DESIGN, ANALYSIS, AND FABRICATE OF LOW SPEED WATER TUNNEL

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A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

Dedicated to my beloved father and mother, Mohd Khalid bin Ramli and Hatiah binti Wahi

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion this thesis is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis entitled "*Design, Analysis and Fabricate of Low Speed Water Tunnel"* is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my supervisor Mr. Fairussham for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a Bachelor program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I also would like to express very special thanks to my co-supervisor Mr. Fadzil Abdul Rahim for his suggestions and co-operation throughout the study. I also sincerely thanks for the time spent proofreading and correcting my many mistakes. I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This project goal was to construct a water tunnel that can used to do the experiment to analyze the hydrodynamic behavior of submerged bodies in flowing water. A new design was proposed to overcome the problem occurred from the project done at Wilkey University several years ago where it is can reproduce condition that can be decreased the reflection of water in tunnel. In order to design a water delivery system to the tunnel and produce an adequate flow, a 0.5hp pumps and 250 liters of reservoir were used to produce a 50L/min of velocity in the tunnel. Two experiments were conducted to test the functionality of the water tunnel and also the operation for the system. From the result obtained, there is no problem to deliver the water to the tunnel but it is still need some improvement to increase the water velocity in the tunnel

ABSTRAK

Tujuan projek ini dilaksanakan adalah untuk membina sebuah terowong air yang digunakan untuk menganalisis kelakuan pergerakan air pada sesebuah jasad yang tenggelam air yang mengalir. Satu reka bentuk baru telah dicadangkan bagi mengatasi masalah yang terdapat pada projek yang telah dilakukan di Wilkey Universiti beberapa tahun yang lalu di mana ianya menghasilkan persekitaran yang boleh mengurangkan pantulan air di dalam terowong. Untuk mereka bentuk satu sistem penghantaran air kepada terowong dan menghasilkan aliran yang mencukupi, satu 0.5hp pam dan 250 liter tangki air telah digunakan bagi menghasilkan 50L/min halaju air dalam terowong. Dua eksperimen telah dilakukan untuk menguji keupayaan dan sistem operasi terowong air ini. Daripada keputusan yang didapati,tiada masalah yang wujud dalam sistem penghataran air tetapi masih memerlukan sedikit pembaikan untuk meningkatkan halaju air di dalam terowong tersebut.

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ρ	Fluid density
R_H	Hydraulic radius of the channel
P_w	Wetted perimeter
m	Mass flow rate
μ	Dynamic viscosity
τ_w	Wall shearing stress

CHAPTER 1

INTRODUCTION

1.1 Project Background

A water tunnel is an experimental facility used for testing the hydrodynamic behavior of submerged bodies in flowing water. It is very similar to a with wind tunnel but the different is use water as the working fluid, and related phenomena is investigated, such as measuring the forces on scale models of submarines or lift and drag on hydrofoils. Water tunnels are sometimes used in place of wind tunnels to perform measurements because techniques like particle image velocimetry (PIV) are easier to implement in water. For many cases as long as the Reynolds number is equivalent, the results are valid, whether a submerged water vehicle model is tested in air or an aerial vehicle is tested in water. For low Reynolds number flows, tunnels can be made to run oil instead of water. The advantage is that the increased kinematic viscosity will allow the flow to be a faster speed (and thus easier to maintain stably) for a lower Reynolds number.

Whereas in wind tunnels the driving force is usually sophisticated multiblade propellers with adjustable blade pitch, in water and oil tunnels the fluid is circulated with pumps, effectively using a net pressure head difference to move the fluid rather than imparting momentum on it directly. Thus the return section of water and oil tunnels does not need any flow management; typically it is just a pipe sized for the pump and desired flow speeds. The upstream section of a water tunnels generally consists of a pipe (outlet from the pump) with several holes along its side and with the end open followed by a series of coarse and fine screens to even the flow before the contraction into the test section. Wind tunnels may also have screens before the contraction, but in water tunnels they may be as fine as the screen used in window openings and screen doors.

Additionally, many water tunnels are sealed and can reduce the internal static pressure, to perform cavitations studies.

1.2 Problem Statement

Usually water tunnel required a large space to perform the analysis. With about 2.0m long, 0.2 m width and 0.25m in height model of water tunnel; it is just required small space. In term of costing of the project, the high cost needed to construct the big one with high power of pump required to produce adequate flow in the tunnel. It is expensive to buy all the components in order to build the model of water tunnel. Thus, a small of water tunnel model with low speed of flow will construct to minimize the cost. Then, a proper piping design and water pump need to be determining in order to produce an adequate flow in the tunnel. The last problem is to check the functionality and also the system base on the requirement. Two experiments were conducted to test the operation of this water tunnel.

1.3 Objective

1. To design and fabricate a low speed water tunnel
2. To test the functionality of the water tunnel system by doing the experiment and visualization method.

1.4 Scopes

1. The scope of the project covered the study and analysis to construct a low speed water tunnel.
2. Water tunnel fabrication is open channel type.
3. A water system is a tunnel where a scaled down model of the water craft is held stationary, while water is moved past.
4. Used 0.5hp pumps and $0.16m^3$ of reservoir was used to produce low speed of water movement in channel. It's about 0.6 – 1.0 L/s

1.5 Significant of Study

Usually, to investigate the force (drag and lift forces) or aerodynamic behavior when the vehicles are move along a straight road, wind tunnel is quite frequently used for it. But how about investigations for water vehicle such as kayak, submarine and ship, submerged and flowed in the water are considered to. So, to get valid result for examination the force of that submerged body and hydrofoil behavior is by using the water tunnel as the alternative way besides doing the simulation.

Water tunnel also can perform for the low Reynolds number with faster speed of fluid. Theoretical analysis shows how it will be achieve this condition. By increase the kinematic viscosity of fluid, the Reynolds number still will be lower even the speed of fluid is increase. This is advantage use the water tunnel compared to wind tunnel. For the sentence cases, likes in designing the high speed of submarine, the high speed of fluid is needed in order to prepare the situation or condition same as the real one. So, water tunnel can be used for it.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the application of water tunnel, part of water tunnel and also the theory and analysis of the data and the system of water tunnel are discussed. Several solutions that were considered to adapt the existing facility to the needs for external flow visualization are described.

2.2 Type of Water Tunnel

Basically a water tunnel is used for testing the hydrodynamic behavior of submerged bodies in flowing water. It is similar with wind tunnel but the different is water is used as working fluid. Not all cases that need the wind to investigate the phenomena. Sometime, the result from water tunnel more reasonable compared wind tunnel according the condition required such as in measuring the forces on scale models of submarines. So, water tunnel is also important same as wind tunnel in measuring the hydrodynamic behavior. There are two types of water tunnel.

1. High speed water tunnel
2. Low speed water tunnel

2.2.1 High Speed Water Tunnel

This tunnel usually has a big amount of water capacity with high velocity in it. It is required high power of pump to produce the variable speed water at the inlet. Example of high speed water tunnel at Pennsylvania State College, called Garfield Thomas Water Tunnel the world's largest water tunnel built in 1947. The requirement to produce water movement as fast as possible in the inlet, the electric motor used to drive the main pump was specified at 2,000-hp with variable speed range between 0 and 180 rpm. (Robertson and Ross, 1946)

Total capacity of the this tunnel, which is nearly 100 feet long and about 32 feet high, is 100,000 gallons. When operating at top speed, more than a million gallons of water will pass through the test section every three minutes. (Billet, 1946)

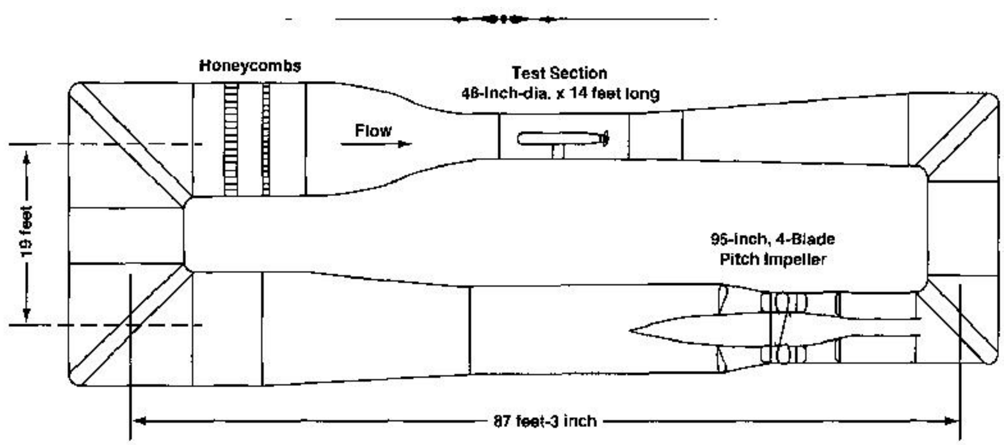


Figure 2.1 The Garfield Thomas Water Tunnel specifications.

Source: Robertson and Ross (1946)

2.2.2 Low Speed Water Tunnel

Compared with high speed water tunnel, of course the requirement for this tunnel is less to produce low speed water in it. Low speed water tunnel needs lower power of pump in order to provide the low speed of water. The speed of water is not so important for low speed water tunnel. Mostly this type of tunnel is use for cavitations' tests with models of ship propellers and for tests with various profiles in cavitating and non-cavitating conditions. (Anderson, 2006). Example for low speed water tunnel is cavitations tunnel designed for use in laboratories of Technical Universities. The maximum velocity of water for this tunnel just only 3.6 m/s with operating pressure range in measuring section 200 to 2000 Pa absolute.

Figure 2.2: Cavitations tunnel.

Source: Anderson (2006)

Figure 2.3: Cavitating propeller model.

Source: Anderson (2006)

2.3 Design Tunnel

In order to construct a small water tunnel model, the parameters must be considered are:

1. The characteristic flow in the tunnel,
2. Flow in open tunnel,
3. Flow drive by pump.

2.3.1 Characteristic of water flow

The basics concept of fluid flow is different between flow in pipe and in open channel. If the water assumed completely flow fill the conduit, the pressure at point 1 and 2 is different. Meanwhile, for the open channel flow, gravity alone is driving force in case for water flows down a hill. But the main driving force is pressure gradient along the channel. If the water is not filling the channel, pressure at point 1 and 2 is same as figure below. (Thorley, 2004)

i.General fluid flow

Can be classified into two:

1. Steady flow
2. Unsteady flow

Steady flow means the velocity at a given point in space does not vary with time. (Munson et. al, 2006) It will be constant velocity for all the time. But in reality phenomena, almost all the flows are unsteady on some sense. It is difficult to obtain the steady flow. The analysis for unsteady flow is more difficult compared the steady flow.

For the steady flow, the values of all fluid properties likes' velocity, temperature, and density are not change for all the point in the test section area. It is independent with the time. But, the values for fluid's particles may change with the time. (Munson et. al, 2006)

ii.Characteristics of Flow

The flow of a fluid in a pipe may be laminar flow or it also can be turbulent flow. Osborne Reynolds, a British scientist and mathematician, was first to distinguish the different of these classification flow by using dye injection method. (Munson et. al, 2006) The water flow in a pipe of diameter D with an average velocity V, the classification of flow can be viewed by injecting dye. These three characteristics of flow in a pipe donated as laminar, transitional and turbulent flow illustrated in figure 2.4.

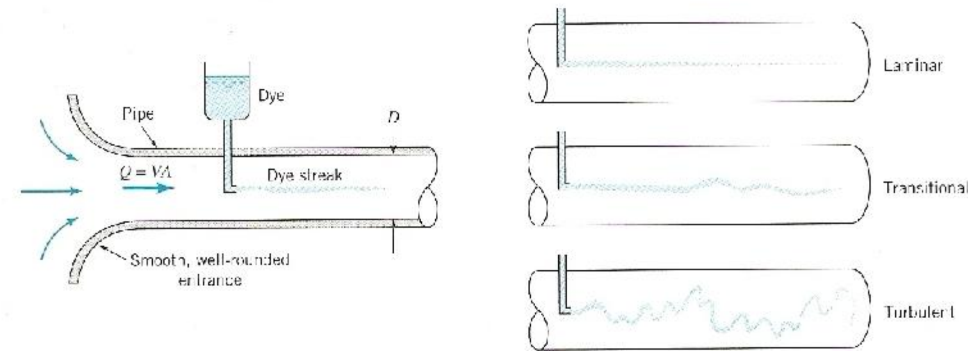


Figure 2.4: Experiment to illustrate type of flow. Typical dye streaks.

Source: Munson et. al (2006)

2.3.2 Flow in Open Tunnel

Open tunnel flow is defined as flow in any channel where the liquid flows with a free surface as figure 2.5. Open channel flow is not under pressure; gravity is the only force that can cause flow in open channels and a progressive decline in water surface elevation always occurs as the flow moves downstream. (Warzinski and Lynn, 2001)

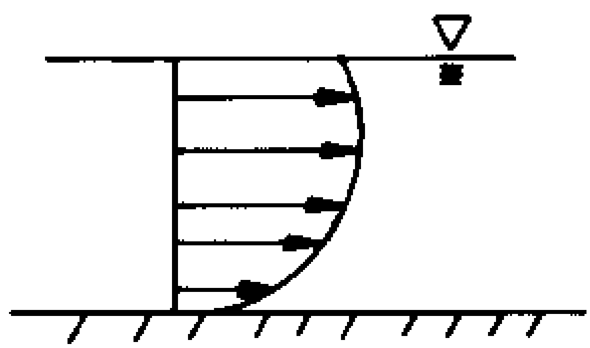


Figure 2.5: Typical open channel velocity profile

Source: Warzinski and Lynn (2001)

In open channel, unsymmetrical velocity profile formed when the water move passed along the channel. The actual distribution of flow velocity is generally quite complex. Open channel flow is often laminar or near-laminar, with the different layers moving at different velocities. From the figure above, the highest velocity flow is located in the center of the flow channel and slightly below the water surface. To calculate the velocity in channel, Manning equation have to be applied.

$$Q = [(1.49 / n) A R^{2/3} S^{1/2}] \ldots \tag{2.1}$$

Where

Q = discharge (m^3/s)
n = Manning's roughness coefficient (see Appendix A for n values)
A = cross-sectional area of flow (m^2)
R = hydraulic radius = A/P (m)
P = wetted perimeter (m)
S = channel slope (m/m)
V = channel velocities

2.3.3 Driving flow by Pump

In wind tunnel, basically the axial fan used to drive the flow. The energy generated by that fan is enough in order to provide the speed of the wind. Otherwise, in water tunnel, it is more likely to use a pump rather than an axial fan. (Demaneuf, 2005). Thus the return section of water tunnels does not need any flow management. Typically it is just a pipe sized for the pump and desired flow speeds.

2.4 Water Tunnel Design Fundamental

Water tunnels are not very common and it is difficult to get related information. However, wind tunnels are widely used and very similar to the water tunnels in principle. In this subtopic shows the relation of fundamental in designing wind tunnels that can be adapted to the water design.

The basic components of a conventional wind tunnel are shown in figure 2.6. The description and role of these components are presented in following sections. (Demaneuf, 2005)

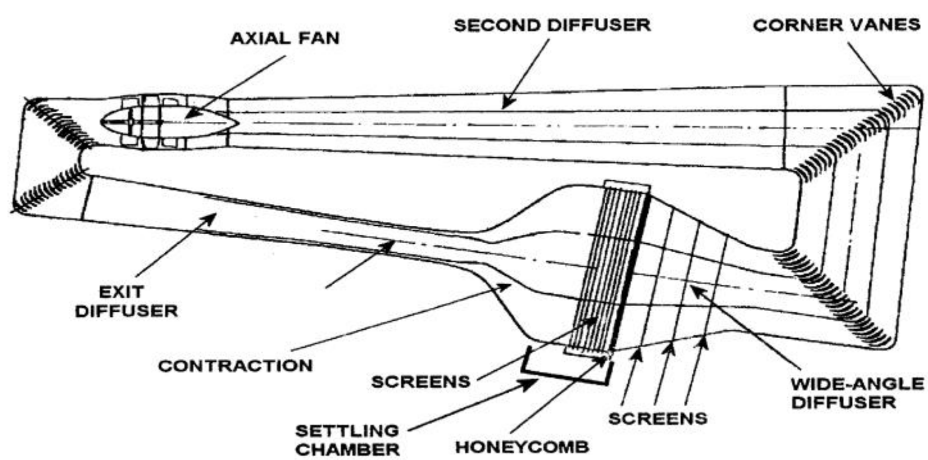
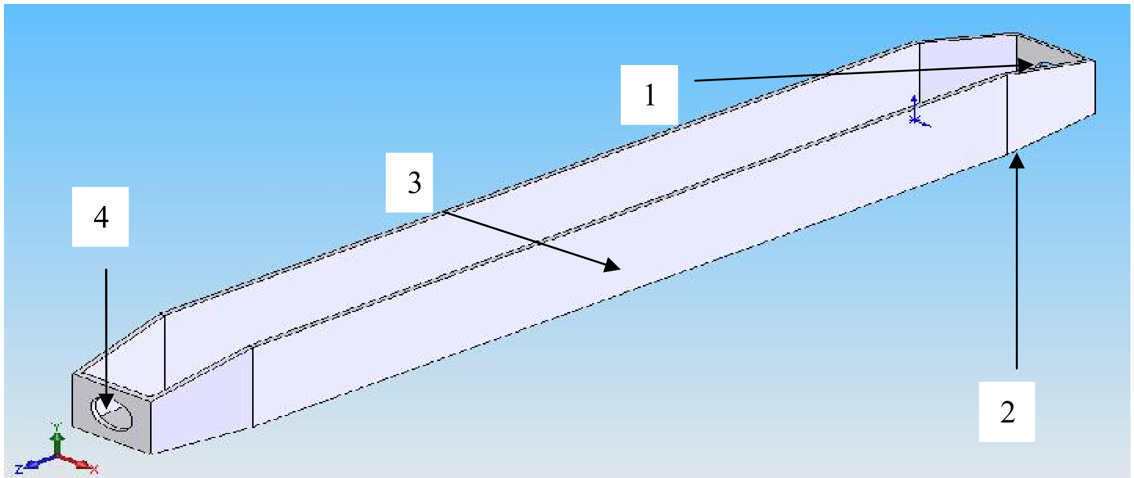


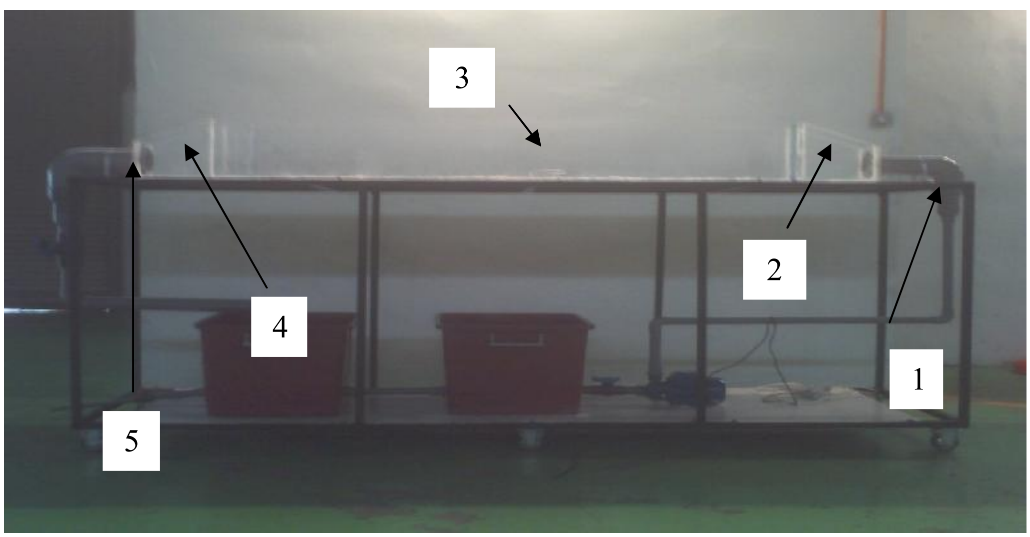
Figure 2.6: Conventional closed-circuit low speed wind tunnel

Source: Demaneuf (2005)



1. Inlet
2. Wide angle difusser
3. Settling chamber
4. Outlet

Figure 2.7: Tunnel design



1. Diffuser
2. Wide angle diffser
3. Settling chamber
4. Nozzle
5. Contraction

Figure 2.8: Water tunnel design

i. Wide-angle diffuser

The diffuser is usually short and therefore has large expansion angle. The rapid cross-sectional area increase tends to produce flow separation, so a boundary layer control is needed.

ii. Honeycomb

The cells restrain the lateral components of turbulent and reduce swirl. The honeycomb is placed after wide angle diffuser.

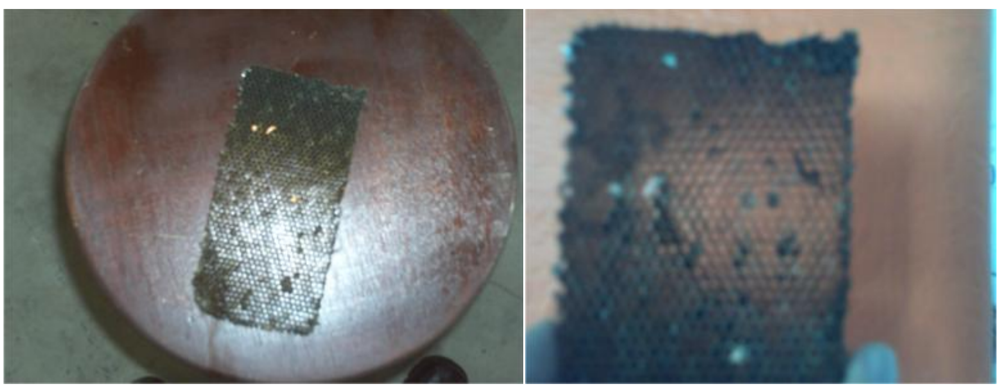


Figure 2.9: Honeycomb

iii. Contraction

Used to reduces the pressure losses, and also reduces the turbulence

iv. Settling section

Situated before the test section, the settling chamber includes a honeycomb. At this part the boundary layer exist because of viscous effect that can cause water stick at the wall. Velocity profiles vary along this section.

2.4.1 Application to water tunnel

As mention before, in water tunnel more likely use pump to drive the flow of fluid, in this case, the water is carried by circular pipes of a constant cross-sectional area.

The previous discussion indicates that to obtain good flow characteristic when the water enters through the entrance, the important features are the flow conditioners:

1. The settling chamber with a honey comb.

2. The contraction section.

However, using water instead of a gas might cause other problems. When water passes through the honeycomb and screens, the pressure drop might be such that the bubbles of gas behind these components. It is called cavitations phenomenon and of course will affect the flow in water tunnel. Therefore, special attention must be taken to overcome this problem. (Thorley, 2004)

2.5 Reynolds number in open channel

As for any flow geometry, open channel flow maybe laminar, transitional, or turbulent, depending on various conditions involved. (Munson et. al, 2006) Which type of flow occurs depends on the Reynolds number,

$$Re = \frac{\rho V R_H}{\mu} \quad (2.2)$$

Where ρ = fluid density

V = average velocity of the fluid

R_H = the hydraulic radius of the channel

The flow is

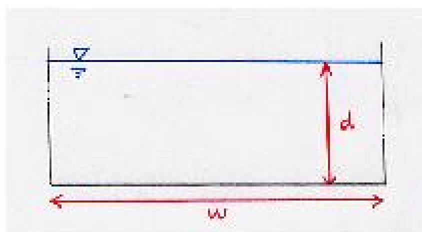
1. **laminar** if Re < 500
2. **transient** if 500 < Re < 12,500
3. **turbulent** if 12,500 < Re

Value for R_H defined as the ration of wetted area over wetted perimeter.

$$R_H = \frac{A}{P_W}$$

Where A = wetted area

P_w = wetted perimeter



$$R_H = \frac{dW}{W + 2d} \qquad 2.3$$

$$D_H = \frac{4dW}{W + 2d} \qquad 2.4$$

CHAPTER 3

METHODOLOGIES

3.1 Research Methodology and Work Plan

Literature study was done in the early stage of study to have a better understanding on the project. The management of all procedures for the whole project will be viewed in this chapter. It is cover from the starting title investigation until the fabrication part at the last of this project. Shows how data collected, the analysis of parameter, the design consideration and the data analysis from the experimental.

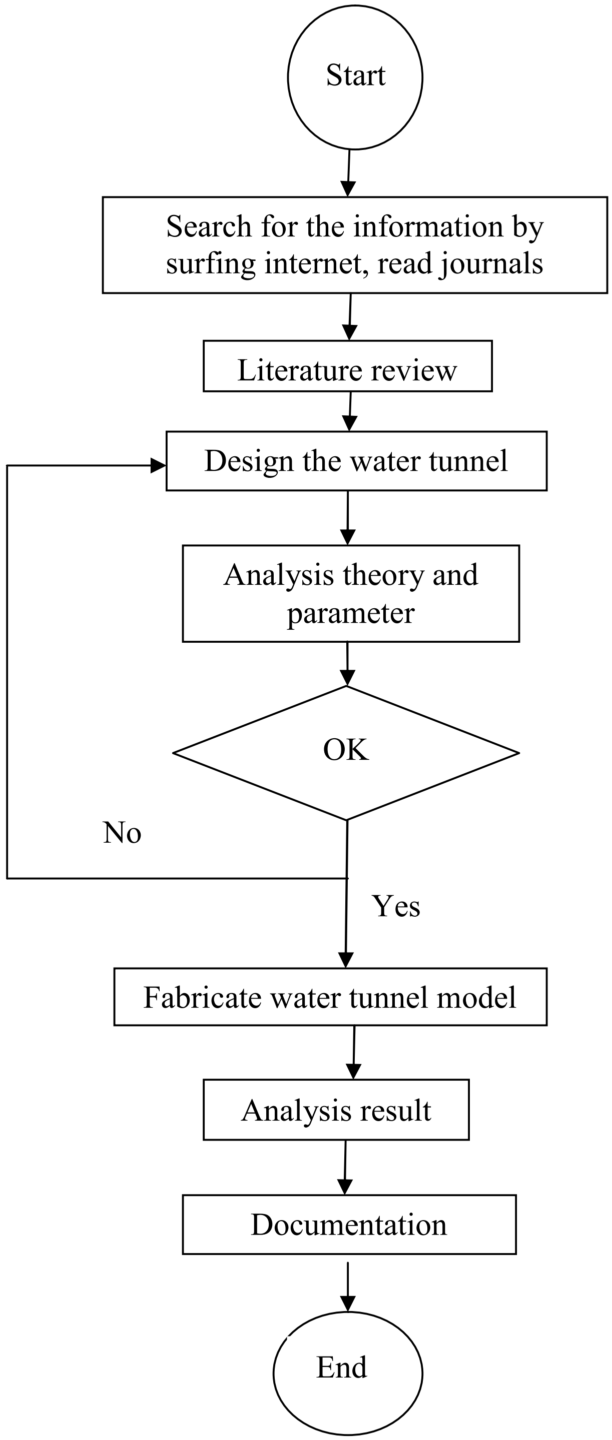


Figure 3.1: Flow chart for project

3.2 Design consideration

Before water tunnel analyzed, some parameter must be considered to obtain the result that achieves the objectives of this project. These are the list of parameters that be considered in water tunnel.

1. The flow rate of the water in tunnel.
2. The power of pump requirement to produce the adequate flow in the tunnel.
3. Controlling the water flow in tunnel.
4. Tunnel shape.
5. The model that can be used to do the analysis.

In order to achieve the objective, the new design will propose. All the parameters and dimension of the tunnel design are to be considered.

The shape of the tunnel as figure 3.2 designed to minimize the reflection of the water at the outlet. The design is rectangular so that a faster, more laminar flow is achievable. This design cause very little reflection.

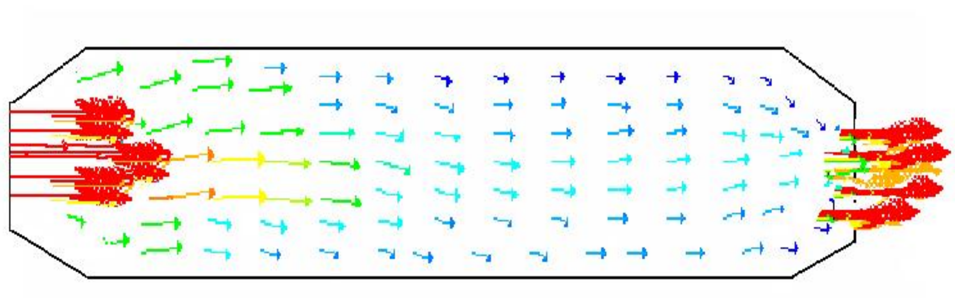


Figure 3.2: Model for design 1

Source: Bucci (2002)

Figure 3.3, a tunnel had problems with reflections and eddy currents. As water flowed to the outlet it would bounce off the back wall around the outlet. This created eddy currents and turbulence.

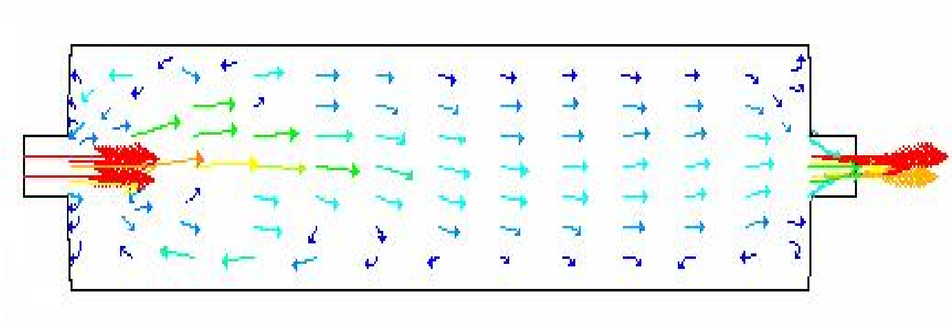
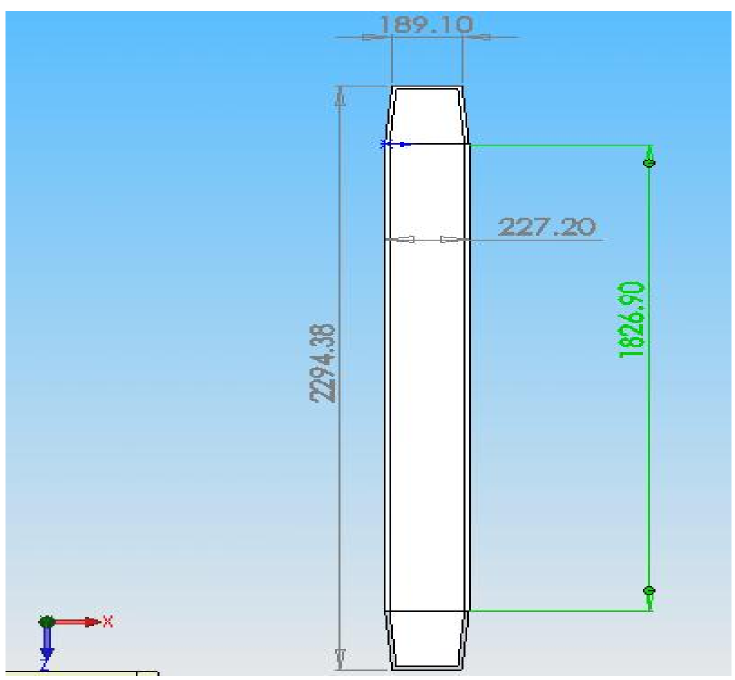


Figure 3.3: Model for design 2

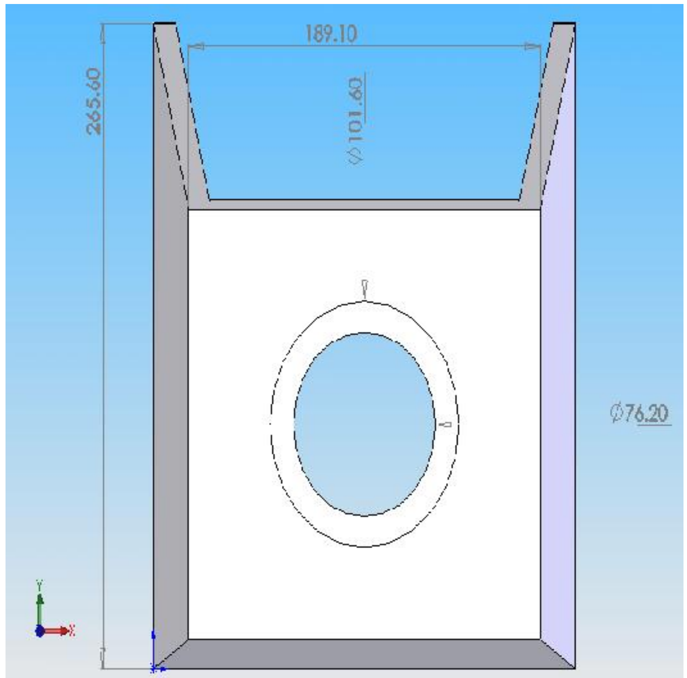
Source: Bucci (2002)

3.3 Concept Design

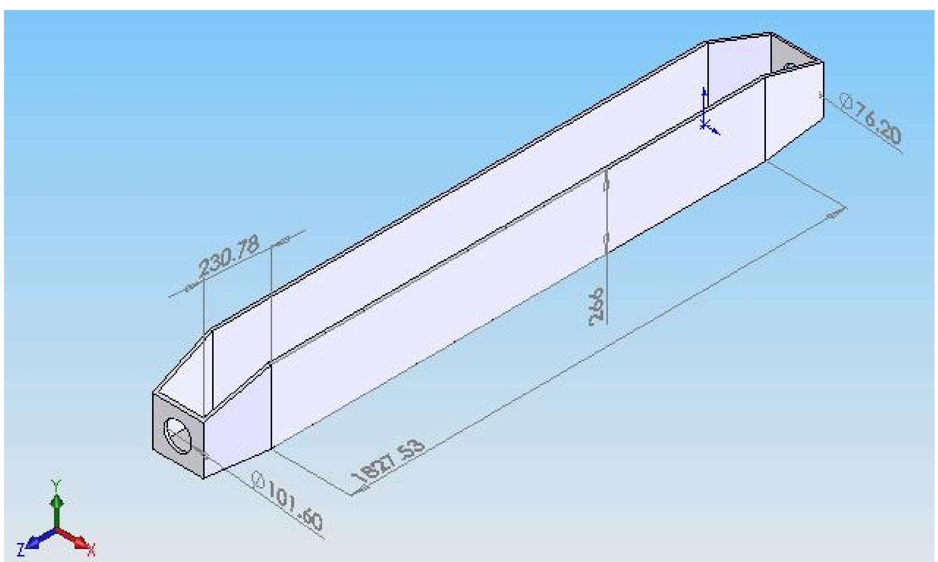


Top view

Figure 3.4: The dimensions of the design 1



Front view



Isometric view

Figue 3.4: Continue

3.4 Theory Consideration

3.4.1 Flow rate of water in tunnel

One major fluid mechanics concept was used in the design of the water tunnel. The calculation of flow rate was used to find the velocity in our tunnel. This is shown in Equation 3.1.

$$Q = A \cdot v \tag{3.1}$$

Where, Q = Flow rate (W), and
v = velocity (m/s).

3.4.2 Energy flow

Flowing water contains energy in two forms, potential and kinetic. The potential energy at a particular point is represented by the depth of the water plus the elevation of the channel bottom above a convenient datum plane. (Warzinski and Lynn, 2001) The kinetic energy, in feet, is represented by the velocity head: Kinetic energy

$$\frac{V^2}{2g} \tag{3.2}$$

In channel flow problems it is often desirable to consider the energy content with the channel bottom. This is called the specific energy or specific head and is equal to the depth of water plus the velocity head: Specific energy

$$d + \frac{V^2}{2g} \tag{3.3}$$

At other times it is desirable to use the total energy content (total head), which is the specific head plus the elevation of the channel bottom above a selected datum. For example, total head may be used in applying the energy equation, which states that the total head (energy) at one point in a channel carrying a flow of water is equal to the total head (energy) at any point downstream plus the energy (head) losses occurring between the two points. The energy (Bernoulli) equation is usually written:

$$d_1 + \frac{V_1^2}{2g} + Z_1 = d_2 + \frac{V_2^2}{2g} + Z_2 \tag{3.4}$$

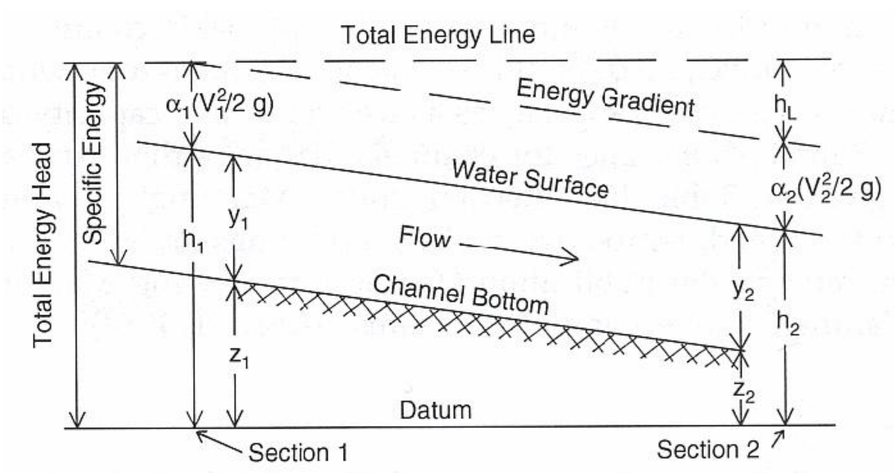


Figure 3.5: Channel flow term

Source: Warzinski and Lynn (2001)

3.5 Water Tunnel Delivery System

The water delivery system consists of a 250 liters drum, a 0.5hp pump, plastic tubing, and numerous PVC fittings. The entire water delivery system and the tunnel itself are mounted on a movable cart for easy transportation. Figure 3.8 shows the basic layout of the system.

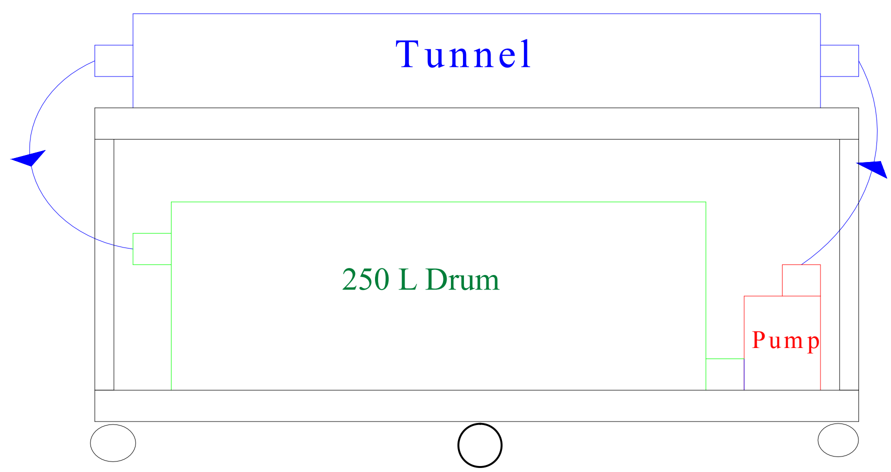


Figure 3.6: Water Delivery System

The pump that was selected is a Precision Water Pump type QB-60. It is designed for use in hot tubs but the flow rate and easy installation fit the needs of this project. The power of pump is a 0.5 horsepower pump that pumps 50 liters per minute and 1 meter of head.

Numerous fittings and hoses were needed to connect the system. Table 3.1 shows what hoses and fittings were used and where they were placed.

Table 3.1: Fittings and Hoses

Location	Hose	Fittings
Barrel to Pump	D=1in, L=0.5m	Ball Valve
Pump to Inlet	D=1in, L=1m	Sudden Expansion from 1in to 3in 90^o bend
Outlet to Barrel	D=2in, L=1m	Sudden Contraction from 4in to 2in Ball Valve 90^o bend

3.6 Experimental Procedures

3.6.1 Filling the system

In order to run the water tunnel for experimental use the closed system must be filled with water from an outside source. Below are the steps for filling the system.

1. Open the ball valve located at the outlet of the tunnel. The other globe valves should be in the closed position.
2. The tank can be filled using a hose attached to a facet. The hose must be placed in the tunnel and the water turned on. The tunnel will drain into the barrel filling the barrel. Allow a few minutes for the barrel to fill. Make sure that the barrel does not fill past the air hole near the barrel inlet. When barrel is full turn off the water and remove the hose from the tunnel.

3. Another method, close the ball valve at the outlet. Then fill up the barrel with the water. Make sure the water sufficient during the experiment operation.

3.6.2 Measuring flow rate of the water

1. Calculate the volume of any container that can be used to stagnant the water. Then place it at the outlet of the tunnel.
2. Fill the water in it. At the same time, take the time for the water to fill up that container.

3.6.3 Testing a model

1. Placed the model in the tunnel.
2. Open remaining ball valves located at the between the barrel and the pump.
3. Plug the pump in and turn the switch located below the tunnel on the opposite side of the pump's valve to the on position.
4. Allow the water to fill the tunnel.
5. Open the ball valve located at the outlet slowly. Make sure the water flow through the outlet equivalent with water enters the tunnel.
6. Inject the dye on the model to view the flow of the water after the model.
7. Record the data.

3.6.4 Cleaning Up

1. After all measures are taken and recorded turn water pump off.
2. Open the ball valves at the inlet and pump and allow water in the tunnel to drain into the barrel.
3. If it is necessary to empty the tunnel siphon the water into a usable drain until empty.

3.7 Bill of Material and Costing

Table 3.2: Total cost of base

No.	Item	Quantity	Price (RM)	Total (RM)
1	*Rectangular bar 1” x 1”	2		
2	*Rectangular bar 2” x 1”	1		
3	*Sheet metal mild steel 2” thickness	1		
4	*Sheet metal mild steel 1” thickness	1		
5	Self thread screw	20	0.50	10.00
6	Rubber roller	6	6.00	36.00
				46.00

Note: * shows that the materials get from laboratory.

Table 3.3: Total cost of tunnel

No.	Item	Quantity	Price (RM)	Total (RM)
1	*Acrylic 12mm thickness	2		
2	Silicon glue	1	6.00	6.00
3	‘Gajah’ glue	5	1.90	9.50
4	Rubber gasket 3” Ø	1	1.80	1.80
5	Rubber gasket 4” Ø	1	4.00	4.00
				21.30

Table 3.4: Total cost of piping system

No.	Item	Quantity	Price (RM)	Total (RM)
1	PVC pipe 4”	1 feet	3.00 per feet	3.00
2	PVC pipe 3”	1 feet	2.00 per feet	2.00
3	PVC pipe 2”	3 feet	1.00 per feet	3.00
4	PVC pipe 1”	5 feet	0.50 per feet	2.50
5	Water tank/barrel	2	30.00	60.00
6	Connector tank	4	1.50	6.00
7	Pump	1	180.00	180.00
8	Ball valve 2”	1	35.00	35.00
9	Ball valve $1^{1/2}$”	1	5.00	5.00
10	Ball valve 1”	1	3.00	3.00
11	Reducer 4” to 3”	1	4.00	4.00
12	Reducer 3” to 2”	2	3.00	6.00
13	Reducer 2” to 1”	1	2.00	2.00
14	PVC glue	1	5.00	5.00
				316.50

Note: * shows that the materials get from laboratory.

3.8 Fabricating Process

In fabricating process, three stages were divided in order to build the water tunnel. There are base making, tunnel construction and piping system connection. For the rashness in constructing the project, for each stage must be completed before move to the next stage.

3.8.1 Base Making

Processes involve during first phase operating are:

1. Grinding
2. Welding
3. Drilling

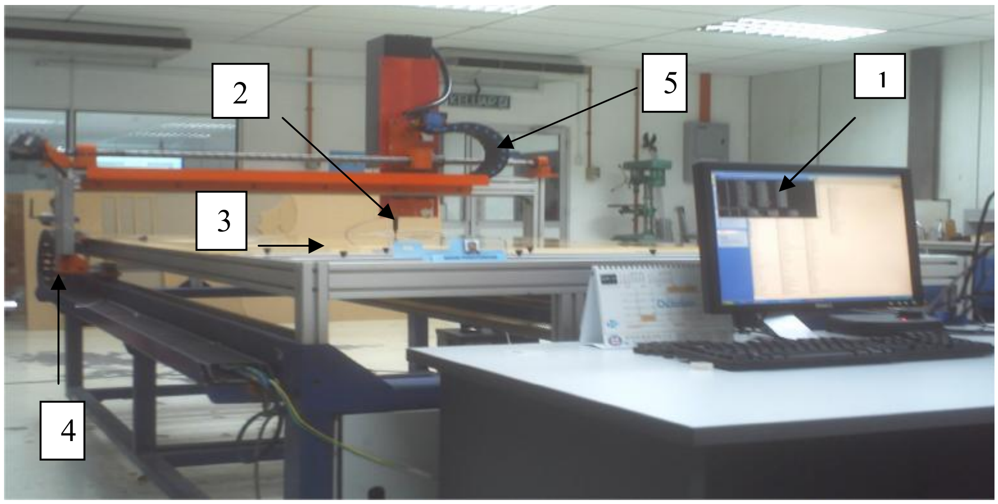
For the top and bottom plane at the base, sheet metal was used to put the tunnel and barrel at the system. However, the weights of these parts need to be considered to avoid sheet metal from bending. Because of the limitation of cost and material, only one piece of 2mm sheet mild steel can be provide. It was placed at the bottom of base because weight of water is more heavy compare to the tunnel's weight. Addition, by the end of the experiment, water will remove from the tunnel and will store in the barrels.

3.8.2 Tunnel Construction

Basically, the important part during this phase is to cut the 12 mm thickness of acrylic. At laboratory, there is one machine that can be used for this purpose named as laser cutting machine.

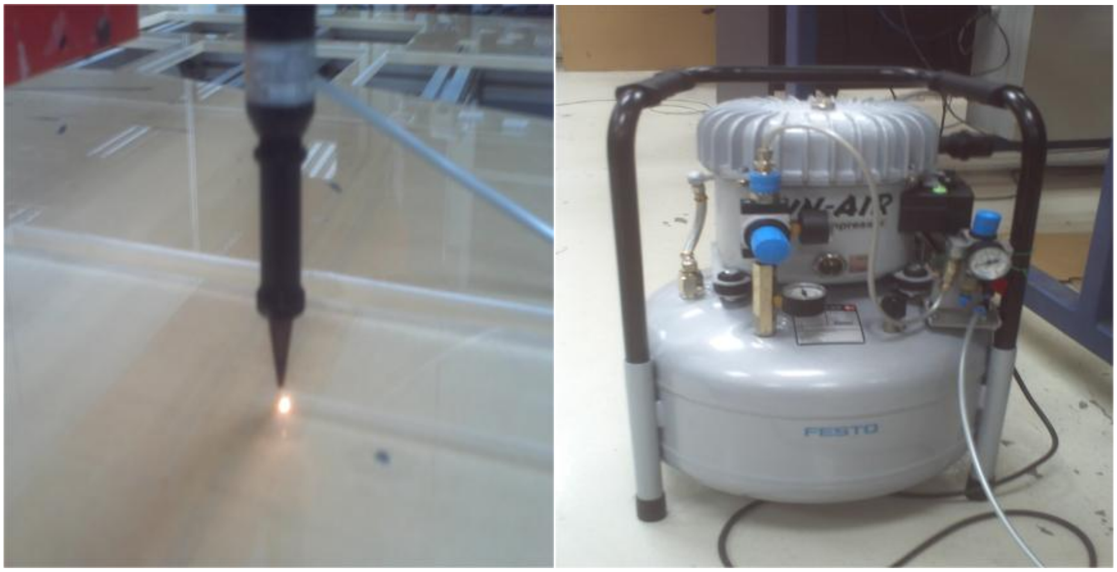
But the problem occurs when the laser machine in figure 3.7 can't cut off this material because of its thickness. Usually this machine used for 9mm of acrylic but it is take long time to finish cut for one part. It is require more power support to make the laser perforate that acrylic.

So, as solution, the air-compressor was used. The compressor's pressure was increased to two bars and delay for laser machine system was set up at 3000. The advantages by using this compressor are first; the laser machine can cut that 12mm acrylic and second; save time because it will increase speed of laser movement.



1. Code generator
2. Cutting laser
3. Workpiece
4. X-axis bar
5. Y-axis bar

Figure 3.7: Laser machine



(a) (b)

Figure 3.8: a) Laser tool; b) Air-compressor

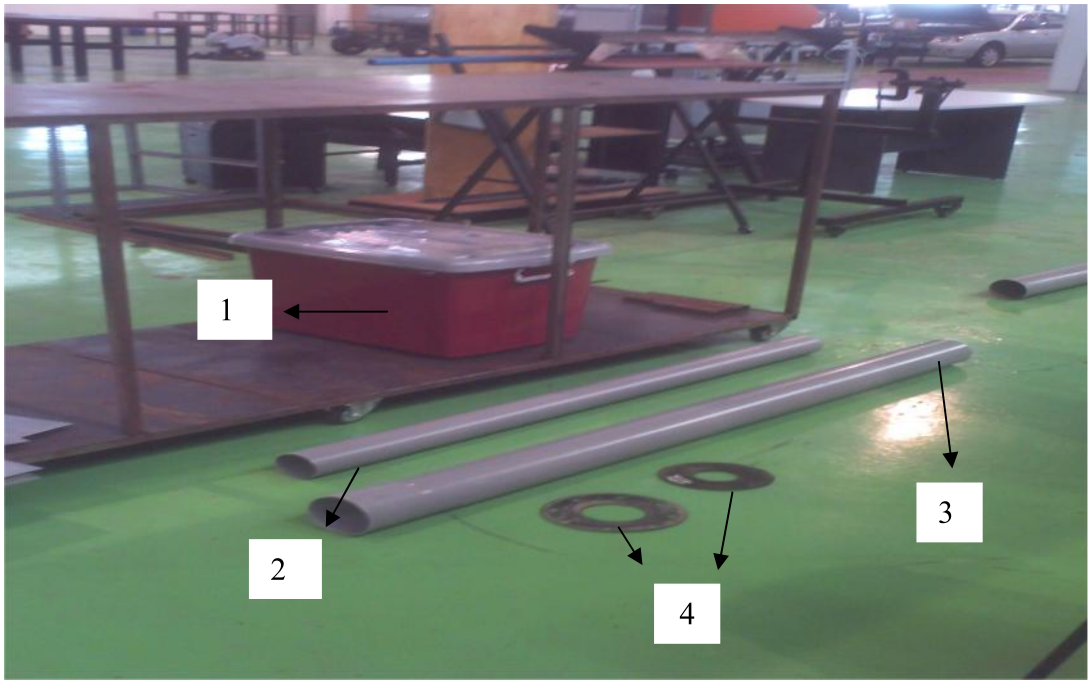
3.8.3 Piping system

It is involved pump installation, connection with barrels, pump, and tunnel using PVC pipe, and water delivery in the system consideration.

Two barrels was placed to store the water for experiment usage. It is can store about $0.16m^3$ of water. In between of these barrels, one inch of connector was used to connect them. So, pump will suck the water from the barrels to the tunnel. With one inch outlet of pump, the reducer used to expand the water flow to the three inches at the inlet of the tunnel.

Then, from the outlet of the tunnel, reducer is used again to connect to the barrel. At this time two reducers was used and they are 4”-3” and 3”-2” reducer was installed. Water will flow trough out into two inches pipe and enter the barrel again. That is how water floe in this system.

Two inches of ball valve was installed at the outlet of the tunnel before the water enters to the barrel. That valve use to control water flow rate in the system.



1. Barrel
2. PVC 3"Ø
3. PVC 4 Ø
4. Rubber gasket

Figure 3.9: Material used for piping system

(a) (b)

(c)

(a) Inlet and outlet part

(b) Connection between two barrels

(c) Pump connection

Figure 3.10: Important part in piping system

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter explains about the result, finding and discussion about the finalization of project. It is including how the dimensioning was predicted, the pump determination, and the calculation of parameter involve using the data obtained from the experiment. Then, discussion about the result obtains using the theory of fluid mechanic and what the improvement that can be implement to the next design in order to get more accurate result.

4.2 Justification

4.2.1 The tunnel

A channel is about 2 meters length, 0.26 meter of height and 0.19 meter width. The water will flow along this channel and return back to the barrel. It is made from 12 mm of acrylic and need silicon glue to paste in between parts of channel's body.

The consideration of dimensioning for a channel is how to make the flow of water is laminar. So, a channel should have very long path from entrance region. When the water moves trough a channel, viscous effect causes it to stick to the body of a channel as in figure 4.1. Because of this, the velocity profile vary with some this distance from inlet of a channel. Thus, a boundary layer formed.

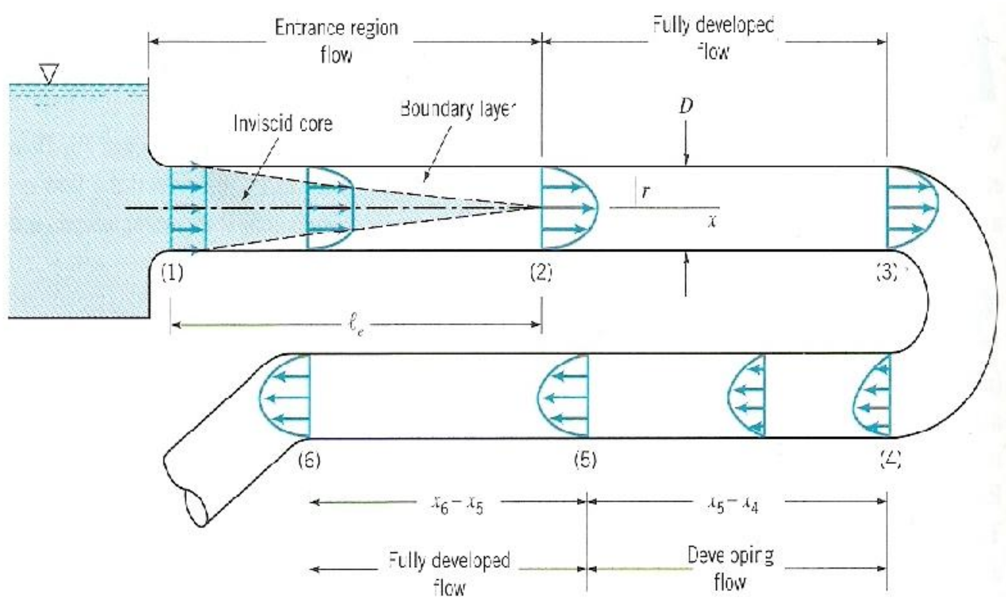


Figure 4.1: Entrance region, fully developed flow, inviscid core, boundary layer

Source: Munson et. al, (2006)

4.2.2 Inlet and outlet of tunnel

The inlet and outlet was designed to be circular in shape. It is because that parts need to be fit with PVC pipe where the water is sucked by pump in to the inlet then flow along a channel.

The size of the inlet and outlet are different. Several factors were considered in determining the size of them. The factors are:

1. Pressure at the inlet
2. Flow of the water
3. Water balance at the inlet and outlet flow

A PVC pipe with 3 inches of diameter is used at the inlet and this causes low pressure of water while entering the tunnel. Based on equation 4.1, the velocity of the water increases if smaller PVC pipe is used at the inlet, and the same time, cause high pressure at the beginning.

$$P = \frac{F}{A} \qquad (4.1)$$

Where P = pressure

F = force from pump

A = area of the inlet

The high pressure cause the turbulent flow to occur at the inlet. The analysis tries to minimize the degree of turbulent in the tunnel. So the area must be big in order to decrease the pressure entering the tunnel.

Then analysis goes to consideration about the size of the outlet. The analysis by using ANSYS done by Bucci (2002) shows that the flow of the water through the outlet without any reflection.

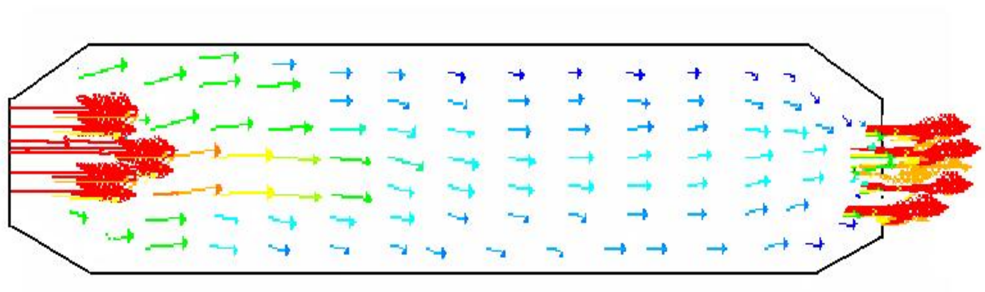


Figure 4.2: Water flow in the tunnel

Source: Bucci (2002)

But from front view, the reflection still occurs because the water is not totally out from the tunnel. Yellow region show where the reflection occurs at the outlet of tunnel.

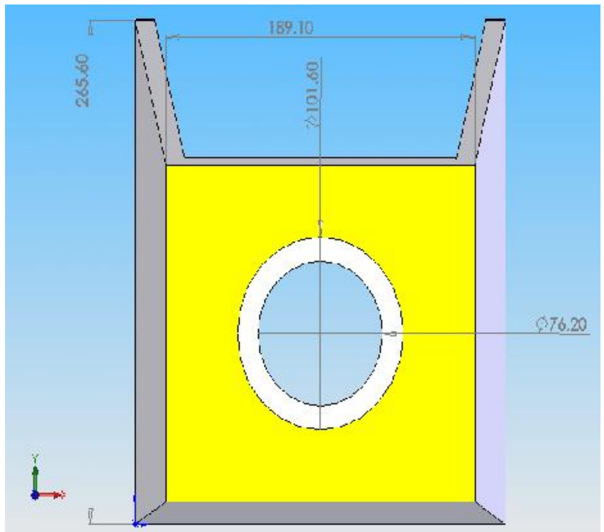


Figure 4.3: Region where reflection occur

As the solution the diameter of outlet must big as possible with surface outlet. Four inches diameter is the biggest of PVC pipe. So, that size was selected in tunnel design.

1.2.3 Pump

Before determine what pump suitable for the system, the range of velocity must be determined first. From this range, the minimum and maximum flow rate can be calculated. Then, what is the height (head) from inlet tunnel to pump. From graph provided from manufacturer, the accurate pump can be choosing.

For this project, range for low speed velocity is 0.04 m/s – 0.06 m/s. by using mass flow rate equation,

$$m = Q\rho = \rho AV \tag{4.2}$$

Where m = mass flow rate

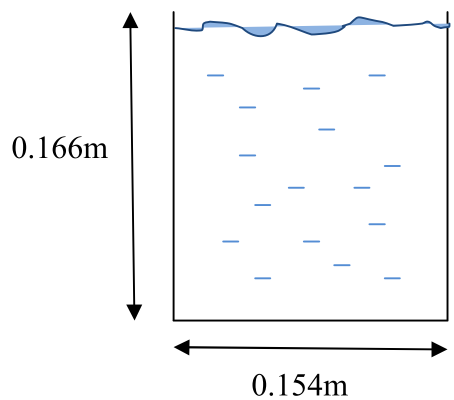
Q = volume flow rate

ρ = density of water

A = cross sectional area

V = velocity in tunnel

The area is base on the design of the tunnel. It is:



Then, Q_{min} and Q_{max} were determined by substituting all the parameters into the equation.

$Q_{min} = 1.1704 \times 10^{-3}\ m^3/s = 1.1 L/s$

$Q_{max} = 1.7556 \times 10^{-3}\ m^3/s = 1.7 L/s$

Figure 4.4: Pump 0.5hp QB series

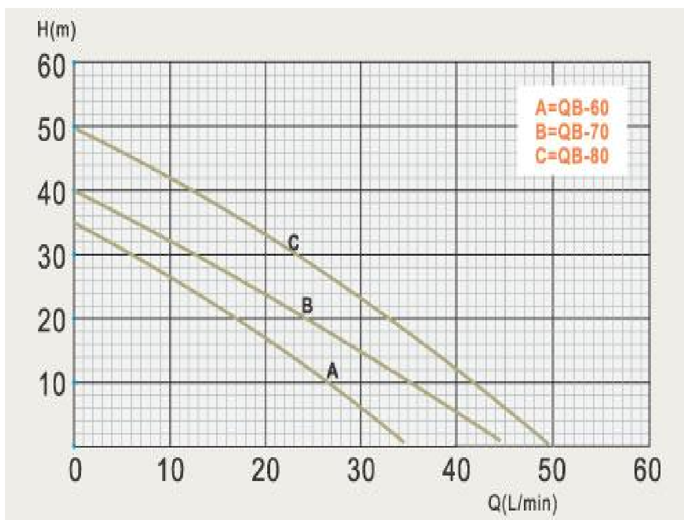
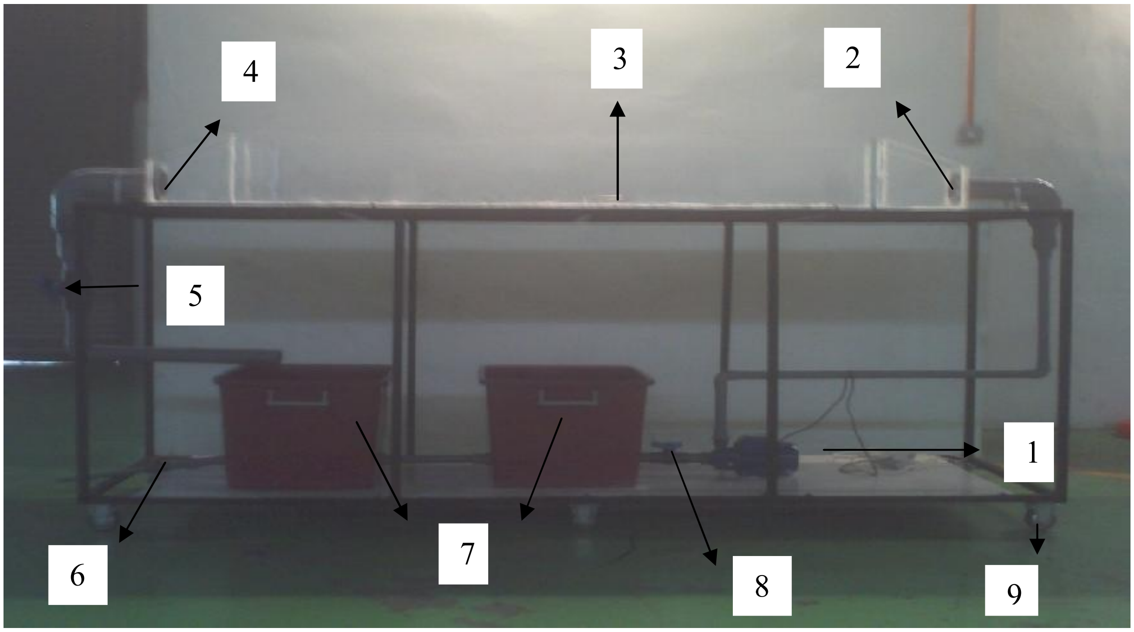


Figure 4.5: Total head capacity pump curve

4.3 Picture of water tunnel

As a result, here is the low speed water tunnel after final fabrication.



1. Pump
2. Inlet
3. Tunnel
4. Outlet
5. Valve 3
6. Valve 2
7. Barrels
8. Valve 1
9. Roller

Figure 4.6: Components of water tunnel

Figure 4.7: Water tunnel after fabrication process

4.3.1 Function of each part

1. Pump : Used to pump the water from barrels to the tunnel
2. Inlet : Water entrance
3. Tunnel: Water flow through this part. The model placed in this part.
4. Outlet: Water exit
5. Valve 1: Used to control the water flow to the pump
6. Valve 2: Used to empty the water from the system/water tunnel
7. Valve 3: Used to control speed of water flow
8. Barrel: Used to store the water during the experiment.

4.4 Result

By using this water tunnel, two experiment can be run for test whether the system follow the requirement or not. First experiment used to determine how fast the velocity of water in a tunnel and the second one used to test the functionality in order to view the flow of water after submerge body.

4.4.1 Experiment to determine the velocity

The velocity of water can be determined by using flow meter. In this experiment, the velocity is measure base on the distance from the inlet. As figure 4.1 above, viscous effect causes the water stick to the wall and make it slow in motion. That is why boundary layer occurs at the inlet of the tunnel.

So, the objective of this experiment is to view whether the boundary layer exist in this water tunnel or not. If yes the distance where fully developed flow occurs should be determined.

First, prove the velocity with the equation 3.1.

$$Q = AV$$

Where $A = 0.025564\ m^2$ (base on design)

Table 4.1: Comparison value between calculation and experiment

Distance from inlet, m	**Volume flow rate,** L/s	**Velocity using flow meter,** m/s	**Calculation,** m/s	**Percentage error, %**	**Prove**	
					Yes	**No**
0.2	0.7	0.035	0.02738	21.77		X
1.0	0.7	0.040	0.02738	31.55		X
2.0	0.7	o.040	0.02738	31.55		X

0.7 L/s $\longrightarrow$ $m^3/s = 0.0007\ m^3/s$

Velocity, $V = \frac{Q}{A}$, substitute all parameters in this equation,

$$= \frac{0.0007}{0.025564}$$

$$= 0.02738\ m^3/s$$

Even the value is different from calculation, but it is not too far from the data gathered from experiment. So, the conclusion for the average velocity in tunnel is about $0.038m^3/s$.

Then, equation 2.2 applied to determine Reynolds number

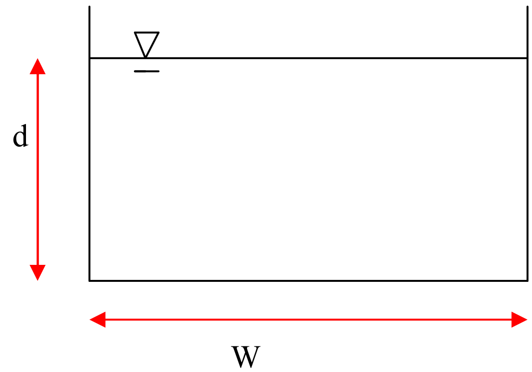
$$\frac{\rho V R_H}{\mu}$$

Where ρ = density of water, 1000 kg/m^3

V = average velocity in tunnel

R_H = hydraulic radius of the channel, m

For a rectangular open channel of width *W* and depth d, equation 2.3 was applied:



$$R_H = \frac{A}{P_W} = \frac{Wd}{W+2d}$$

$$= \frac{(0.154)(0.166)}{0.154+2(0.166)}$$

$$= 0.0526 \text{ m}$$

Thus, Reynolds number in the system is

$$= \frac{(1000)(0.038)(0.0526)}{0.798\text{x}10^{-3}}$$

$$= 2505$$

Laminar if Re < 500

Turbulent if Re <12,500

From the velocity gathered from the experiment, energy flow in tunnel was calculated by using equation 3.3 where the assumption was be made. There is no elevation in this design.

$$d + \frac{V^2}{2g} \quad .$$

Where V_{avg} = 0.038 m/s

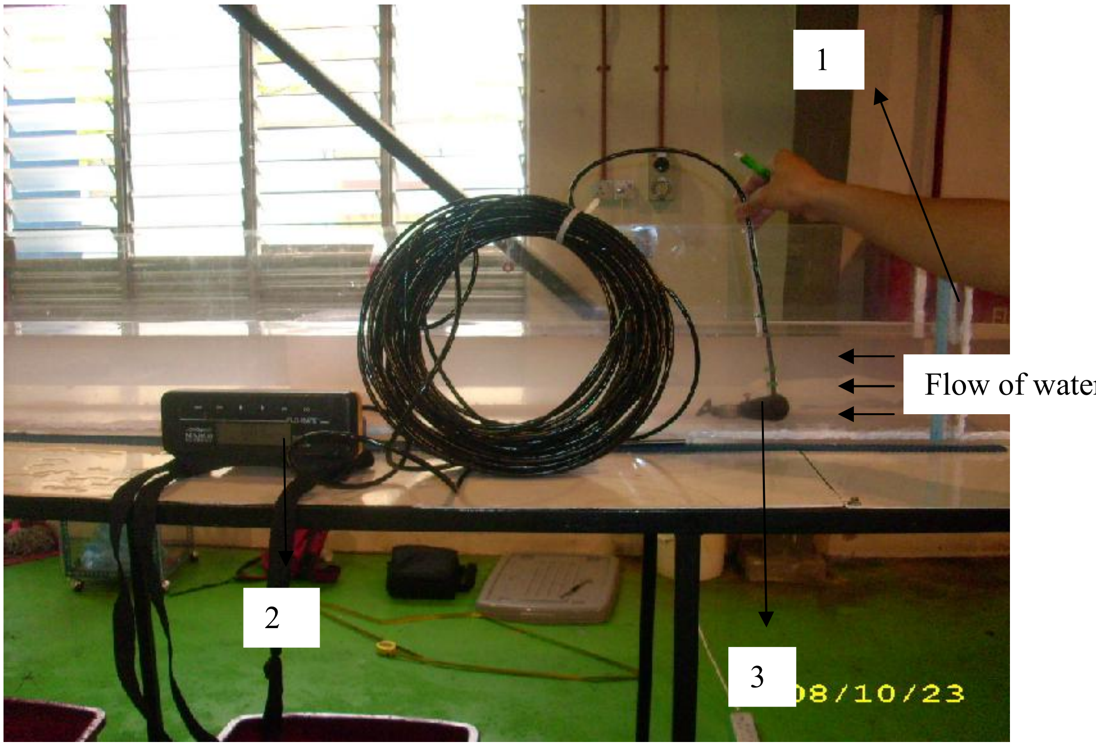
d = 0.166m

g = 9.81m/s^2

Energy flow = 0.1660073 m (in term of energy per weight of fluid)

Thus, the energy is come totally from the specific energy, contributed by the depth of the water and also velocity head in the tunnel. Seems it is very low energy in the tunnel.

In order to trace existence of boundary layer in the tunnel, the velocity for every single of depth at the certain distance from inlet, X must be measure. In this case, flow meter was used to measure the velocity.

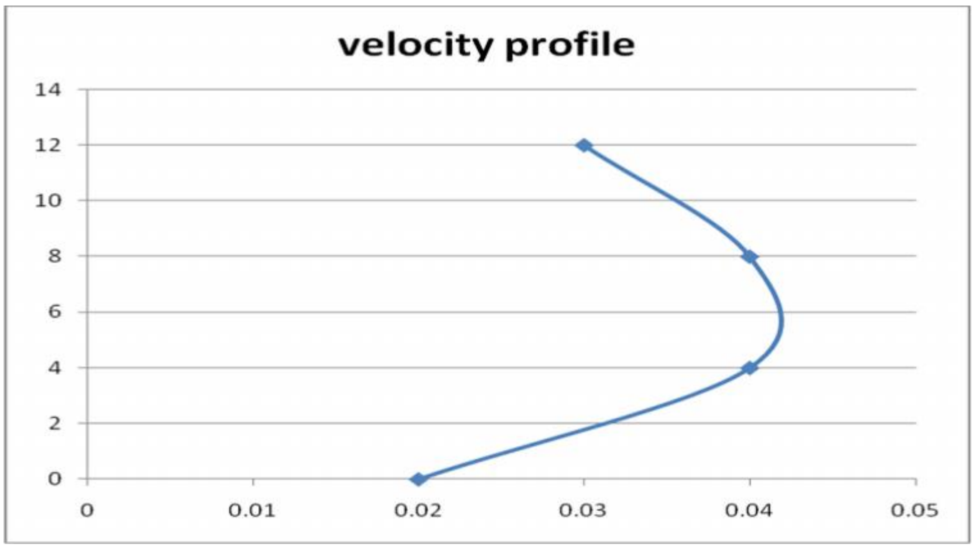


1. Depth indicator
2. Reading
3. Sensor

Figure 4.8: Flow meter devise

Table 4.2: Velocity at 0.2 m from inlet

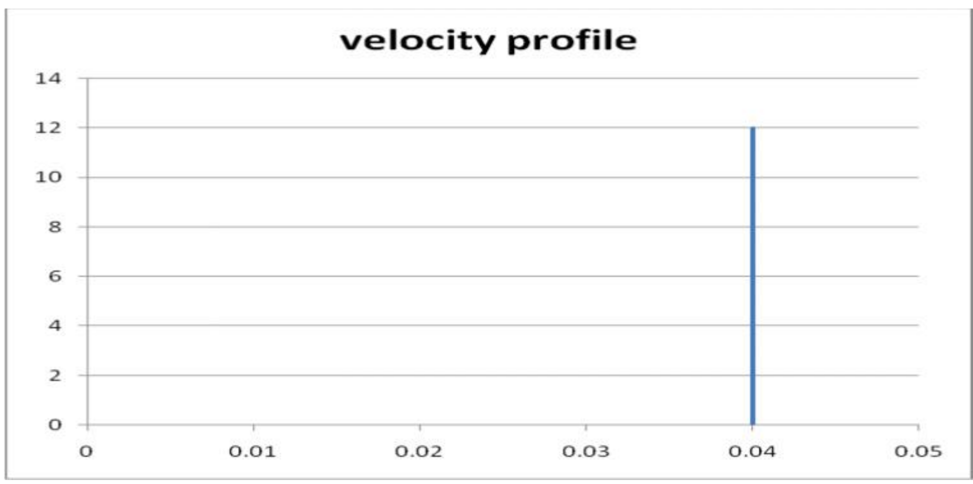
Volume flow rate, Q (L/s)	**Depth measure from bottom wall of tunnel (cm)**			
	0	4	8	12
0.70	0.02	0.03	0.04	0.05
0.66	0.02	0.02	0.02	0.02
0.79	**0.02**	**0.04**	**0.04**	**0.03**



Unsymmetrical shape of velocity profile occurs at the beginning. The maximum velocity at the centerline ($r = 0$) of tunnel where there is no shear stress, $\tau_w = 0$. At the tunnel wall ($r = \frac{D}{2}$) the shear stress is a maximum. This phenomenon was caused by viscous effect where the water sticks with the wall of the bottom at the tunnel.

Table 4.3: Velocity at 1.0 m from inlet

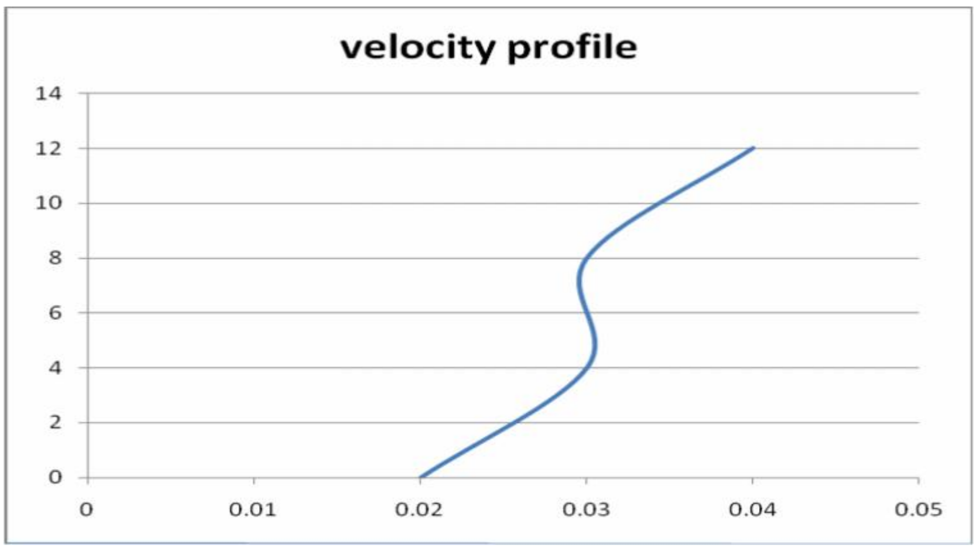
Volume flow rate, Q (L/s)	**Depth measure from bottom wall of tunnel (cm)**			
	0	4	8	12
0.75	0.06	0.04	0.04	0.02
0.75	0.04	0.05	0.04	0.04
0.92	**0.04**	**0.04**	**0.04**	**0.04**



The linear velocity profile occurs at the middle of tunnel. The viscosity is approaching to zero, there is no shear stress and the pressure becomes constant trough the tunnel. At this point, viscous effect does not effect too much.

Table 4.4: Velocity at 2.0 m from inlet

Volume flow rate, Q (L/s)	Depth measure from bottom wall of tunnel (cm)			
	0	4	8	12
0.71	**0.02**	**0.03**	**0.03**	**0.04**
0.66	0.02	0.02	0.02	0.03
0.70	0.02	0.03	0.03	0.03



Non-uniform velocity profile occurs at the end of tunnel. It is caused by the reflection of water with tunnel wall. It was affecting the flow of water at the outlet of this tunnel.

4.4.2 Experiment to test functionality of the system

This experiment is done by placing the model in the tunnel while the water moves past through it. Then the dye is injected exactly in front of that model, and the degree of turbulence is observed. If the flow obeys the theory of fluid mechanics, the system can be say operate successfully and it is can be used to analyze the vortex shading after the submerge body in the water.

Two models were used for this experiment. First model named Ahmed body. Its shape most likely shape of general car was scaled down in this experiment. And the second model was cylindrical shape.

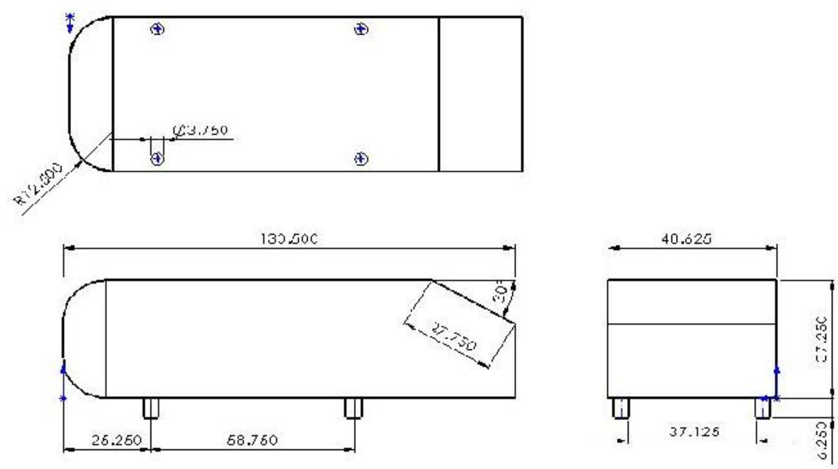


Figure 4.9: Ahmed body dimension

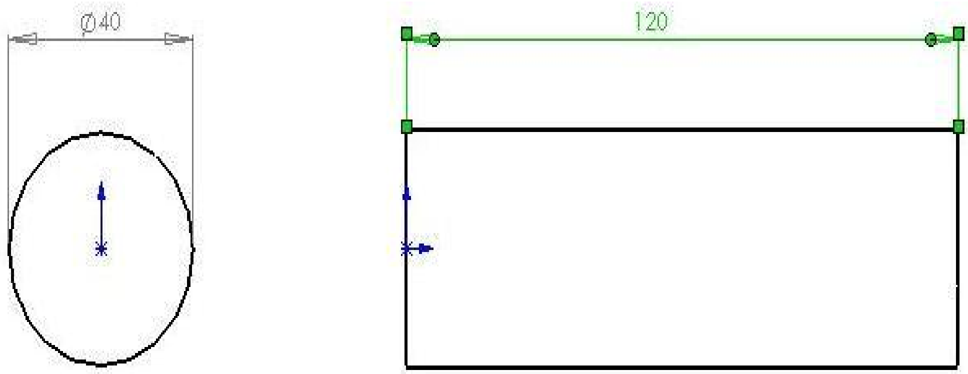


Figure 4.10: Cylindrical model dimension

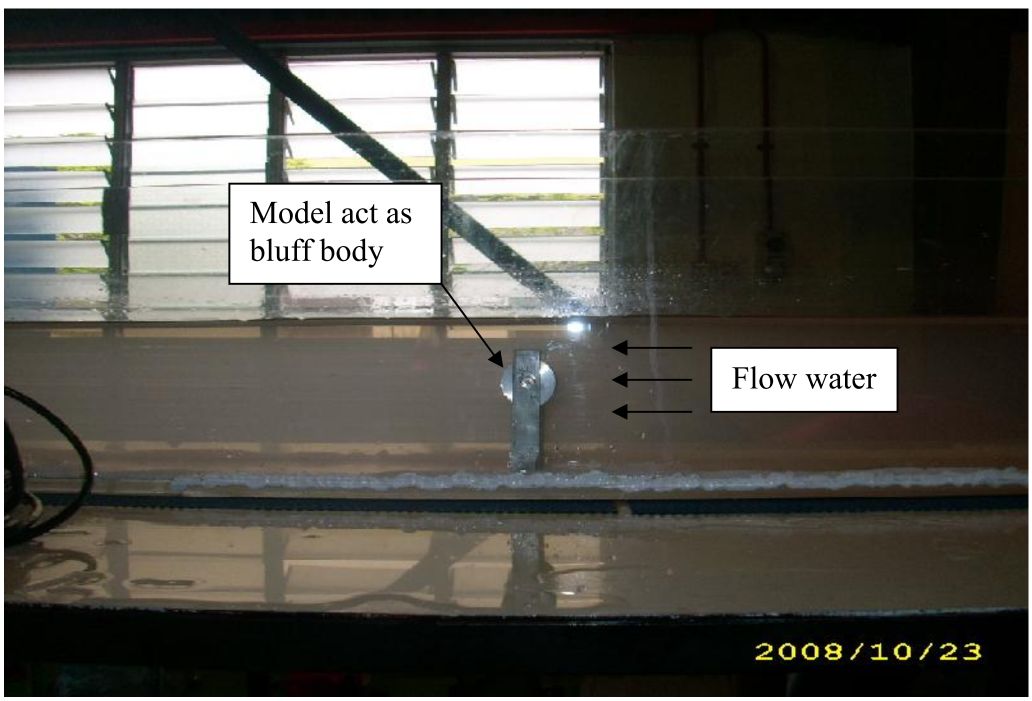


Figure 4.11: The models placed in the tunnel

Figure 4.11: Continue

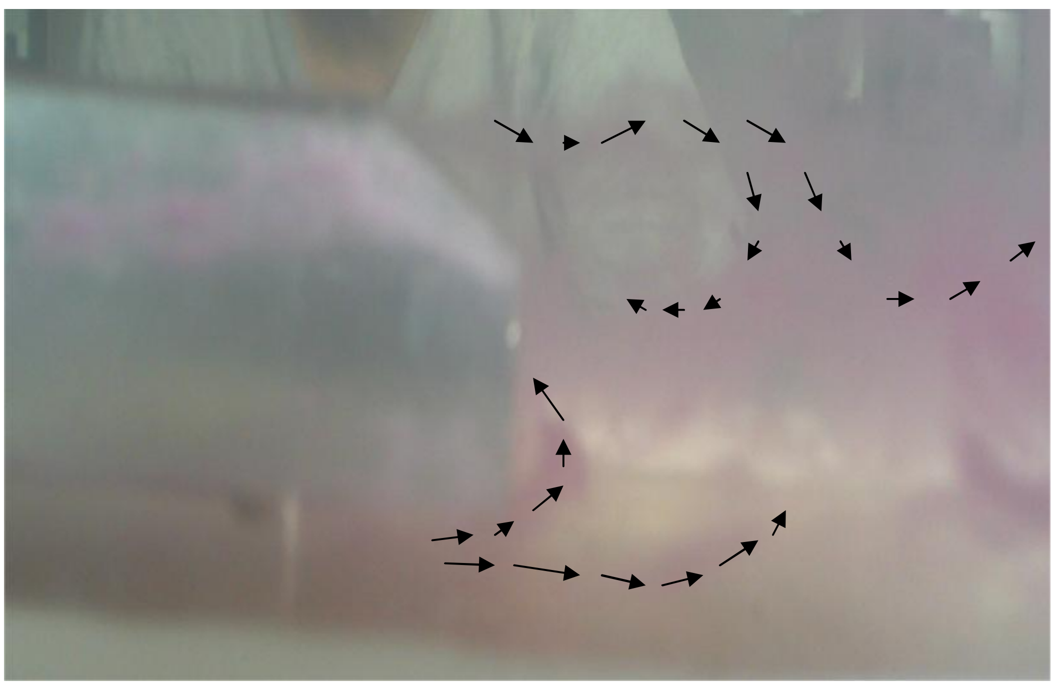


Figure 4.12: Flow water after Ahmed body. Obtain from experiment.

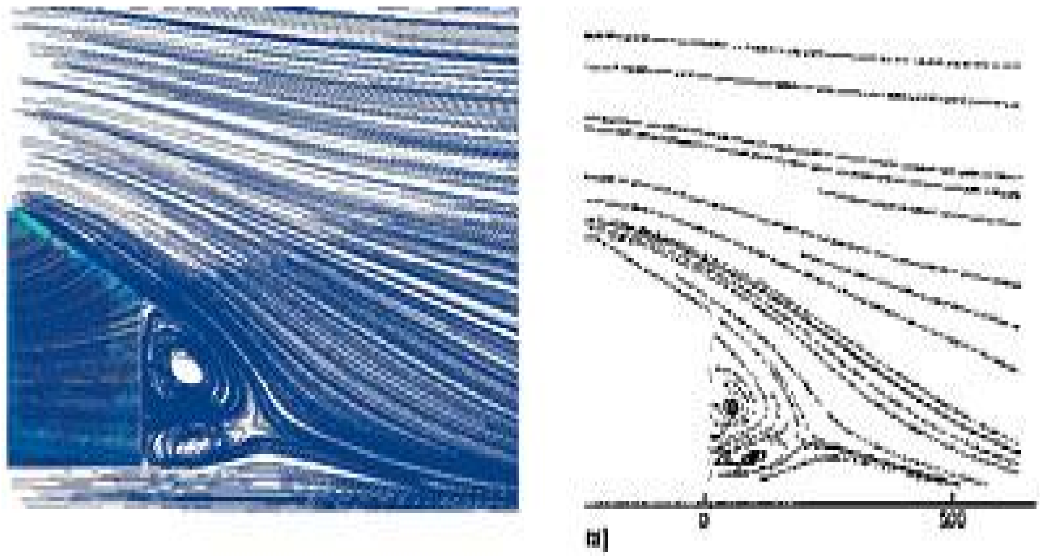


Figure 4.13: Analysis using CFD software.

Source: Mathey (2003)

Figure 4.12 get from the experiment and figure 4.13 flow analysis using Computational Fluid Dynamic (CFD) software. The result obviously has a little bit different with CFD analysis where flow on the slant moving upward compares to CFD analysis. It is because the insufficient velocity produced by water in the tunnel made the dye freely move to upward. The dye supposes to be flow likes in figure 4.13.

Figure 4.14: Flow after cylindrical model

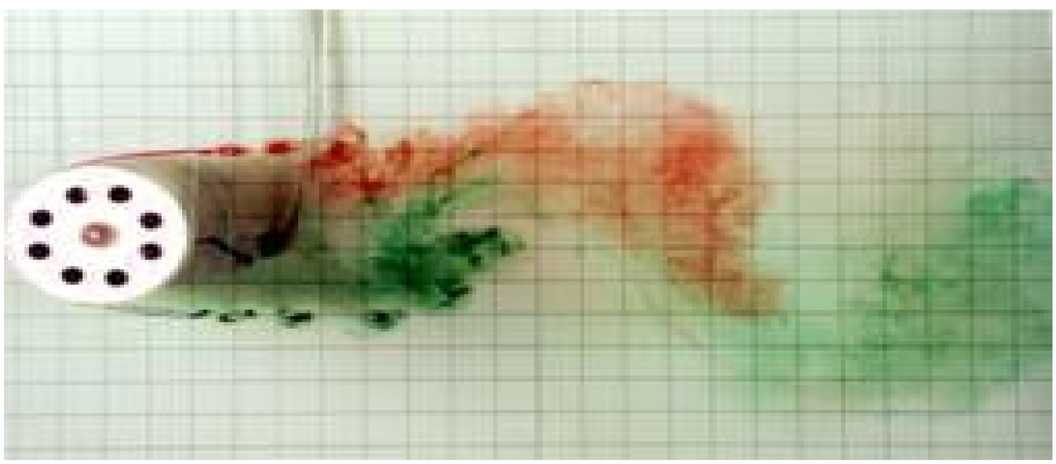


Figure 4.15: Result from Project H_2O during the experiment done by Bucci (2002)

Same goes to cylindrical model in figure 4.14. There is just a little bit vortex shading occur after that model because of low speed of water. After that, dye going upward and no more vortex form.

4.5 Discussion

This type water tunnel can be implementing to do experiments especially to monitor drag effects and water turbulence on self-propelled water craft, like kayaks or submarine. But several parts must be modifying in order to get the accurate data with more appropriate condition. In this subtopic, it is discussed about how to improve the design in order to achieve the objectives of the project.

4.5.1 Modifying the tunnel design

The important thing is the tunnel should have close test section in this design. Even it is open channel but to investigate the flow after submerge body; close test section is required because it is can produce the symmetrical flow of water in the tunnel. As mention before, there is existence of free surface between the flowing fluids above it can affect the water flow in the tunnel. There is another velocity occur at that free surface called wave velocity.

The uniform velocity profile exists in the close tunnel. See figure 4.1. The best place to put the model is at fully developed flow area. The figure below shows the symmetrical distribution of velocity profile pass the model.

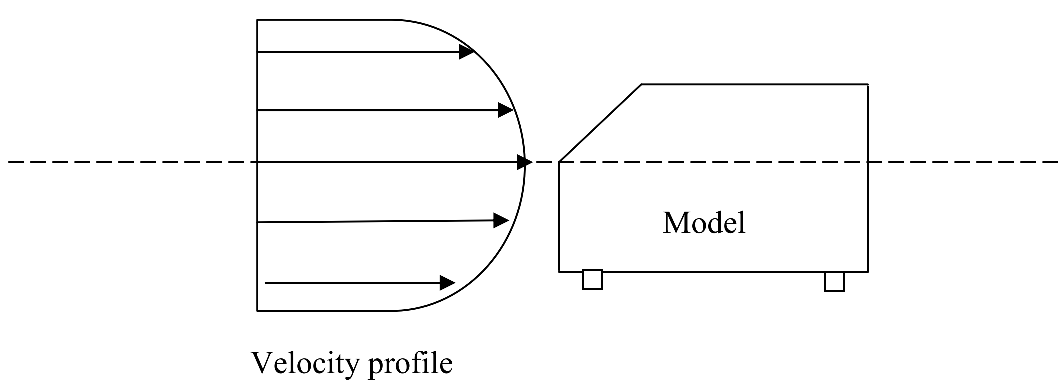


Figure 4.16: Uniform flows of water move pass the body

4.5.2 Modifying the base

Usually in open channel system, there is a slope in between point 1 and point 2. Then using Manning equation, the velocity in the channel can be measured. But in this project, this equation cannot be applied because no slope, S_0.

$$S_o = \frac{Z_1 - Z_2}{\text{Length from point 1 and 2}} \tag{4.3}$$

It is one meter height at left side and right side too.

Slope at the base is really important in order to increase the velocity of water in the tunnel. When the slope occur, gravity force act as driving force for the system. But the main driving force is likely to be a pressure gradient along the pipe.

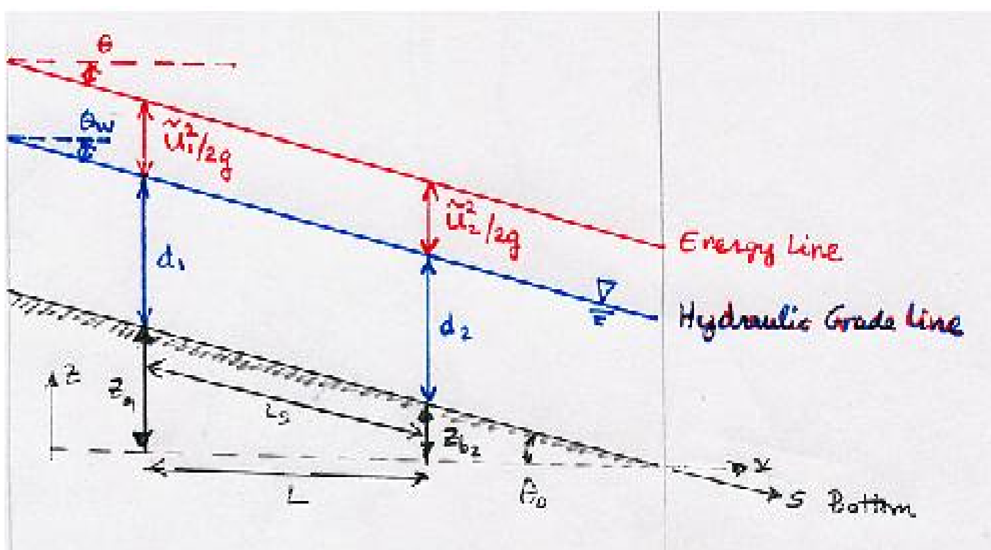


Figure 4.17: Flow in open channel

Source: *Quality Flow Measurements at Mine Site,* 1961

CHAPTER 5

CONCLUSION AND RECOMMEDATION

5.1 Summary of Project

Begin with collecting data from other thesis, books, articles, lecturers etc about the water tunnel then do some analysis, analyze the new concept design, start fabricate the water tunnel and finally test the functionality of the system and performance, all of these are about this project.

The result shows that range of water speed is 0.02 m/s until 0.06m/s. It is quite slow for testing or running the experiment to investigate the force acting on the model or analysis the flow with variable of Reynolds number.

Overall, this project seem successfully done, able to finish on time even have some problem in fabricating stage, limitation of cost and time. Based on data collected, this project was achieving the objectives but it is still need some improvements in the further work.

5.2 Advantages and Disadvantages

After gathering the data from the experiment using this water tunnel, the conclusion has made and come out with this finding.

1.2.1 Advantages:

1. Small
2. Save cost
3. Can do analysis same likes the bigger one
4. Can be move
5. Simple procedure in conducting the experiment

5.2.2 Disadvantages:

1. Heavy-cause a plane bend
2. Have difficulty in removing/empty the water from channel
3. Because of the non-uniform pressure distribution, dye is going upward during the analysis

5.3 Recommendation and Suggestions

As mention earlier in this project, water tunnel is used for testing the fluid mechanics behavior and study about aerodynamic phenomenon. There are some suggestions for the further work and improvement regarding to this project

For the improvement:

1. The tunnel should have the test section. It is must be close one and water must totally fill up that section.
2. Modify the base. Consider about the slope for speed of water purpose.
3. If possible to change the pump inlet and outlet diameter, try to make it bigger. So, it is can maximize the pump power. If not, the piping system must be modifying according to pump outlet diameter in order to increase the speed of water flow in tunnel. But it will cause pressure increase at the inlet of tunnel.

For the further work:

1. Use that water tunnel to do the experiment to investigate or analyze the vortex shading after the submerge body in the tunnel.
2. Understanding the force and aerodynamic behavior by doing the experiment.

Appendix A

Table 6.1: Values of Manning Coefficient

Wetted Perimeter	n
Natural channels	
Clean and straight	0.030
Sluggish with deep pools	0.004
Major river	0.035
Floodplains	
Pasture, farmland	0.035
Light brush	0.050
Heavy brush	0.075
Trees	0.15
Excavated earth channels	
Clean	0.022
Gravelly	0.025
Weedy	0.030
Stony, cobbles	0.035
Artificially lined channels	
Glass	0.010
Brass	0.011
Steel, smooth	0.012
Steel, riveted	0.014
Cast iron	0.015
Concrete, finished	0.013
Concrete, unfinished	0.014
Planed wood	0.012
Clay tile	0.014
Brickwork	0.015
Asphalt	0.016
Corrugated metal	0.022
Rubble masonry	0.025

Appendix B

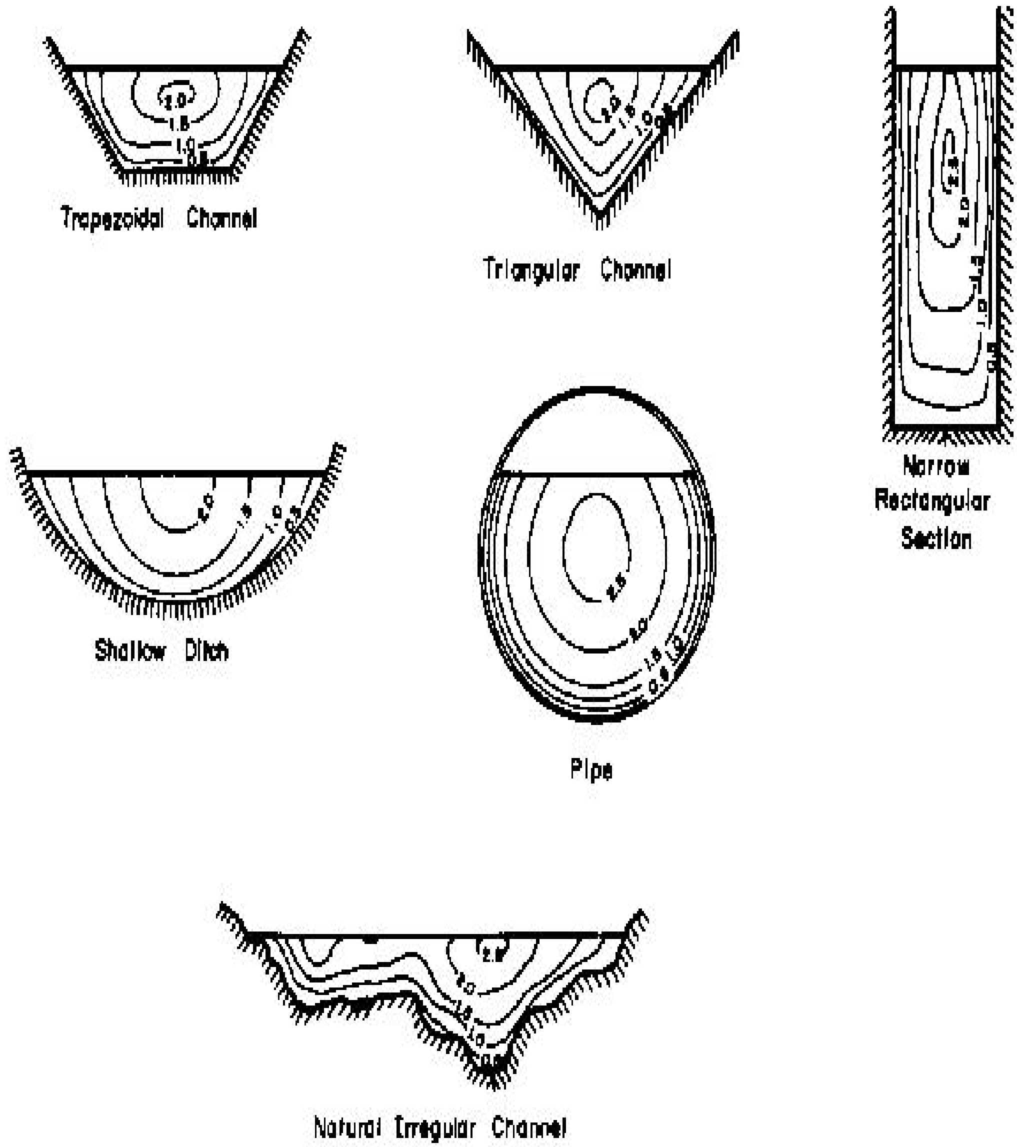


Figure 6.1: Typical velocity distribution for several channels

Appendix C

Table 6.2: Pump specification (at 240V/50 Hz 2850 RPM)

Model	**Max capacity (L/mil)**	**Max head (m)**	**Max Suct. Lift (m)**	**Power (W)**	**Pump diameter (mm)**
QB-60	35	35	9	370	25 x 25

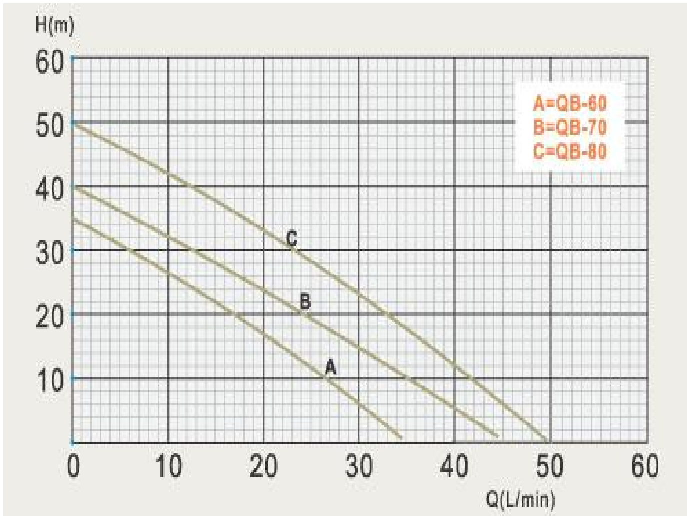


Figure 6.2: Total head capacity pump curve

Reference

Bucci.M (2002), *The Water Tunnel Project H_2"O"* PhD Thesis, from Wilkes University, pp 1-10.

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