Development Length for Non-Newtonian Laminar Flow in Circular Pipe

by

Muhammad Umar Rijaluddeen Bin Husni

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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(MECHANICAL ENGINEERING)

Approved by,

____

(Dr. Azuraien bt Jaafar @ Japper)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD UMAR RIJALUDDEEN B HUSNI

ABSTRACT

This paper consists of the research that had been done based on this chosen topic, **Development Length for Non-Newtonian Laminar Flow in Circular Pipe**. The application of the information gained from this research can benefit various industries handling and utilizing Non-Newtonian Fluid. The objective of this project is to study the development length requirement of a non-Newtonian fluid via experimental measurements. The requirement for this experiment is that, the literature reviews for development length of non-Newtonian fluid through a circular pipe was mostly on analytical and numerical analysis. With that the scope for the experiment will only be within laminar regime with non-Newtonian fluid in order to investigate the development length. In the early stages a flow loop design was proposed for the project in order to carry out the experiments. The design of the flow loop was proposed and adapted from Dr. Azuraien bt Jaafar flow loop in Liverpool, UK which was used for her degree of Doctor in Philosophy. The test section for the flow loop however was designed using ASME B31.3 standard taking into account the operating pressure, possible erosion by designing the appropriate thickness. The pressure tapping part at the test section design was taken from an already available design at the block 18-laboratory. Experiment was designed with pre-set conditions in accordance to the available pump at our disposal. Certain parameters like pressure and volume flow rate are fixed. Using the completed flow loop, the experiment was done using 5 different samples (UTP Tap water, Xanthan Gum solution 0.02wt %, 0.03wt %, 0.04wt % and 0.05wt %) in which the results have been analyzed. The findings from the experiments were that the development length for non-Newtonian is slightly shorter than Newtonian fluids.

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First and foremost, I give thanks and praise to God for His guidance and blessings throughout the entire course of my Final Year Project. I wish to express my gratitude to Dr. Azuraien bt Jaafar, for her guidance and support throughout completing my Final Year Project as partial fulfillment of the requirement for the Bachelor of Engineering (Hons) of Mechanical Engineering. I received an immeasurable amount of guidance, ideas, assistance, support and advice from various figures. Without their help, this Final Year Project may not have been successful. Here I express my greatest appreciation to Mr. Hazri Shahpin, Mr. Vinod Kumar, Ms. Amalina bt Daud and Mr. Che Mohd Hashrul b Che Baharum. Many thanks to Universiti Teknologi PETRONAS, especially the Mechanical Engineering Department for giving me the opportunity to embark on this project in which has equipped students with essential skills for self-learning. Finally, I would like to thank my family for they have been a wonderful source of encouragement and joy to me and not to forget as well my fellow colleagues which gave their effort in ensuring the smooth completion of this project. Their help was a tremendous gift to me. May God bless all of them, as only HE, the Almighty could recompense them for their goodwill.

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ABBREVIATIONS

t_m Minimum required thickness, including mechanical, corrosion, and erosion allowances.

t Pressure design thickness, as calculated in accordance with para. 304.1.2 for internal pressure or as determined in accordance with para. 304.1.3 for external pressure.

c The sum of mechanical allowances plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension h of ASME B1.20.1 or equivalent) shall apply. For machined surface surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of cut.

T pipe wall thickness (measured or minimum per purchase specification)

D Inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specifications.

P internal design gage pressure

D outside diameter of pipe as listed in tables of standards or specifications or as measured

S stress value for material from Table A-1

E quality factor from Table A-1A or A-1B

Y coefficient from Table 304.1.1, valid for $t < D/6$ and for materials shown, the value of Y may be interpolated for intermediate temperatures

Re Reynolds number

ρ density

μ viscosity

$\dot{V}$ volume flow rate

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Application of circular pipe can be seen in various industries. Such industries like cosmetics, food and especially oil and gas, all of them have dealings with non-Newtonian fluid. The relevance of non-Newtonian entrance length on the industries is significant as it deals with efficiency and cost. With respect to this project, the information gained from the experiments can be applied to the design of piping systems.

1.2 PROBLEM STATEMENT

The length required for the velocity profile to be non-varying in the axial direction is important as its prediction is of high practical use especially in the design of pipe flow systems. Extensive literature is available on the prediction of the development length in the circular and annular Newtonian pipe flows. However, for the circular pipe flow relationship between the entrance (development) length and the Reynolds number for non-Newtonian flows only literature on numerical and analytical is available. Poole and Ridley (2007) proposed a relationship for the development length of laminar power law non-Newtonian fluid flow which was obtained via numerical simulations. This may be used to cross reference the data achieved by experimental means while the available literature regarding experimentation with non-Newtonian fluid is scarce.

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objective of this study is to study the development length requirement of a non-Newtonian fluid via experimental measurements. To achieve this objective, it is essential

- To design, fabricate and assemble a circular pipe flow loop.
- To conduct experiments (pressure drop measurements along the test section of the flow loop) on various non-Newtonian fluid flow to determine entrance length

The scopes of this project will be simplified as follows:

- Use of polymer fluid as non-Newtonian fluid.
- Flow in circular pipe
- Measurements of pressure drop to determine the development length.
- Laminar Flow of non-Newtonian fluid.

CHAPTER 2
LITERATURE REVIEW

2.1 ENSURING LAMINAR FLOW

In order for the experimental results of the project to be valid, the fluid flow within the flow loop must be maintained at low Reynolds Number to ensure laminar flow throughout the experiment. Since Non-Newtonian fluid have an extended transition regime (Pinho & White, 1990) the best way to ensure laminar flow is if we retain the Reynolds Number below or at 2300.

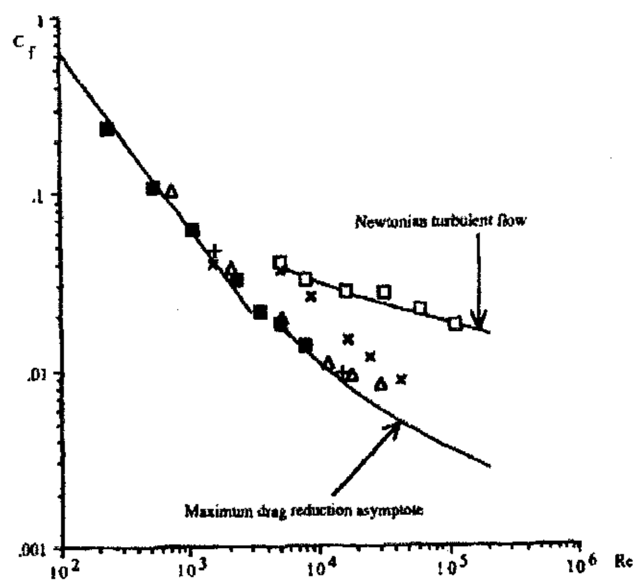

Figure 1: Friction factor versus Reynolds number. x 0.1%, Δ 0.2%, + 0.3%, ■ 0.4% Carboxymethyl cellulose (CMC) by weight, and □ Newtonian fluid (water and maltose syrup solution) (Pinho & White, 1990).

The above figure shows varying friction factor with varying polymer weight percentage in solutions. We can see that for non-Newtonian fluid, the laminar regime is slightly extended compared to the Newtonian laminar regime.

2.2 FLOW IN CURVED PIPES

This piece of information is critical in verifying the validity of the project experiment. Previous studies have shown that fluid development not only occurs in straight pipes, but also in curved pipes as well. The latter is shown by the figure below.

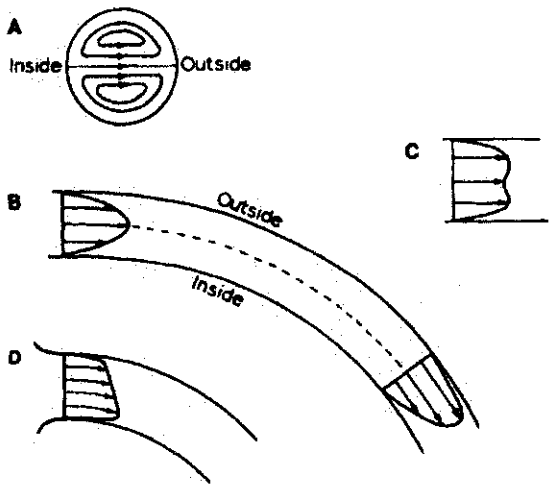

Figure 2: Flow patterns of fluid in curved pipes (Pedley & Drazen, 1986)

A: secondary motions develop when fluid flows in a curved tube, with flow in center of tube directed toward outside of bend and returning near walls.

B: axial velocity profile in plane of the bend is also distorted from Poiseuille flow (upstream) to a form having a peak near the outside wall (downstream).

C: profile in transverse plane is distorted to an M shape.

D: note initial skew in velocity profile when entry-flow profile is flat.

As we can see at B, the faster flow in the center portion tends to migrate to the outer regions due to the presence of centrifugal force in flows at curved pipes as an initial part of an entrance region under the conditions of small curvature and large dean number. A dean number is the Reynolds number over the square root of the curvature radius ratio. (Takami, Sudou, Tomita, 1990).

$$Dean\ number, \boldsymbol{De} = \frac{-\boldsymbol{Re}}{\sqrt{\boldsymbol{Rc}}} \qquad \textbf{(Eqn 2.1)}$$

Rc is the curvature radius divided by the radius of pipe. Below is a summary of the results obtained by Takami, Sudou and Tomita from their numerical and experimental analysis of the flow patterns within the curved pipe. With torus coordinates (r, θ, and φ):

When the fully developed flow of the straight pipe enters the curved pipe, the fast fluid in the center portion produces a stronger centrifugal force than the surrounding slow fluid, which induces the secondary flow towards the outer wall near the pipe center. The secondary flow, induced after entry increases dramatically from φ= 10 to φ= 20, forming a strong vortex pair in the cross section. With such an increase in the secondary flow toward the outer wall, the fast flow in the center portion gradually migrates to the outer region of the curved pipe. At φ= 30, part of the fast fluid shifted to the outer region begins to encroach on the inner region along the pipe wall with the strong secondary flow toward the outer wall. At φ= 40, the slow velocity region of the primary flow appears near the center portion. Consequently, the centrifugal force reduces in the center portion, causing a rapid decline of the secondary flow toward the outer wall. At φ= 60, the secondary flow is relatively reduced in the center portion and turns upward or downward near the pipe center. Also the stagnation region of the secondary flow appears near the symmetric plane in the inner region. At φ= 90, due to the decline of the secondary flow toward the inner wall near the pipe wall, the encroachment region of the fast fluid returns to the outer region along the pipe wall, and a reverse-rotating vortex appears near the symmetric plane in the inner region

And so, when the fluid enters straight pipes, the fluid will repeat the development cycle again. This is how we ensure that during our experiment, the fluid has not yet developed when it enters the test section of the straight circular pipe as right before the test section we have placed a curved pipe to imitate this exact situation.

2.3 XANTHAN GUM SOLUTION VISCOSITY

During the experiment, several samples of Xanthan Gum solutions are used with each varying in weight percentage for us to conclude a pattern. The weight percentages used are 0.02wt %, 0.03wt %, 0.04wt % and 0.05wt %. With each increase weight percentage, the viscosity would increase as shown in the figure below.

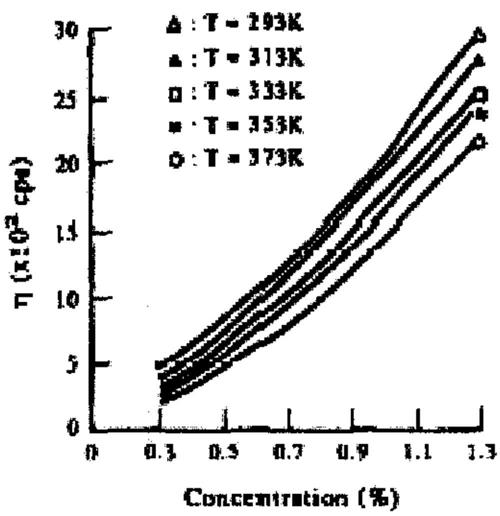

Figure 3: Effect of concentration on viscosity of Xanthan Gum at various temperatures (Zhang, 1996)

2.4 PRESSURE DROP

A numerical analysis showed that pressure differences along the test section are expected to drop drastically before having constant pressure loss along the pipe due to the displacement of the axial boundary layer as the flow is accelerated (Lun-Shin, 1977). This will also be proven from the results that were taken during the experiment. During the development stage, the pressure drop should be larger than the pressure drop after the fluid has fully developed; this is due to the axial velocity of the fluid has decreased significantly from the point of entry. (Cengel, 2006)

CHAPTER 3

METHODOLOGY

3.1 PROJECT IDENTIFICATION

The overall project work follows the flow chart as below:

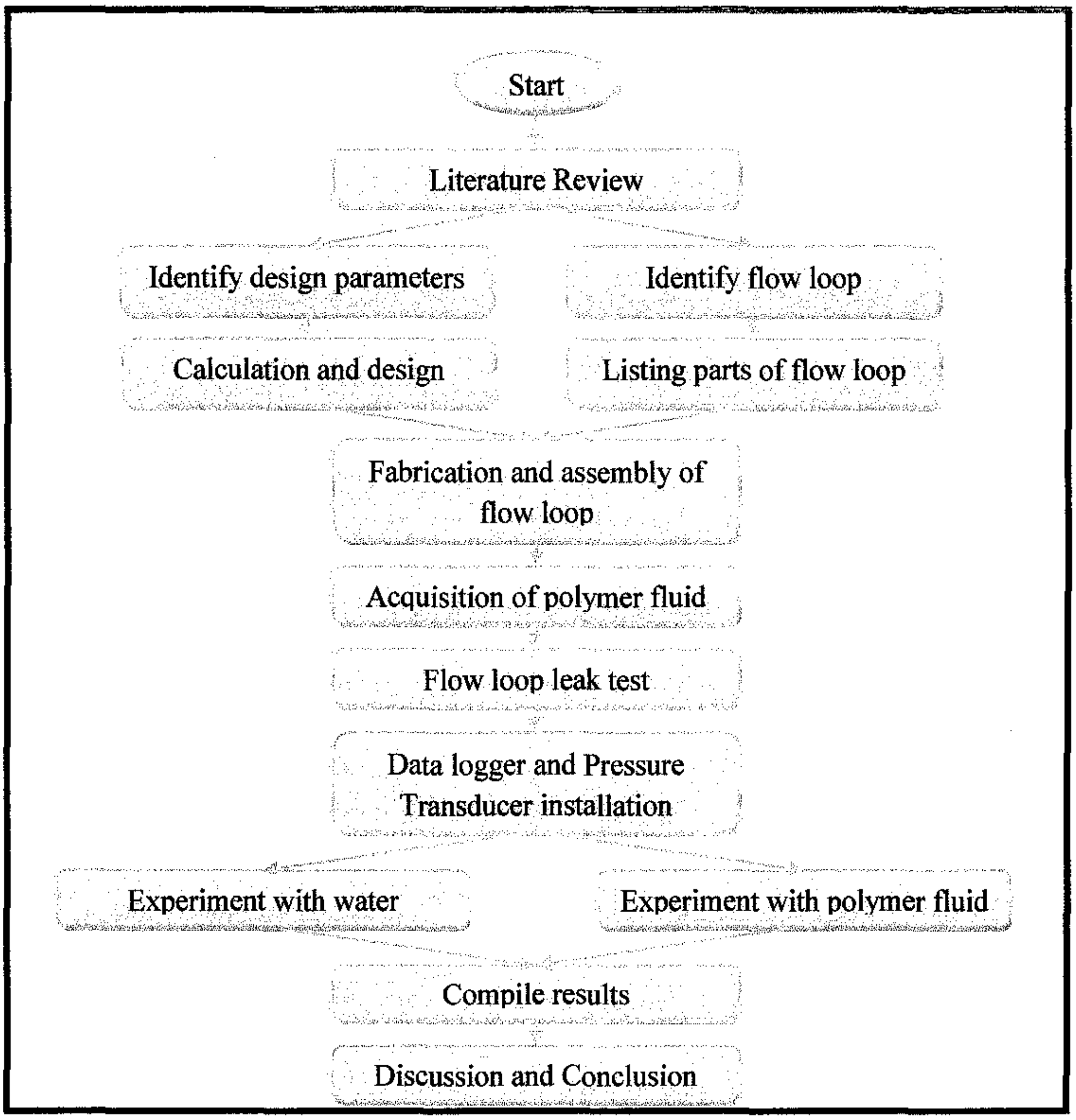

Figure 4: Project Identification

3.1.1 Final Year Project 1

Table 1: Gantt chart for Final Year Project 1

No	Task \ Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14	15
1	Choosing Topic							Mid semester break									
2	Literature Review																
3	Flow Loop Identification																
4	Preliminary Report Submission				x												
5	Procurement of Flow Loop																
6	Flow Loop Assembly																
7	Progress Report Submission									x							
8	Seminar									x							
9	Polymer Procurement																
10	Leak Test																
11	Submission of Interim Report Final Draft															X	
12	Oral Presentation																x

Legend	
Dateline	x
Time Allocation	

3.1.2 Final Year Project 2

Table 2: Gantt chart for Final Year Project 2

No	Week Task	1	2	3	4	5	6	7	Mid semester break	8	9	10	11	12	13	14	15
1	Leak Test																
2	Experiment with flow loop																
6	Data analysis																
7	Progress report 2 preparation																
8	Progress report 2 submission									x							
9	Experiment continues																
10	Data analysis continues																
11	Poster exhibition preparation																
12	Pre-SEDEX												x				
13	Dissertation preparation																
14	Submission of Draft Report													x			
15	Submission of Dissertation (soft bound)														x		
15	Oral presentation preparation																
16	Oral presentation															X	
17	Submission of Project Dissertation (hard bound)																x

Legend	
Dateline	x
Time Allocation	

3.2 PROJECT ACTIVITIES

3.2.1 Final Year Project 1

1) Initial research on non-Newtonian fluids

Non-Newtonian fluids shear stress is not linearly related to the shear strain rate. They are generally divided into two categories which are shear thinning fluids (pseudo-plastic) and shear thickening fluids (dilatants). Pseudo-plastic fluids becomes less viscous the more it is sheared while dilatants becomes more viscous with increasing shear. (Cengel, 2006)

2) Flow Loop Identification

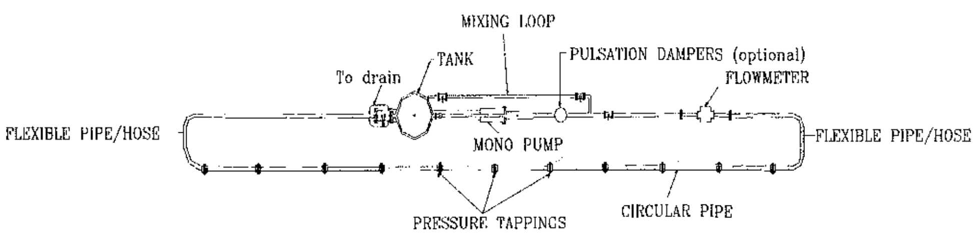

Figure 5: Flow Loop / Experiment Loop

Flow Loop Equipments:

- ❑ Pressure Transducer
  - ✓ Measuring pressure at pressure tapping points.
- ❑ Data Logger
  - ✓ To record results within a designated time frame.
- ❑ Mixing Loop & Tank
  - ✓ To mix polymer with water.
  - ✓ Mixing occurs after pump to reduce shearing effect of pump to polymer fluid.
- ❑ Flexible Pipe / Hose
  - ✓ For connecting circular pipe to tank and pump.

- Circular Pipe
  - ✓ Length of pipe is 3.6m.
  - ✓ Pressure tapping along pipe to measure pressure difference.
  - ✓ Circular pipe is transparent.
- Flow meter
  - ✓ To monitor and measure the rate of flow.
- Frequency regulator
  - ✓ Controls pump speed by adjusting the frequency.
- Pulsation dampers
  - ✓ To stabilize the variable and oscillating flow in each revolution of pumps.

3) Polymer Fluid Identification (Xanthan Gum)

Xanthan gum is a polysaccharide used as a food additive and rheology modifier (Davidson, 1980). For this project, Xanthan gum will be used as the non-Newtonian fluid to be studied within the flow loop. Xanthan gum is able to produce a large increase in the viscosity of a liquid by adding a very small quantity of gum.

4) Circular Pipe Design Calculation

Pressure Design

$$t_m = t + c \qquad \textbf{(Eqn. 3.1)}$$

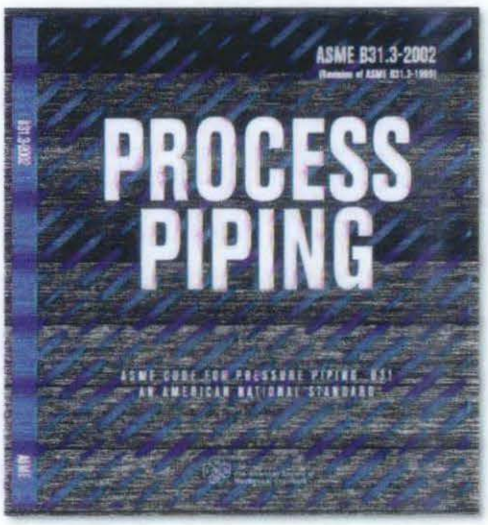

Figure 6: ASME B31.3- Process Piping

For t≥ D/6	For t< D/6
$\boldsymbol{Y = \frac{d + 2c}{D + d + 2c}}$ (***Eqn* 3.2**)	$\boldsymbol{t = \frac{PD}{2(SE + PY)}}$ (***Eqn* 3.5**)
$\boldsymbol{t = \frac{PD}{2(SE + PY)}}$ (***Eqn* 3.3**)	
$\boldsymbol{t = \frac{P(d + 2c)}{2[SE - P(1 - Y)]}}$ (***Eqn* 3.4**)	

<u>Data Taken from pump to be used:</u>

$$Mass\ flowrate, \dot{m} = 125\ lpm = 7.5\frac{m^3}{hr}\ x\ \frac{1\ hr}{3600\ s} = 2.083x10^{-3}\frac{m^3}{s}$$

$$Frequency, f = 1450\ rpm$$

$$Area\ of\ pipe, A = 7.069cm^2 = 7.069x10^{-4}m^2$$

$$Density\ of\ Xanthan\ Gum, \rho = 1.185\ \frac{g}{cm^3}$$

<u>Computing pressure within pipe:</u>

$$\boldsymbol{\dot{m} = VA} \qquad \textbf{(Eqn 3.6)}$$

$$Velocity, V = \frac{\dot{m}}{A} = \frac{2.083x10^{-3}\frac{m^3}{s}}{7.069x10^{-4}m^2} = 2.947\ \frac{m}{s}$$

$$\boldsymbol{V = \sqrt{2gh}} \qquad \textbf{(Eqn 3.7)}$$

$$Head, h = \frac{V^2}{2g} = \frac{(2.947\ \frac{m}{s})\hat{}2}{2(9.81\frac{m}{s^2})} = 0.443m$$

$$Pressure, P = \rho gh$$

$$\boldsymbol{P = \rho_{XG}\ x\ g\ x\ h} \qquad \textbf{(Eqn 3.8)}$$

$$\rho_{XG} = 1.185\ \frac{g}{cm^3} = 1.185x10^3\frac{kg}{m^3}$$

$$P = 1.185x10^3 \frac{kg}{m^3} \, x \, 9.81 \frac{m}{s^2} \, x \, 0.443m = 5149.8 \, Pa = 5.15 \, kPa$$

<u>Computing Hydrostatic Design Stress (HDS):</u>

$$\boldsymbol{HDS = \frac{PC(\,SIDR+1)}{2}} \qquad \textbf{(Eqn 3.9)}$$

Where:

$$\boldsymbol{SIDR = \frac{Inside\ diameter}{wall\ thickness}} \qquad \textbf{(Eqn 3.10)}$$

$$\boldsymbol{PC = Pressure} \qquad \textbf{(Eqn 3.11)}$$

HDS data on Acrylic or Poly (methyl methacrylate) is not available in the standard B31.3

Was not able to access data from ASTM, so alternative method is to back calculate from preferred wall thickness and see the HDS it can withstand.

Using the ASME B31.3

$$HDS = 24500 \, Pa = 24.5 \, kPa \, for \, t = 0.5cm$$

5) Test Section Drawing Design

Below is the test section drawing design sent to the fabricator following the requirement of the ASME B31.3 calculation done above.

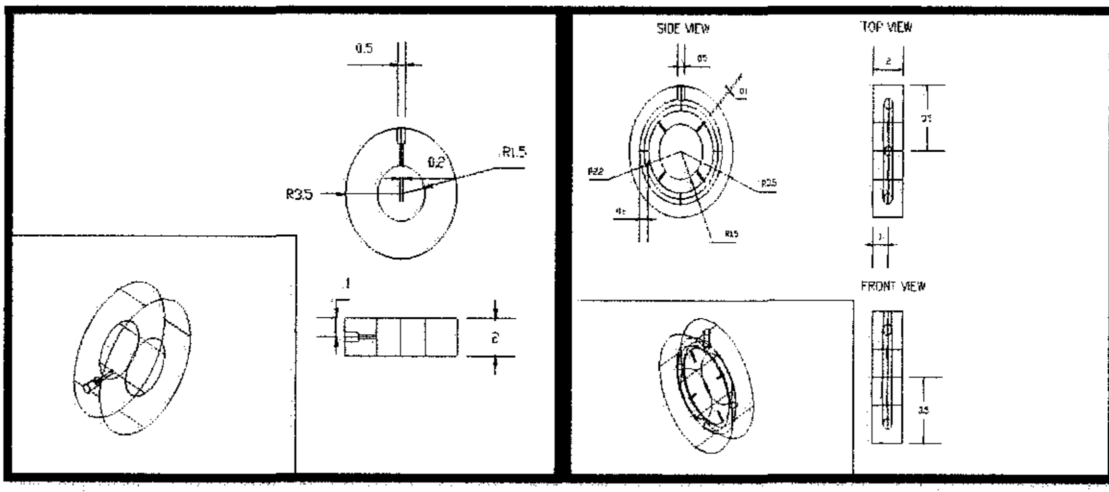

Figure 7: Two designs of pressure tapping on circular pipe.

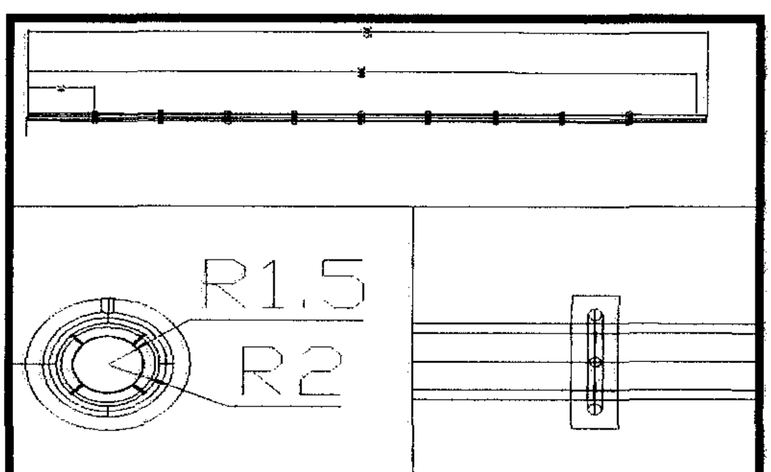

Figure 8: Circular Pipe with pressure tapping. [The design on the right was used for the pressure tapping]

6) Procedure Preparation – Experiment and Leak Test

Leak Test (Static)

Fill flow loop with water and leave it overnight. If there are any leaks, seal the leak points and redo test. If not, bleed the water from the flow loop.

Leak Test (Dynamic)

1. Close valves leading to test section.
2. Fill tank and pump with water.
3. Run the pump by circulating water within mixing loop for 30min.
4. Check flow loop for leaks.
5. Seal leak points and start step 1-4 again, if there are no leaks, proceed to step 6.
6. Open valves leading to test section and close valves within the mixing loop.
7. Check flow loop for leaks.
8. Seal leak points and start step 6-7 again, if there are no leaks, turn pump off and bleed water from flow loop.

Experiment

1. Fill the tank and pump with water before turning on the pump.
2. Close the mixing loop valves and open the valves leading to the test section.
3. Turn pump on.
4. Let the water fill the test section. Make sure there are no bubbles.
5. If there are bubbles, open up all valves (Except the bleed valve) to allow entrapped bubbles to escape.
6. Connect pressure transducer to the 1st and 2nd pressure taps.
7. Bleed the bubbles (if any) that is seen in the pressure transducer.
8. Record the pressure difference for at least 5minutes.
9. Save the data and reconnect the pressure transducer to the 2nd and 3rd pressure taps.
10. Repeat step 6-8 in the respective order of pressure taps until the last pressure tap.
11. Turn pump off.

12. Measure the static pressure from pressure tap 1-9 following similar steps as in step 6-8.
13. Once done, bleed the water from the flow loop.

For Xanthan Gum Solution 0.02wt%, 0.03wt%, 0.04wt% and 0.05wt%, the solution has to be mixed outside first, once the solution has been mixed well, flow the Xanthan Gum solution within the mixing loop first for 10minutes, after that, proceed with step 2 until step 13 to finish the experiment.

Mixing Xanthan Gum solution

- Use motorized/magnetic stirrer to ensure that the Xanthan Gum does not form lumps within the solution that might distort the readings with reference to Ernst, 1966.

3.2.2 Final Year Project 2

1) Flow Loop Assembly And Testing

1. Flow loop assembly:
   a. GI pipe, flexible pipe, pump, frequency regulator, flow meter, pressure transducer, data logger, power supply converter, decade resistance box and laptop.
2. Hydraulic leak test:
   a. Static Leak Test
      i. Pressure taps were sealed.
      ii. Flow loop was filled with water.
      iii. Water was left stagnant in the flow loop for 24hours.
      iv. Observation after 24hours.
   b. Dynamic Leak Test
      i. Pressure Taps were sealed.
      ii. Flow loop was filled with water.
      iii. Using the frequency regulator, run the pump at 20,25,30,40 and 50Hz

c. Observation:

   i. The first leak test shows that the test section has several leaking points. Chloroform was applied to leaking areas.

   ii. Leak test was repeated for the second time where no leaks were observed.

3. Flow loop completion:

   a. A small filter was added within the tank to avoid lumps of Xanthan Gum from forming. This is to prevent the system from clogging.

Figure 9: Complete setup of flow loop at block 18 laboratory.

2) Reynolds Number Calculation

Calculations in ensuring laminar flow were done to determine the operating parameter of the pump during experimentation. This is because the experiment is supposed to be within the laminar region for it to achieve its objective. First we need to determine whether the pump can deliver a laminar flow using water.

Reynolds Number Calculation

$$Re = \frac{\rho V D}{\mu} \qquad \textbf{(Eqn 3.12)}$$

$$f = \frac{64}{Re} \qquad \textbf{(Eqn. 3.13)}$$

Pipe Size

D = 3cm

A = 0.00071m2

Pump Operating Parameter

Parameters at 25 Degree C running the pump at 1.4Hz

Water

Density = 997.13 kg/m3

Dynamic Viscosity = 0.000891 kg/ms

Frequency regulator

50Hz = 125 liter/minute

1.4Hz = 2.8liter/minute

Computing Reynolds number

$$\dot{V} = 2.8\ lpm\ x\ \frac{1m^3}{1000l} x \frac{1min}{60s} = 4.667\ x\ 10^{-5} \frac{m^3}{s}$$

$$V_{avg} = \frac{4.667\ x\ 10^{-5} \frac{m^3}{s}}{0.00071m^2} = 0.0657 \frac{m}{s}$$

$$Re = \frac{997.13 \frac{kg}{m^3}\ x\ 0.0657 \frac{m}{s}\ x\ 0.03m}{0.000891\ \frac{kg}{ms}} = \mathbf{2207} - Laminar\ Regime$$

The Reynolds number above suggests that using the above operating parameters will result in a laminar flow. And so the experiment can be carried on using the above parameters.

3) Preparing Xanthan Gum Solution

The experiment shall be done with multiple Xanthan solutions each varying in weight percentage. A simple calculation can help determine the required mass of Xanthan Gum and mass of water to create a solution of certain weight percentage.

$$\%weight = \frac{m_{XG}}{m_{XG}+m_{water}} x\ 100 \qquad \textbf{(Eqn. 3.14)}$$

$$m_{water} = \rho_{water}(V_{water}) \qquad \textbf{(Eqn. 3.15)}$$

Example:

To create a 0.5% of Xanthan solution in a 15kg mass of water.

$$0.5\ \% = \frac{m_{XG}}{m_{XG} + 15kg} x\ 100$$

$m_{water} = 0.075kg$ to be used for a weight percentage of 0.5%

Xanthan gum solutions having weight percentage 0.02, 0.03, 0.04, 0.05 shall be prepared as such, by computing the required weight with the desired volume of water mixing them well using either a magnetic stirrer or a motorized stirrer. Use of stirrer is to ensure that the Xanthan gum is well mixed with water without producing any lumps.

Figure 10: Magnetic stirrer and Xanthan gum powder used to make Xanthan gum solution.

4) Measuring Xanthan Gum Viscosity

After preparing the Xanthan gum solution, before starting the experiment, we need to measure its viscosity. This information will later be used to analyze the data that is acquired during the experiment. For this project, a low viscosity digital viscometer was used.

Figure 11: Digital viscometer used to measure Xanthan gum viscosity.

Brookfield DV -1+ procedure:

1. Pour solution into the provided beaker.
2. Select the spindle to be used.
3. Attach spindle to Viscometer.
4. Turn the Digital viscometer on.
5. Lower the spindle into the beaker until the solution is at the calibration point.
6. Select the speed at which to run the spindle.
7. Run viscometer.
8. Ensure that the display shows a minimum of 10% reading to avoid error.
9. Record the viscosity displayed.
10. Turn the Digital Viscometer off.

5) Experiment with Xanthan Gum Solutions and Water

After ensuring that the pump can deliver a laminar flow using water, the Xanthan gum solution that was prepared in advance can now be poured into the tank to be flowed in the flow loop. Following the procedures that have been prepared earlier during Final Year Project 1, the tank and pump is first filled with the solution.

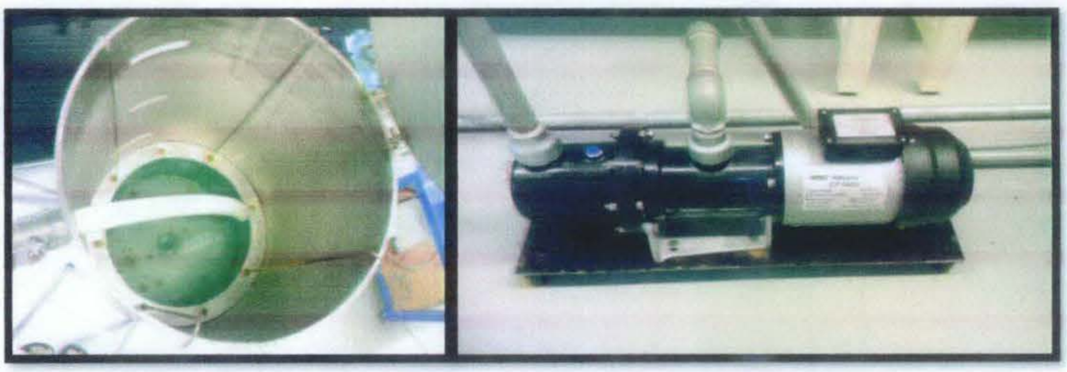

Figure 12: Tank and pump within the flow loop

During the experiment, make sure that there are no bubbles inside the test section as this can distort the pressure transducer readings.

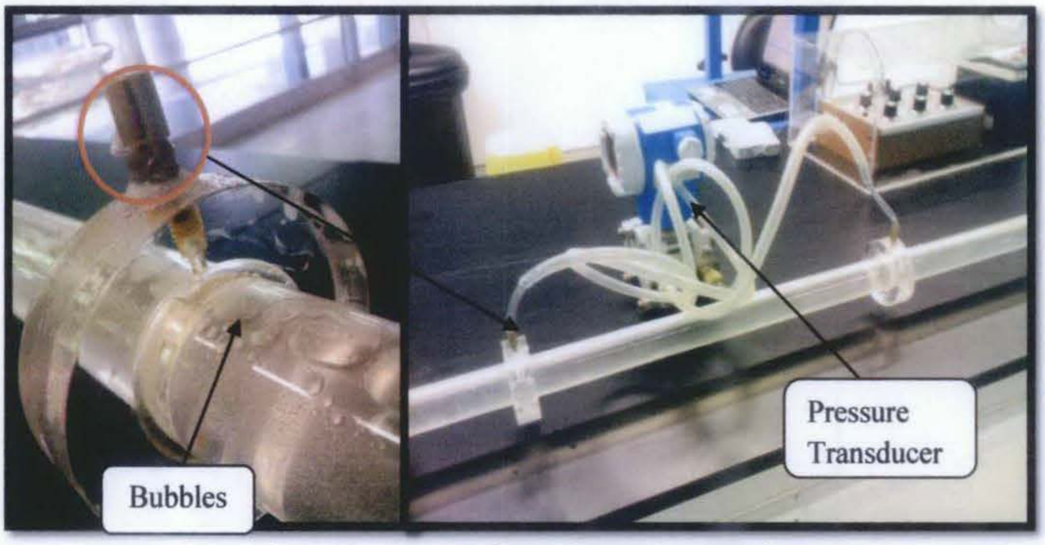

Figure 13: Test section and pressure transducer.

Also, make sure the pressure transducer tube is not pinched to avoid error in measurements. The pressure reading will show as voltage in the software "PicoScope 6" installed within the laptop. After duration of 5 minutes, stop the reading and save the data. The graph from the pressure measurements should be almost constant, if there are fluctuations in the graph, check the pressure transducer for bubbles, and rerun the measurement.

Figure 14: PicoScope software with PicoLog(Data Logger)

The data that is acquired are recorded, compiled and analyzed. When preparing to flow a new batch of Xanthan gum solution, the flow loop needs to be flushed using water to ensure no leftovers from the previous solution will contaminate the readings of the new solution.

Fill the tank and pump with water and run the pump at 25Hz – 50 liters per minute. Let the pump run for at least 10 minutes before flushing the water to ensure that the leftovers from previous solution has been completely dissolved with the water.

Drain the water through the drain valve until the flow loop is empty. And redo the entire process with a new batch or a different solution of Xanthan gum.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 RESULTS

The experiment was controlled to allow laminar regime only, and so below are the operating conditions that was set during the entire experiment.

Table 3: Experiment operating conditions

Parameter	**Value**	**Unit**
Flow rate	2.8	Liter/min
Density	997.13	kg/m3
Viscosity	0.000891	kg/ms
Area	0.00071	m2
Velocity	0.06573	m/s
Re	2207	-

Below are the tabulated results from the experiment. Each of these data has been averaged from a graph obtained during the experiment.

4.1.1 UTP Tap Water

Table 4: Averaged reading from pressure transducer, water

Pump On				Static	
Part	Top	Down	Avg	Part	Avg
1	639.20	607.20	623.20	1	623.17
2	638.70	606.50	622.60	2	621.06
3	632.80	608.90	620.85	3	619.83
4	628.30	608.00	618.15	4	618.62
5	629.30	606.20	617.75	5	617.73
6	628.20	607.10	617.65	6	617.63
7	628.30	606.90	617.60	7	617.58
8	627.90	607.00	617.45	8	617.43
9	628.00	606.00	617.00	9	616.97

4.1.2 Xanthan Gum Solution

Table 5: Averaged reading from pressure transducer, Xanthan gum **Solution: 0.02wt%**

Pump On				Static	
Part	Top	Down	Avg	Part	Top
1	640.20	608.50	624.35	1.00	624.33
2	638.70	606.70	622.70	2.00	622.69
3	634.90	605.70	620.30	3.00	620.27
4	632.40	603.80	618.10	4.00	618.07
5	629.70	605.80	617.75	5.00	617.73
6	629.90	605.30	617.60	6.00	617.55
7	629.70	605.00	617.35	7.00	617.35
8	629.80	604.70	617.25	8.00	617.26
9	629.50	603.20	616.35	9.00	616.37

Table 6: Averaged reading from pressure transducer, Xanthan gum **Solution: 0.03wt%**

Pump On				Static	
Part	**Top**	**Down**	**Avg**	**Part**	**Top**
1	643.8	602.7	623.25	1.00	623.24
2	638.7	602.6	620.65	2.00	620.66
3	629.3	601.2	615.25	3.00	615.22
4	632.1	597.7	614.9	4.00	614.88
5	627.7	601.6	614.65	5.00	614.64
6	627.5	601.3	614.4	6.00	614.20
7	627.5	601.2	614.35	7.00	614.32
8	627.2	600.6	613.9	8.00	613.86
9	629.3	598.1	613.7	9.00	613.67

Table 7: Averaged reading from pressure transducer, Xanthan gum **Solution: 0.04wt%**

Pump On				Static	
Part	**Top**	**Down**	**Avg**	**Part**	**Top**
1	638.9	604.9	621.9	1.00	621.89
2	635.4	603.4	619.4	2.00	619.37
3	628.7	602.5	615.6	3.00	615.63
4	628.5	601.4	614.95	4.00	614.90
5	628.4	600.8	614.6	5.00	614.56
6	628.2	600.8	614.5	6.00	614.48
7	628.3	600.6	614.45	7.00	614.43
8	627.3	600.7	614	8.00	613.97
9	626.9	600.6	613.75	9.00	613.73

Table 8: Averaged reading from pressure transducer, Xanthan gum **Solution: 0.05wt%**

Pump On				Static	
Part	**Top**	**Down**	**Avg**	**Part**	**Top**
1	637.30	601.20	619.25	1.00	619.23
2	634.60	599.40	617.00	2.00	616.97

Pump On				Static	
Part	Top	Down	Avg	Part	Top
3	628.70	599.40	614.05	3.00	614.53
4	628.60	597.70	613.15	4.00	613.16
5	628.80	597.50	613.15	5.00	613.14
6	628.40	597.00	612.70	6.00	612.68
7	629.10	596.00	612.55	7.00	612.51
8	627.80	597.10	612.45	8.00	612.43
9	628.90	596.00	612.45	9.00	612.41

4.2 DISCUSSION

The results obtained from the pressure transducer reading recorded through the data logger resulted in the output of the data being in voltage. And so the data needed to be converted into output pressure from output voltage to compute the total pressure difference. Data conversion uses basic Ohms Law, $V = IR$. With the decade resistance box providing 120 ohm resistance, we calculate the output current and interpolate the pressure value from the table below.

Table 9: Conversion table from current to pressure output.

Input (%)	Input (kPa)	Output (mA)
0	0	4
25	0.8625	8
50	1.725	12
75	2.5875	16
100	3.45	20

The table below was produced by the technician from the Electrical Department, UTP. It was based upon the operating limits of the pressure transducer and the maximum output current that it can produce. The results of the conversion are as tabulated below.

UTP Tap Water

Table 10: Data conversion, current to pressure (water)

Test Section	Data Logger	Pump On	Output (4mA-8mA)
Length (cm)	Volt (V)	Output (mA)	Pressure Difference (kPa)
20	0.623	4.986	0.213
30	0.621	4.969	0.211
40	0.620	4.959	0.208
50	0.619	4.949	0.204
60	0.618	4.942	0.203
70	0.618	4.941	0.203
80	0.618	4.941	0.203
90	0.617	4.940	0.203
100	0.617	4.936	0.202
Test Section	**Data Logger**	**Static**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.623	4.985	0.212
30	0.621	4.968	0.209
40	0.620	4.959	0.207
50	0.619	4.949	0.205
60	0.618	4.942	0.203
70	0.618	4.941	0.203
80	0.618	4.941	0.203
90	0.617	4.939	0.203
100	0.617	4.936	0.202

Table 11: Overall pressure difference (water)

Part	Total P
1	0.052
2	2.657
3	1.759
4	-0.811
5	0.035
6	0.035
7	0.034
8	0.035
9	0.052

<u>Xanthan Gum</u>: 0.02wt%

Table 12: Data conversion, current to pressure (Xanthan gum: 0.02wt %)

Test Section	**Data Logger**	**Pump On**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.624	4.995	0.215
30	0.623	4.982	0.212
40	0.620	4.962	0.208
50	0.618	4.945	0.204
60	0.618	4.942	0.203
70	0.618	4.941	0.203
80	0.617	4.939	0.202
90	0.617	4.938	0.202
100	0.616	4.931	0.201

Test Section	**Data Logger**	**Static**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.624	4.995	0.21447
30	0.623	4.982	0.21164
40	0.620	4.962	0.20747
50	0.618	4.945	0.20367
60	0.618	4.942	0.20308
70	0.618	4.940	0.20277
80	0.617	4.939	0.20243
90	0.617	4.938	0.20227
100	0.616	4.931	0.20074

Table 13: Overall pressure difference (Xanthan gum: 0.02wt %)

Part	**Total P (Pa)**
1	0.035
2	0.017
3	0.052
4	0.052
5	0.035
6	0.086
7	0.000
8	-0.017
9	-0.034

Xanthan Gum: 0.03wt%

Table 14: Data conversion, current to pressure (Xanthan gum: 0.03wt %)

Test Section	**Data Logger**	**Pump On**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.623	4.986	0.213
30	0.621	4.965	0.208
40	0.615	4.922	0.199
50	0.615	4.919	0.198
60	0.615	4.917	0.198
70	0.614	4.915	0.197
80	0.614	4.915	0.197
90	0.614	4.911	0.196
100	0.614	4.910	0.196
Test Section	**Data Logger**	**Static**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.623	4.986	0.21259
30	0.621	4.965	0.20814
40	0.615	4.922	0.19875
50	0.615	4.919	0.19817
60	0.615	4.917	0.19775
70	0.614	4.914	0.19700
80	0.614	4.915	0.19720
90	0.614	4.911	0.19641
100	0.614	4.909	0.19608

Table 15: Overall pressure difference (Xanthan gum: 0.03wt %)

Part	Total P (Pa)
1	0.017
2	-0.017
3	0.052
4	0.035
5	0.017
6	0.345
7	0.052
8	0.069
9	0.052

Xanthan Gum: 0.04wt%

Table 16: Data conversion, current to pressure (Xanthan gum: 0.04wt %)

Test Section	Data Logger	Pump On	Output (4mA-8mA)
Length (cm)	Volt (V)	Output (mA)	Pressure Difference (kPa)
20	0.622	4.975	0.210
30	0.619	4.955	0.206
40	0.616	4.925	0.199
50	0.615	4.920	0.198
60	0.615	4.917	0.198
70	0.615	4.916	0.198
80	0.614	4.916	0.197
90	0.614	4.912	0.197
100	0.614	4.910	0.196

Test Section	Data Logger	Static	Output (4mA-8mA)
Length (cm)	Volt (V)	Output (mA)	Pressure Difference (kPa)
20	0.622	4.975	0.21026
30	0.619	4.955	0.20591
40	0.616	4.925	0.19946
50	0.615	4.919	0.19820
60	0.615	4.916	0.19762
70	0.614	4.916	0.19748
80	0.614	4.915	0.19739
90	0.614	4.912	0.19660
100	0.614	4.910	0.19618

Table 17: Overall pressure difference (Xanthan gum: 0.04wt %)

Part	Total P (Pa)
1	0.017
2	0.052
3	-0.052
4	0.086
5	0.069
6	0.035
7	0.035
8	0.052
9	0.035

Xanthan Gum: 0.05wt%

Table 18: Data conversion, current to pressure (Xanthan gum: 0.05wt %)

Test Section	**Data Logger**	**Pump On**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.619	4.954	0.206
30	0.617	4.936	0.202
40	0.615	4.916	0.197
50	0.613	4.905	0.195
60	0.613	4.905	0.195
70	0.613	4.902	0.194
80	0.613	4.900	0.194
90	0.612	4.900	0.194
100	0.612	4.900	0.194
Test Section	**Data Logger**	**Static**	**Output (4mA-8mA)**
Length (cm)	**Volt (V)**	**Output (mA)**	**Pressure Difference (kPa)**
20	0.619	4.954	0.20567
30	0.617	4.936	0.20177
40	0.615	4.916	0.19756
50	0.613	4.905	0.19520
60	0.613	4.905	0.19517
70	0.613	4.901	0.19437
80	0.613	4.900	0.19408
90	0.612	4.899	0.19394
100	0.612	4.899	0.19391

Table 19: Overall pressure difference (Xanthan gum: 0.05wt %)

Part	Total P (Pa)
1	0.034
2	0.052
3	-0.828
4	-0.017
5	0.017
6	0.035
7	0.069
8	0.035
9	0.069

From the data that have been converted above, we can plot this graph which shows the pressure against the test section length.

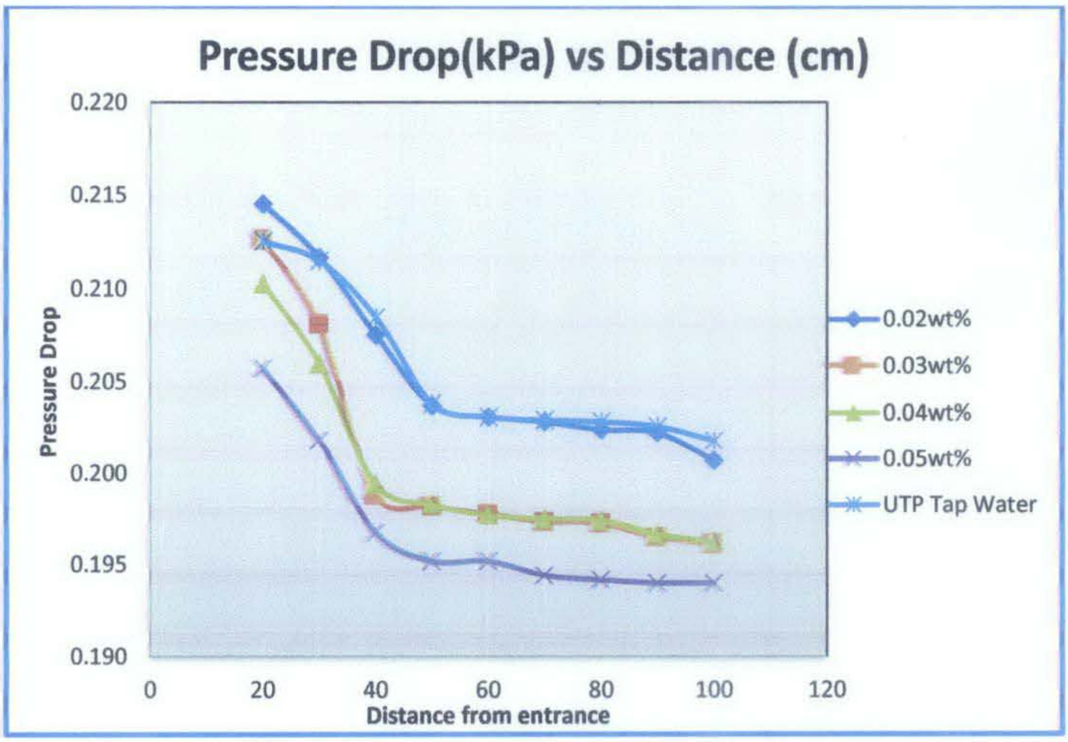

Figure 15: Pressure (kPa) vs. Length (cm)

The graph shows the pressure drop that occurred during the experiment. While we can see clearly the pattern of the pressure drop that is portrayed here, the data seems to be intersecting with each other and isn't showing a smooth pattern. But the early pressure drop shows that the fluid is developing and after the 50cm across the test section the steepness of the graph drastically reduce which suggests that the fluid has now fully developed.

Before starting the experiment, we calculated the Reynolds number to ensure laminar flow throughout the experiment. The results of the calculation are tabulated below along with the entrance length measure for each polymer solution.

Table 20: Experiment results with operating Reynolds number.

Weight Percentage (%)	H20 (kg)	XG (kg)	Density (kg/m3)	Viscosity (kg/ms)	Velocity	Reynolds Number	Entrance Length
0.00	49.86	0.000	997.13	0.000891	0.06573	2207	50
0.02	49.86	0.010	997.3	0.00378	0.06573	520	50
0.03	49.86	0.015	997.4	0.00408	0.06573	482	40
0.04	49.86	0.020	997.5	0.00432	0.06573	455	40
0.05	49.86	0.025	997.6	0.00606	0.06573	325	40

And so we can see that from the Figure 15, as the concentration of the Xanthan gum increases, the development length of the solution decreases due to the effect of increasing viscosity within the walls of the test section.

From the result that we have obtained, we can check the Reynolds number again at the test section by computing Poiseuille's Law using the pressure difference that have been measured. A sample of the calculation is provided below.

Poiseuille's Law

$$\dot{V} = \frac{\Delta P\, \pi D^4}{128 \mu L} \qquad \textbf{(Eqn 4.1)}$$

$$V_{avg} = \frac{\dot{V}}{A} \qquad \textbf{(Eqn 4.2)}$$

Rechecking from the pressure measured (UTP Tap Water)

$$\dot{V} = \frac{0.05Pa\ x\ \pi\ x\ 0.03^4}{128\left(0.000891\frac{kg}{ms}\right)(0.3m)} = 3.7187\ x\ 10^{-6}\ \frac{m^3}{s}$$

$$V_{avg} = \frac{3.7187\ x\ 10^{-6}\ \frac{m^3}{s}}{0.00071m^2} = 5.2376\ x\ 10^{-3}\frac{m}{s}$$

$$Re = \frac{997.13\frac{kg}{m^3}\ x\ 5.2376\ x\ 10^{-3}\frac{m}{s}\ x\ 0.03m}{0.000891\ \frac{kg}{ms}} = \mathbf{175.84 - \textit{Laminar Region}}$$

Table 21: Calculated Reynolds number from measured pressure difference.

Weight Percentage (%)	Viscosity (kg/ms)	Velocity (m/s)	Density (kg/m3)	Pressure (Pa)	Reynolds Number
0.00	0.000891	0.005444	997.13	0.052	182.787321
0.02	0.00378	0.002122	997.33	0.086	16.7996442
0.03	0.00408	0.007888	997.43	0.345	57.8532211
0.04	0.00432	0.001857	997.53	0.086	12.8648069
0.05	0.00606	0.001062	997.63	0.069	5.24589618

The pressure difference is the difference between the averaged static pressure/noise to the dynamic pressure. The calculated Reynolds number is very small due to the flow being very slow and so from here we can conclude that the flow within the test section is in the laminar region as per the calculations.

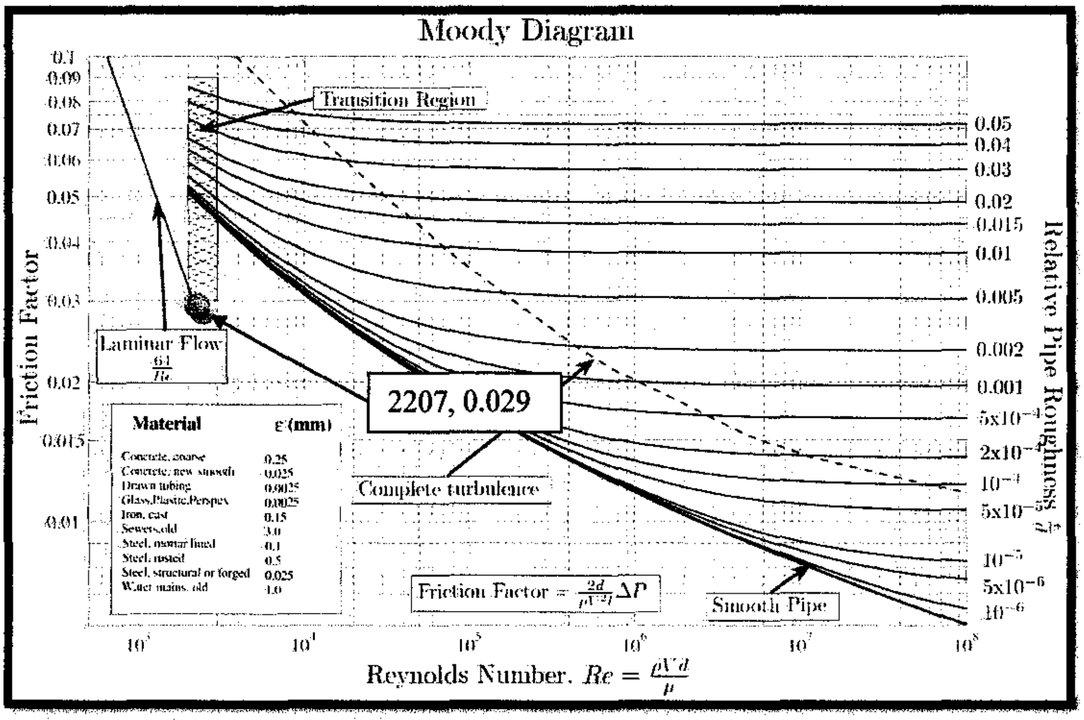

Figure 16: Moody Chart

Table 22: Calculated Darcy Friction Factor

Reynolds Number	Darcy Friction Factor (f)
2207	0.0290015
520	0.1230121
482	0.1327617
455	0.1405571
325	0.1971506

From the Reynolds number that we have, we can see that by plotting the calculated friction factor, most of the values are not within the moody chart as they are too small. While the moody chart is mostly to represent turbulent flow, the flow that we currently have are laminar.

Issues regarding the experiment:

As stated above, the graph that has been plotted shows intersecting pressure value. This may have occurred due to the uncontrollable factors that occurred during the experiment. One of the factors that may have lead to the slight error in reading is that during the experiment, the pump had vibrated the whole time. This will have caused an error in the pressure transducers readings due to the noise that the vibration produces as the pressure transducer is very sensitive.

The second issue is that, we have calculated earlier the required pump operating conditions for the flow to be laminar, and the speed is very slow. At times, the pump would just stop turning low speeds due to the rotation being very slow. There is a point at which when the pump is turning it is slightly delayed (can be observed from the bolt that is turning outside) which suggests that there is a slight resistance to rotation within the pump. And this is only noticeable at very low speeds. This has caused the pressure transducer reading to fluctuate forming a certain pattern of data.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

The development length for the polymer solution is observed to be lower than water. And as the weight percentage increases the pressure drop seems to be faster which implies that the development length decreases. This is due to the increasing viscosity with increasing concentration (Zhang, 1996) which increases the wall shear within the pipe causing the flow to be developed faster (Cengel, 2006).

The results would have been more accurate if it not had been for the limitations of the equipment. However, the objective of this project has been achieved by the successful measurement of the development length of the Xanthan gum solutions.

5.2 RECOMMENDATION

In order to acquire a more accurate result and execute a smoother experiment for future research using this flow loop the pump should be recalibrated by the manufacturer in order to overcome the current limitation of flowing at low speeds also to rectify the issues raised in chapter 4. For the pump vibration, a damper could be added to the flow loop to reduce the noise disturbances in the pressure readings. The piping orientation of the flow loop also has to be rectified in order to ensure that the flow loop is fully drained after each experiment. For the time being the flow meter is blocking the fluid within to be drained entirely. The idea suggested is to simply orient the flow loop to have proper gravitational draining.

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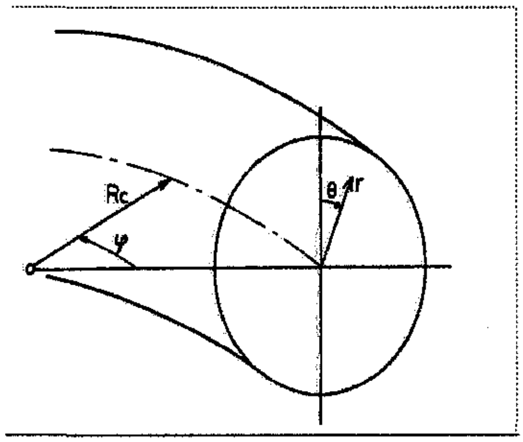
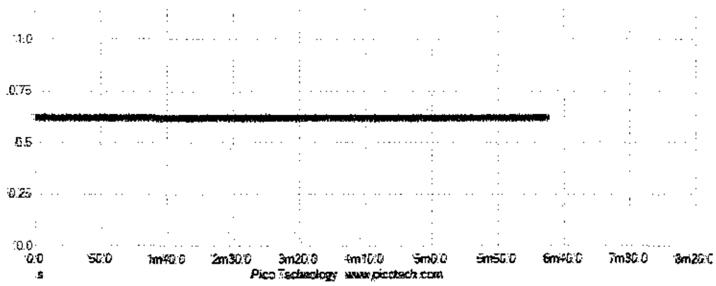
APPENDICES

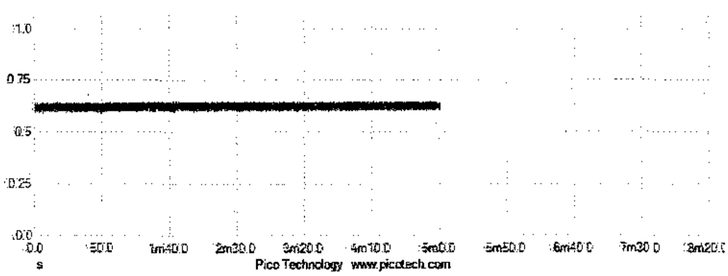
Torus Coordinate System: (r, θ, and φ)



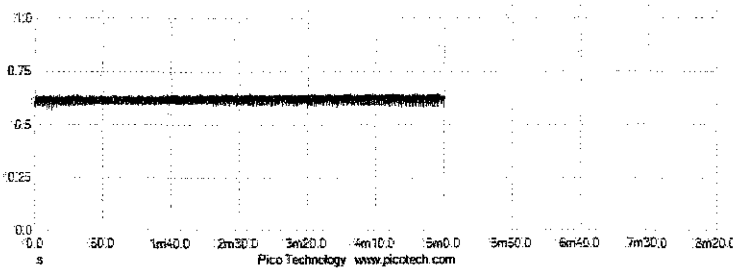
Raw Results: Water 1.5Hz



Pressure taps 1 and 2

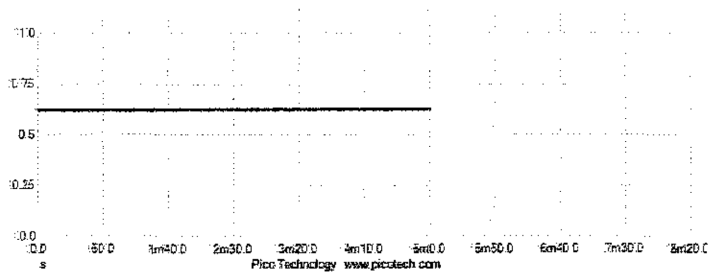


Pressure taps 2 and 3

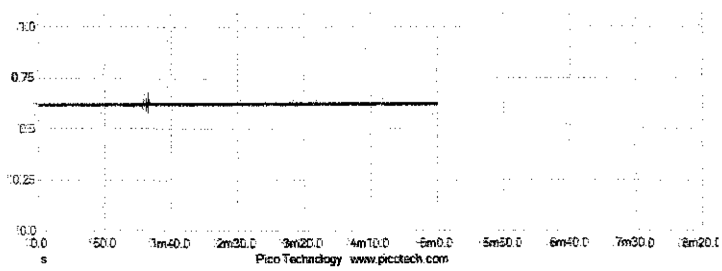


Pressure taps 3 and 4

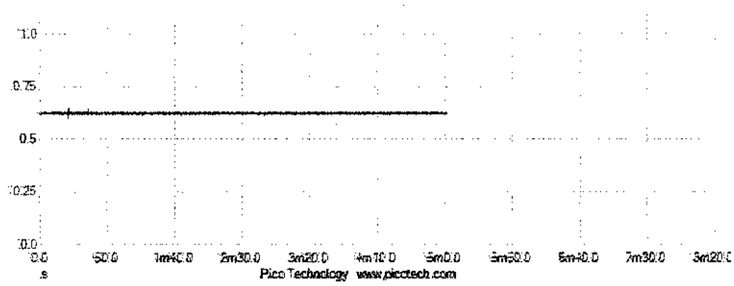
<u>Raw Result</u>: Water static



Pressure taps 1 and 2

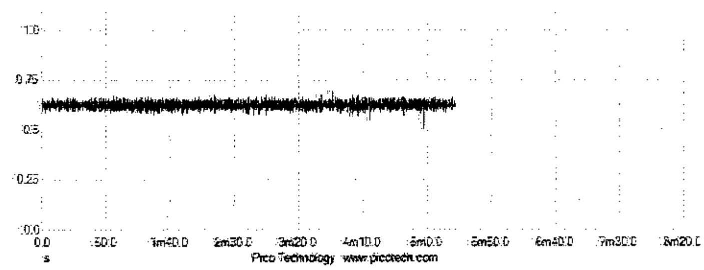


Pressure taps 2 and 3

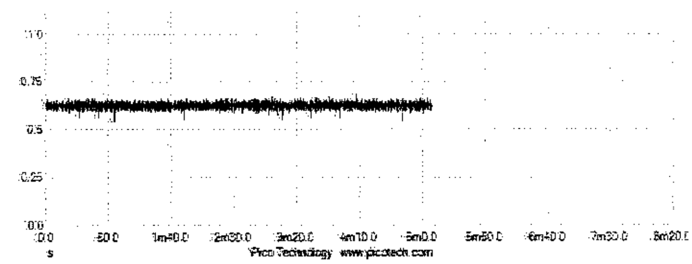


Pressure taps 3 and 4

<u>Raw Result</u>: Water static with loud noise disturbance



Pressure taps 1 and 2



Pressure taps 2 and 3