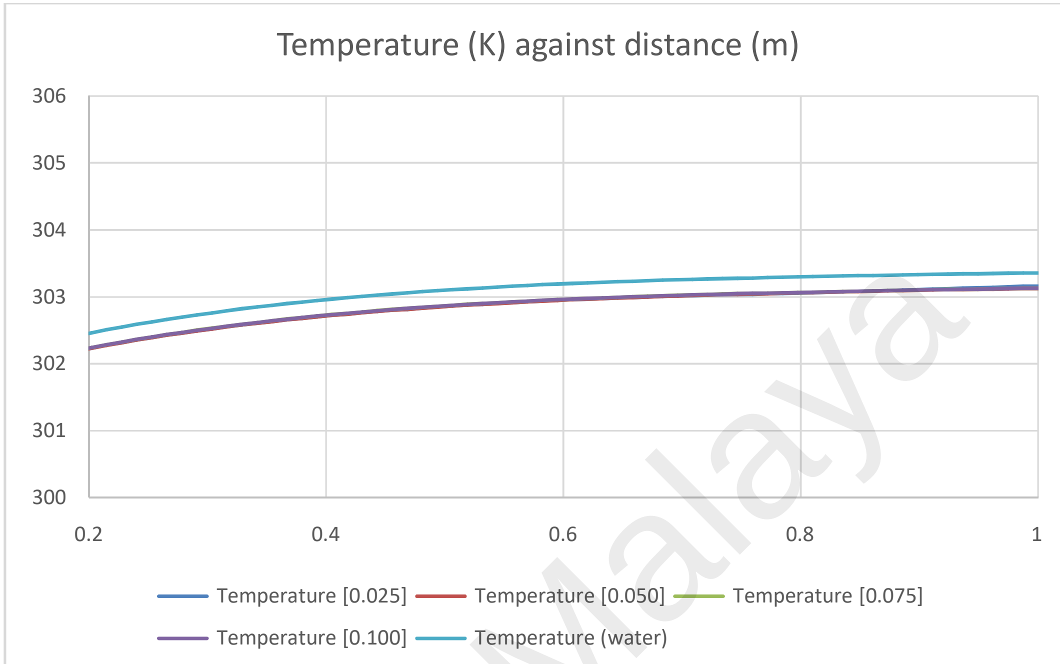

Figure 4-49 Comparison of temperature (K) against distance (m) for circle design, 600W

4.5.3.2 Square design, 600W

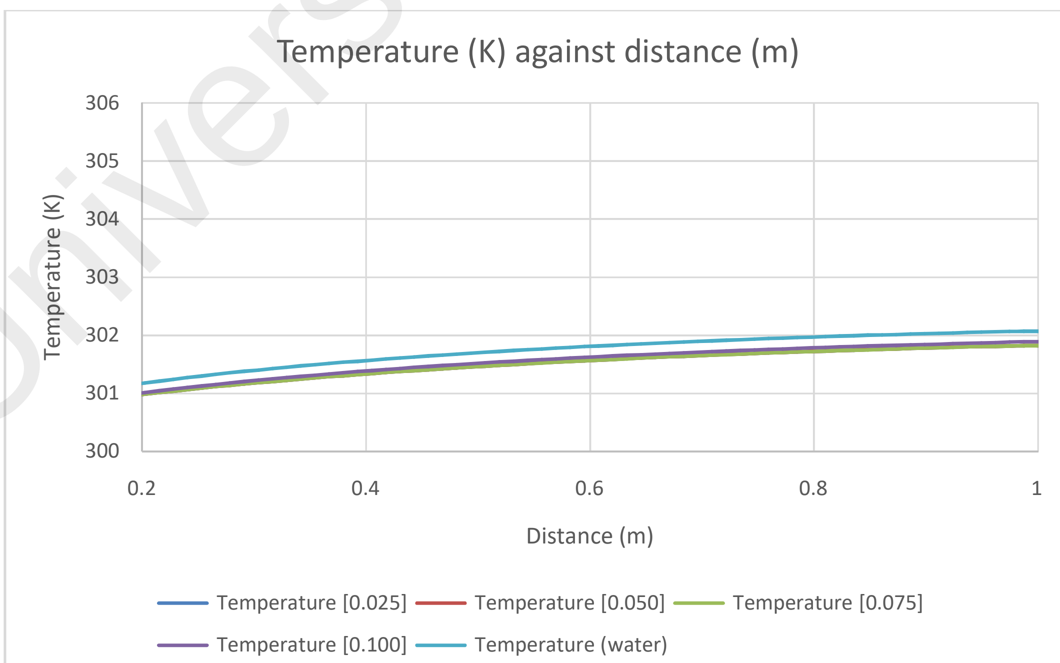

Figure 4-50 Comparison of temperature (K) against distance (m) for square design, 600W

Table 4-9 Comparison of temperature (K) against distance for circle design, 600W

Distance (m)	Temperature (K)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	302.227	302.227	302.281	203.234	302.503
0.4	302.858	302.858	302.376	302.873	303.114
0.6	303.436	303.437	303.461	303.459	303.717
0.8	303.969	303.969	303.995	303.995	305.030
1.0	303.158	303.124	303.127	303.127	303.357

Table 4-10 Comparison of temperature (K) against distance for square design, 600W

Distance (m)	Temperature (K)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	300.979	300.979	301.009	301.008	301.208
0.4	301.406	301.407	301.072	301.466	301.652
0.6	301.810	301.810	301.810	301.903	302.103
0.8	302.192	302.193	302.191	302.309	303.091
301.823	301.823	301.822	301.882	301.886	302.070

Table 4-11 Percentage increase of temperature (K) against distance (m) between the circle and square design, 600W

Distance (m)	Percentage increase (%)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	0.415	0.415	0.423	0.407	0.430
0.4	0.482	0.481	0.433	0.467	0.485
0.6	0.539	0.539	0.547	0.515	0.534
0.8	0.588	0.587	0.597	0.557	0.640
1.0	0.442	0.431	0.432	0.411	0.426

4.5.3.3 Circle design, 800W

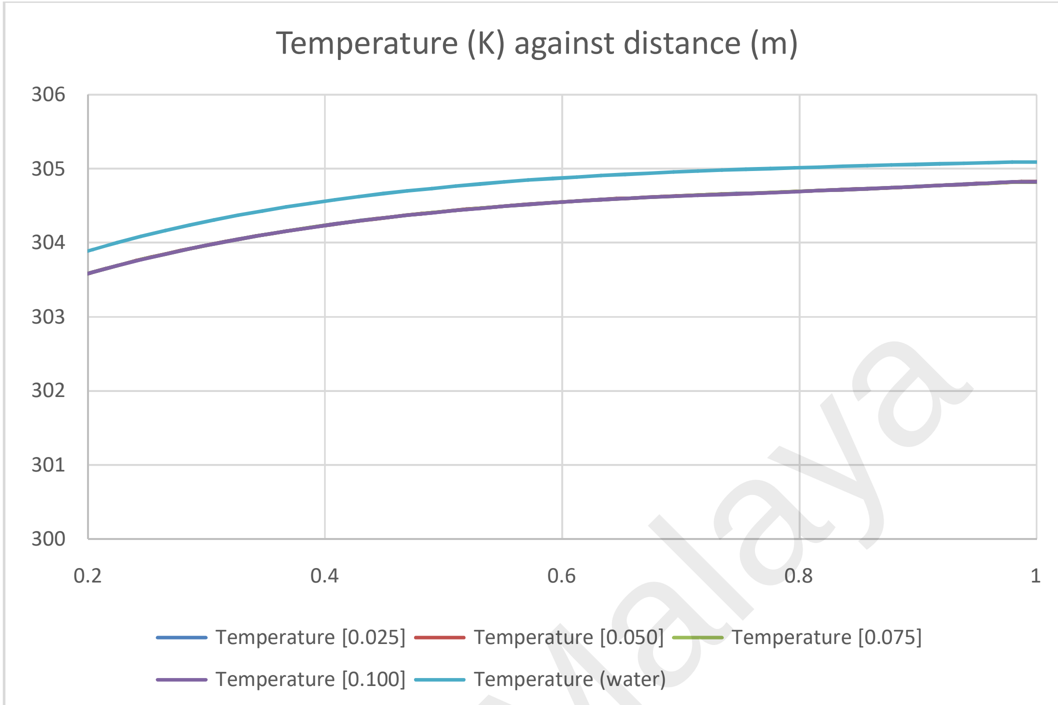

Figure 4-2 Comparison of temperature (K) against distance (m) for circle design, 800W

4.5.3.4 Square design, 800W

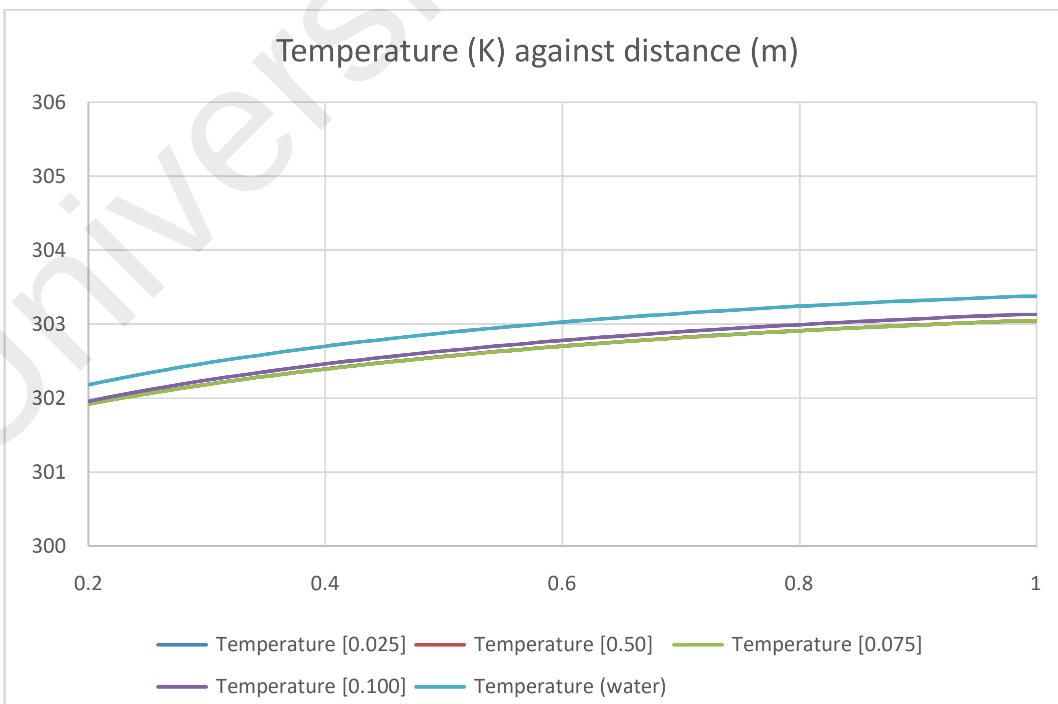

Figure 4-52 Comparison of temperature (K) against distance (m) for square design, 800W

Table 4-12 Comparison of temperature (K) against distance for circle design, 800W

Distance (m)	Temperature (K)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	303.586	303.586	303.175	303.586	303.585
0.4	304.429	304.429	303.787	304.236	304.235
0.6	305.200	305.200	304.170	304.551	304.550
0.8	305.907	305.907	304.417	304.693	304.693
1.0	304.827	304.826	304.819	304.821	305.090

Table 4-13 Comparison of temperature (K) against distance for square design, 800W

Distance (m)	Temperature (K)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	301.924	301.924	301.919	301.918	301.951
0.4	302.539	302.539	302.453	302.452	302.529
0.6	303.141	303.141	302.790	302.790	302.879
0.8	303.724	303.724	303.025	303.024	303.111
301.823	302.911	303.047	302.728	302.807	303.054

Table 4-14 Percentage increase of temperature (K) against distance (m) between the circle and square design, 800W

Distance (m)	Percentage increase (%)				
	[0.025] SiO2	[0.050] SiO2	[0.075] SiO2	[0.100] SiO2	Water
0.2	0.551	0.551	0.416	0.552	0.541
0.4	0.625	0.625	0.441	0.590	0.564
0.6	0.679	0.679	0.456	0.582	0.552
0.8	0.719	0.719	0.459	0.551	0.522
1.0	0.632	0.587	0.691	0.665	0.672

When comparing the 600W and 800W simulations, the 800W simulations obtained a higher overall temperature than that of the 600W simulations. This is expected as the higher heat transfer received by the system is reflected by the amount of heat the fluid absorbed, which is shown by the temperature of the fluid. Meanwhile, when comparing both the circle and square designs, the circle design shows a higher overall temperature. This phenomenon can be explained using the Zeroth Law of Thermodynamics, which states that the total thermal equilibrium of a system is achieved when two systems are in thermal equilibrium with a third (Muller & Ruggeri, 2004). In the beginning, the temperature of the fluid is low while the temperature provided to the design is high, as indicated by the wattage provided: 600W and 800W. However, as the fluid flows throughout the enclosure, heat transfer will occur constantly at every point, which increases the overall energy inside the fluid. The increase in energy is expressed and reflected by the increase in temperature of the fluid and obtained by the result. In this study, the length of the enclosure is limited to just 1m. However, heat transfer will occur constantly until thermal equilibrium is achieved, when the temperature of the design, the fluid, and the external environment is equal.

The circle design will have a higher overall temperature due to the higher heat transfer coefficient of the design. As denoted by the heat transfer equation (Bockh& Wetzel, 2012):

$$Q = U * A * dT$$

where:

Q = heat transfer (W)

U = heat transfer coefficient ($Wm^{-2}K^{-1}$)

A = contact area (m^2)

dT = temperature difference (K)

The amount of heat transferred determines the overall temperature of the system. The higher heat transfer coefficient and contact area of the circle design allows for more heat transfer to occur between the design and the surrounding fluid. This explains why the circle design simulation experiences a higher temperature in the surrounding fluid.If given enough time, both the circular and square designs will eventually achieve thermal equilibrium. However, the time taken for the circular design will be lower due to the higher efficiency of heat transfer. The heat transfer in the circular design is equal in all directions, heat radiates outward in a radial direction. Meanwhile, heat transfer in the square design is concentrated at the edges of the square, thus taking more time for heat transfer to occur due to the higher heat content at the concentrated areas.

4.5.4 Velocity

4.5.4.1 Circle design, 600W

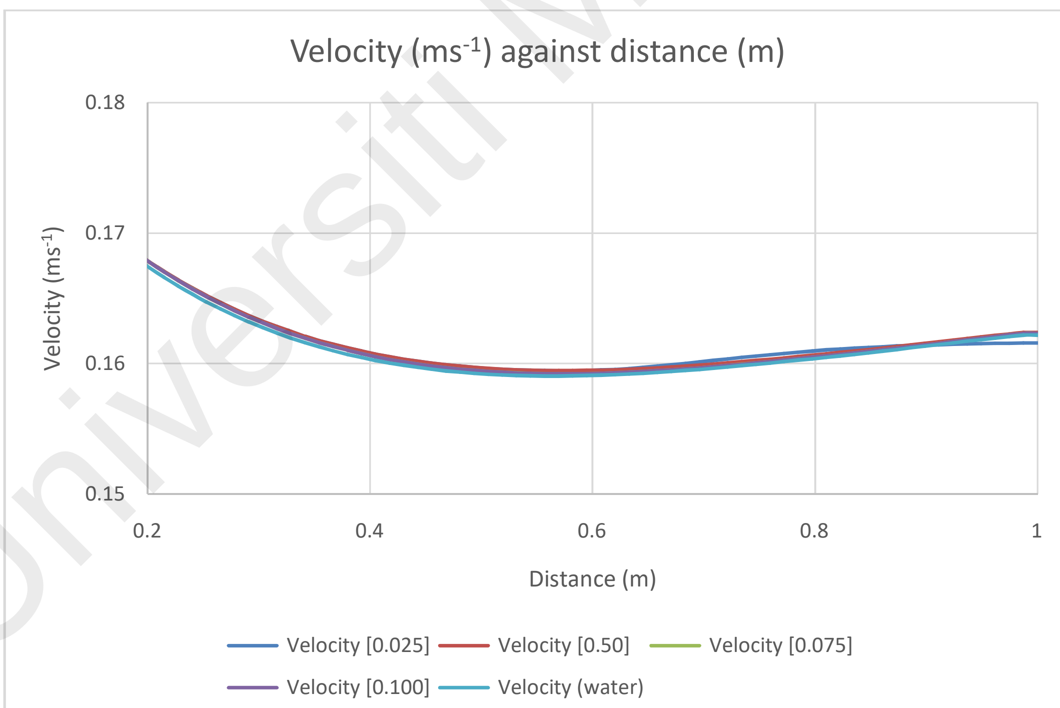

Figure 4-53 Comparison of velocity (ms^{-1}) against distance (m) for circle design, 600W

4.5.4.2 Square design, 600W

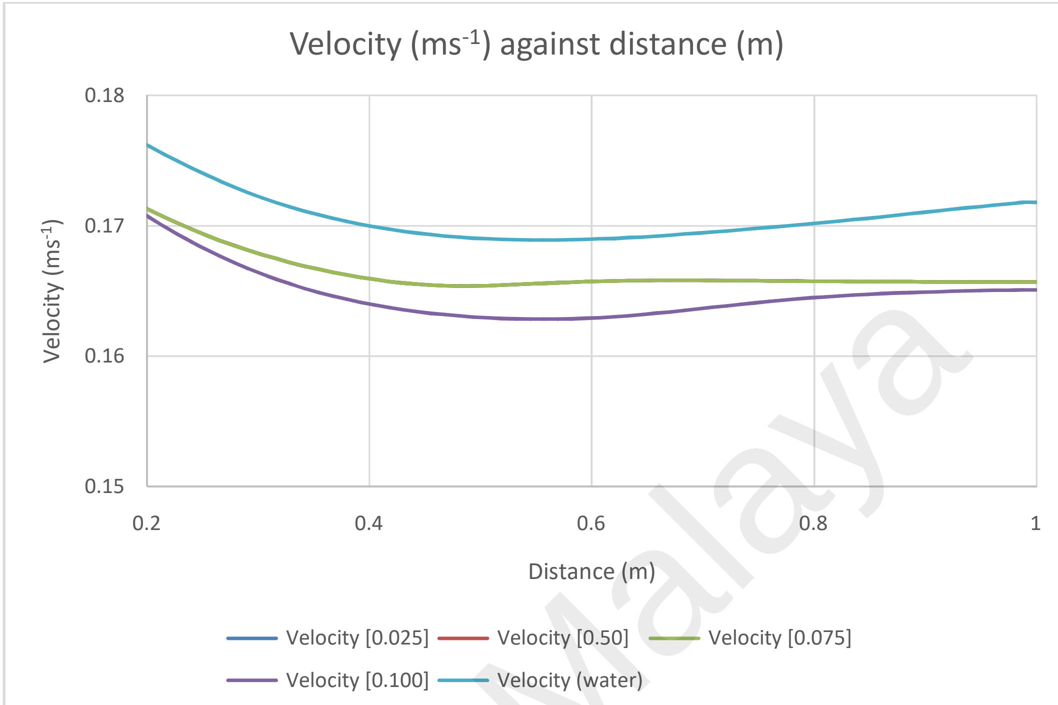

Figure 4-54 Comparison of velocity (ms^{-1}) against distance (m) for square design, 600W

Table 4-15 Comparison of velocity for circle and square design, 600W

Design	Velocity (ms^{-1})				
	0.025	**0.05**	**0.075**	**1**	**Water**
Circle	0.163781	0.163782	0.163658	0.163657	0.163448
Square	0.168096	0.168095	0.168094	0.166793	0.172203
Increase (%)	2.634	2.633	2.710	1.916	5.356

4.5.4.3 Circle design, 800W

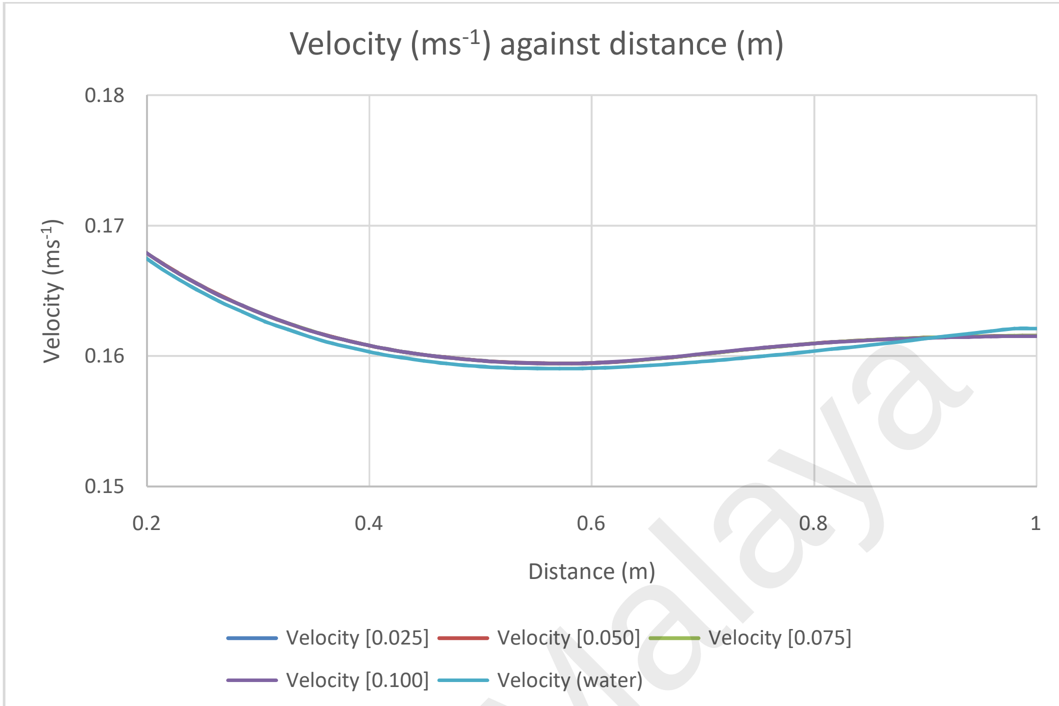

Figure 4-55 Comparison of velocity (ms^{-1}) against distance (m) for circle design, 800W

4.5.4.4 Square design, 800W

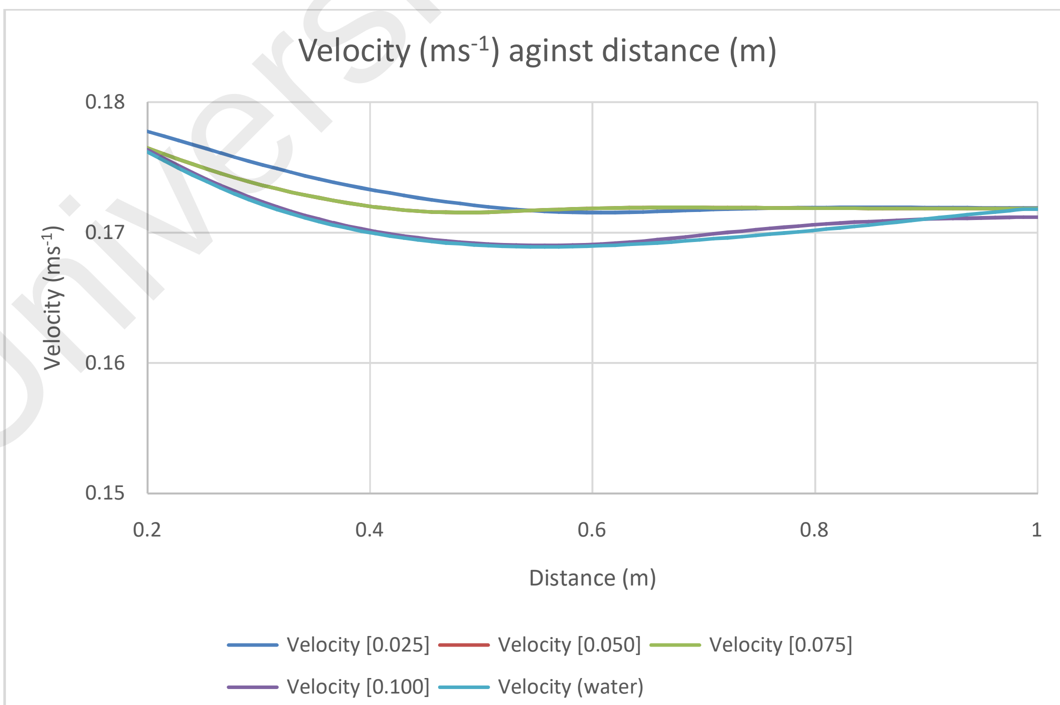

Figure 4-56 Comparison of velocity (ms^{-1}) against distance (m) for square design, 800W

Table 4-16 Comparison of velocity for circle and square design, 800W

Design	Velocity (ms^{-1})				
	0.025	**0.05**	**0.075**	**1**	**Water**
Circle	0.163781	0.16378	0.163816	0.163813	0.163489
Square	0.173933	0.173514	0.173514	0.172312	0.172203
Increase (%)	6.198	5.943	5.920	5.188	5.330

When comparing the 600W and 800W simulations, the difference between the overall velocity is somewhat similar and negligible due to the minor difference. However, when comparing between the circle and square design, the square design showed a slight increase in overall velocity. This phenomenon can be explained using Bernoulli's effect, which is part of the First Law of Thermodynamics, stipulating the relationship between pressure and velocity in an inviscid incompressible flow: The sum of the total potential, kinetic, and thermal energy in a fluid system will remain constant (Widden, 1996). Bernoulli's equation can be expressed as follow:

$$P_1 + \frac{1}{2}pV_1{}^2 + pgh_1 = P_2 + \frac{1}{2}pV_2{}^2 + pgh_2$$

where:

P = Initial/Final pressure (Pa)

p = Fluid density (kg/m^3)

V = Fluid velocity (ms^{-1})

g = Gravitational acceleration (ms^{-2})

h = Elevation (m)

Although the equation above is generally applied for ideal fluids with a steady flow, zero viscosity, and constant density, for this study, the low viscosity makes this an accurate representation of what is happening to the system. The Bernoulli effects dictate that as the fluid pressure inside a system increases, the fluid velocity of the system decreases. Velocity is inversely related to the fluid pressure of the system. At first, a higher pressure might intuitively indicate that the system has a higher velocity, however, that is not the case.

This can be shown with a derived equation suitable for this study. We know from the results of the initial pressure (P_1) is higher than the final pressure (P_2), the density (*p*),and gravitational acceleration (g)are constant, and there is no elevation (h). Thus, the derivation of Bernoulli's equation suitable for this study can be expressed as follow:

$$P_1 + {V_1}^2 = P_2 + {V_2}^2$$

To conserve the total sum of energy in a system, as the initial pressure (P_1) is higher, the velocity must be lower; while the final pressure (P_2) is lower, the velocity must be higher. Since the pressure for the circle design is higher than the square design at each point of the enclosure, the overall velocity will be lower than that of the square design, and vice versa.

CONCLUSION

In the Results and Discussion section, all of the study's objectives were addressed, and the outcome was examined.

Circular designs are more efficient due to the lower wastage due to the equal distribution of heat transfer since the heat is radiating outwards in an equal manner. For square designs, the edges of the square act as areas of concentration, whereby heat transfer will not be as effective as it will take a longer time to absorb the heat from those concentrated areas

The temperature for all concentrations of SiO_2 nanofluid and water display similar graphical trends for both the circle and square design. When comparing between the circle and square design, the circle design exhibited a higher overall temperature than the square design in all cases of SiO_2 concentration and water.

Meanwhile, when comparing the overall pressure and pressure loss for both circle and square design, the circle design has a higher overall pressure when compared to the square design.

5.1 Future Work

The current project is aimed at improving the working fluid. In the meantime, further research could look at combining the improvement of the working fluid with the improvement of the heat exchanger shape to create a more complex design, such as hexagonal and others.

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