FEASIBILITY STUDY OF USING RAIN TURBINE FOR SMALL SCALE POWER GENERATION

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CERTIFICATION OF APPROVAL

Feasibility Study of Using Rain Turbine for Small Scale Power Generation

by

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Approved by,

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(AP Dr. Hussain Al-Kayiem)

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TRONOH, PERAK

JULY 2009

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.

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ADRIAN EE ANAK JAMIT

ABSTRACT

At present, rain has not thoroughly studied as a source of producing energy. Power can be generated from the kinetic energy of flowing rainwater. Rain power is a renewable energy source and does not produce any harmful emissions to the environment. This paper describes the theoretical study undertaken to determine the theoretical amount of power that could be generated by flowing rainwater. In this study, rainwater will first be accumulated in a tank before being released as a stream of water onto a rain rotor. The rain rotor is specifically designed for this application and is a modified version of the Savonius wind rotor. This device can be used for local production of a small amount of electricity.

ACKNOWLEDGEMENTS

I wish to take the opportunity to express my utmost gratitude to the individuals that have taken the time and effort to assist me in completing this project. Without the cooperation of these individuals, my project execution would not have been smooth and reach completion.

First and foremost I would like to express my utmost gratitude to my Final Year Project (FYP) supervisor, AP Dr. Hussain Al-Kayiem. Without his guidance and patience, I would not be able to succeed in completing this project. To the FYP Coordinator, Dr. Saravanan a/l Karuppanan, I would also like to give my appreciation to him for providing me with all the guidelines and rules regarding my FYP.

I would also like to thank H2E Technologies Sdn. Bhd. for their collaboration in my project. They have fabricated the prototype which enabled me to conduct my experimental analysis.

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CHAPTER 1

INTRODUCTION

One form of renewable energy source in nature that is still unexploited is rain power. In a heavy downpour, large volumes of rain water can be collected in a reservoir. This accumulated water provides an opportunity for energy extraction. If the energy can be extracted efficiently, rain power can provide another alternative source of renewable energy.

1.1 Background of Study

The most common method to extract energy from flowing water would be to use Pelton, Francis, Kaplan or other types of water wheels. However, in the application of generating electricity from rain, the available head and flow rate is too low for usage of the previously mentioned water wheels. The design of a conventional Savonius wind rotor has been considered. The basis of design for the rain rotor was based on the water wheels and the Savonius rotor. Further developments and modifications were made to the rain rotor design to suit the rain application.

1.2 Problem Statement

Fossil fuels, which are the current most popular energy source, are fast depleting and non – renewable. Rain power is an energy source which can be developed and improved since it is a renewable energy source. Savonius turbines are most commonly used to extract energy from winds and are mounted vertically. This study focuses on the performance of the modified Savonius rotor in rain applications. This rain rotor would be mounted in a horizontal position and a stream of rainwater will be the working fluid.

1.3 Objective

The objective of this project is to:

- Redesign the conventional Savonius rotor to suit rain application.
- Fabricate a rain rotor.
- Test the performance of the rain rotor in generating power from rainwater.

1.4 Scope of Study

This project involved seeking information regarding Malaysia's weather focusing mainly on the rain conditions. These would include the obtaining information on the annual rainfall rate and distribution in Malaysia focusing on rural areas of Sarawak. Research on the performances of different blade designs of Savonius rotors would be used to determine the most efficient rotor design. Current energy extraction techniques from rain would also be studied. The fabricated rain rotor arrangement would be placed outdoors. The water tank would accumulate the rainwater flowing off the roof and then discharge it to the rain rotor. A drawing is provided in Figure 5.1. This rotor would be subjected to a stream of water coming out from the pipe.

1.5 Significance of Study

Studies have been conducted by scientists in France to extract energy from falling raindrops. Their study focuses on converting the mechanical energy of falling raindrops into electricity that can be used to power sensors and other electronic devices. Rural areas in Sarawak that do not receive electricity supply from the main distribution grid will benefit from this technology. Targeting a small area such as a village, several rain turbines can be installed to generate the required amount of electricity. However, since renewable energy is generally intermittent, it may happen that this rain power is not sufficient to meet the electricity demand in some hours. For this reason, rain power cannot exist alone as a sole electricity generator but only to complement other electricity generation sources such as micro – hydro, solar energy, biomass and even with diesel generators.

CHAPTER 2

LITERATURE REVIEW

The current popular sources of energy and power are from fossil fuels. Fossil fuels are used in vehicles, to drive industrial machinery, generate electricity and are the sources of power for many other applications. However, fossil fuels are non – renewable energy sources and are fast depleting. Their usage also brings environmental impact as the final products are harmful towards the environment. Renewable energy sources: water, wind and solar energies for example are being researched and developed as these might become the main energy source in the future when the fossil fuels deplete.

In the interior parts of Sarawak, electricity cannot be supplied to the villages due to their remote locations. Some of these villages are using micro – hydroelectric power for electricity generation. Development of this rain turbine can be used to complement other electricity generating systems.

2.1 Rainwater Harvesting in Malaysia

Rainwater harvesting (RWH) is a technique of capturing rainwater of roofs or other surfaces before it touched the ground and storing it for usage [1]. RWH has been gaining recognition lately for means of domestic water supply. For domestic purposes, domestic rainwater harvesting (DRWH) systems are used. This system collects rainwater flowing off roofs and diverts the water through a set of filters before storing it. Turbines can be installed along the flow of this rainwater to extract energy from it. Possible locations of turbine installation would be the roof edge, gutter outlets or other locations of high rainwater flow. The energy extracted can be utilized to drive the pump system of the DRWH or other power consuming devices.

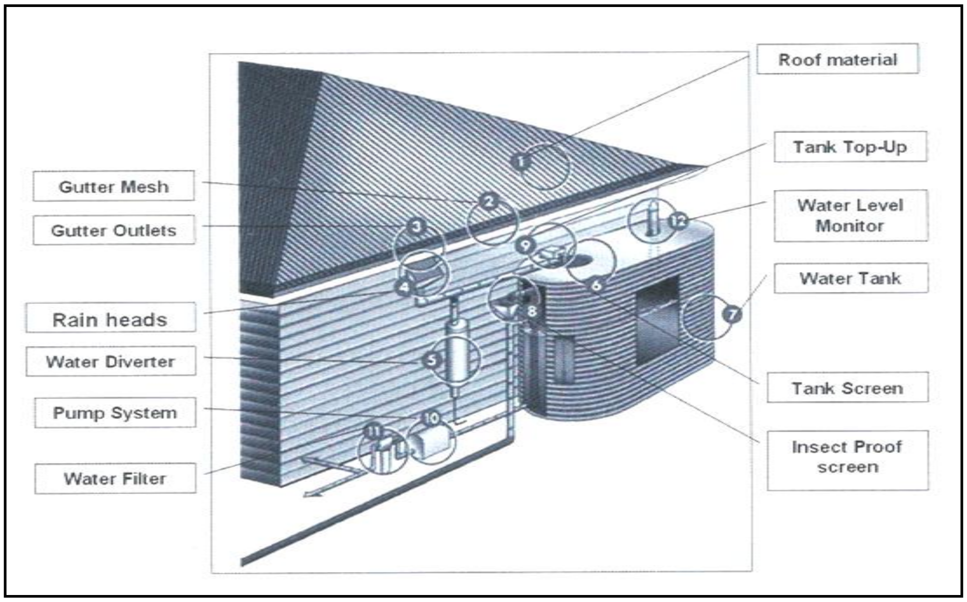


Figure 2.1: Components of a domestic rainwater harvesting system [1]

2.2 Harvesting Raindrop Energy

This paper studies the unexploited source of energy which is rain. The system design scavenges the vibration energy from a piezoelectric flexible structure impacted by a water drop [2]. The vibrational energy harvested from raindrops could be used as an energy source for sensors. Piezoelectric materials have been utilized in other applications such as being installed on windmills to recover wind energy or to harvest acoustic energy.

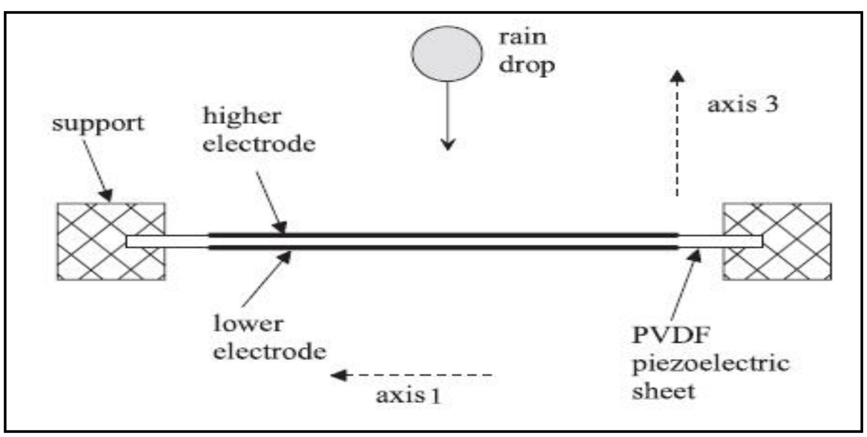
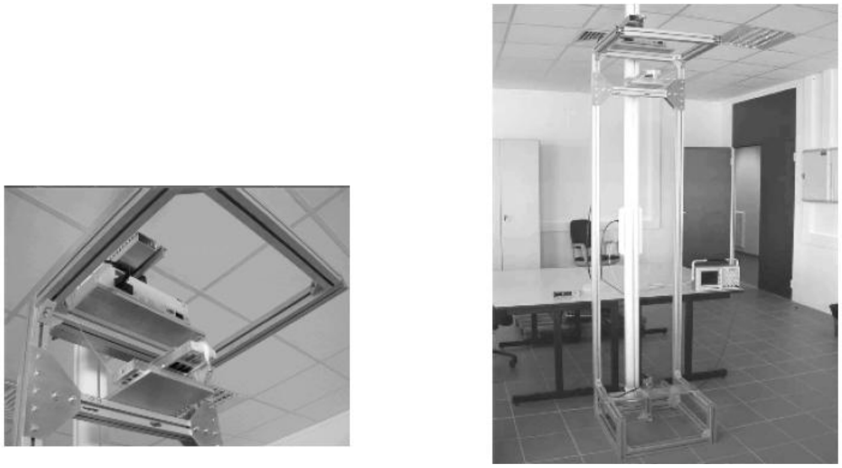


Figure 2.2: System of raindrop energy harvesting [2]



(a) (b)

Figure 2.3: Test bench: (a) syringe pump at the top,

(b) piezoelectric band structure at bottom [2]

Studies have shown that a standard raindrop, on impact, produces a perfectly inelastic shock. Tests with raindrops of different characteristics (diameters and speeds) on various types of material and at different points were conducted. Raindrops provide a significant source of energy, the main drawback being that it occurs in the form of fine, low – energy drops. The optimal structure is being defined to be a very thin, piezoelectric material with no pre – stressing and with a width slightly smaller than the maximum diameter of the impacting drop. This study showed that a 25 μm thick, mono-stretched PVDF material with a piezoelectric strain coefficient d_{31} = 20 pJ N^{-1} is much more effective than a 9 μm thick, bi-stretched PDVF material with a piezoelectric strain coefficient d_{31} = 5 pJ N^{-1}.

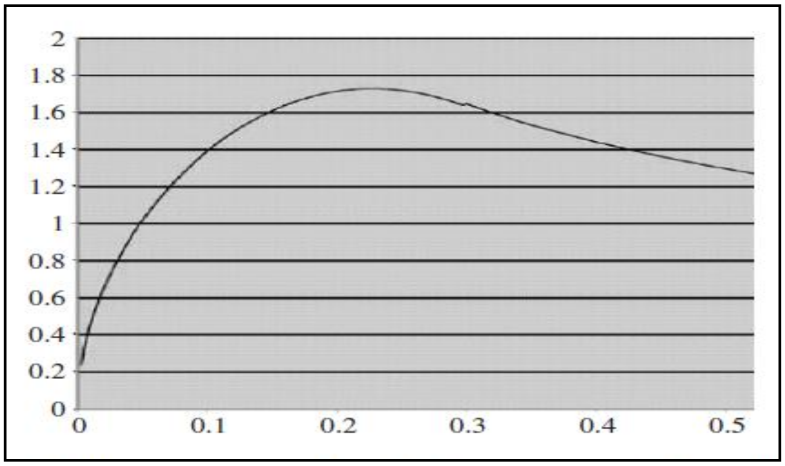


Figure 2.4: Raindrop recoverable voltage (y axis) according to the width of the piezoelectric material (x axis) [2]

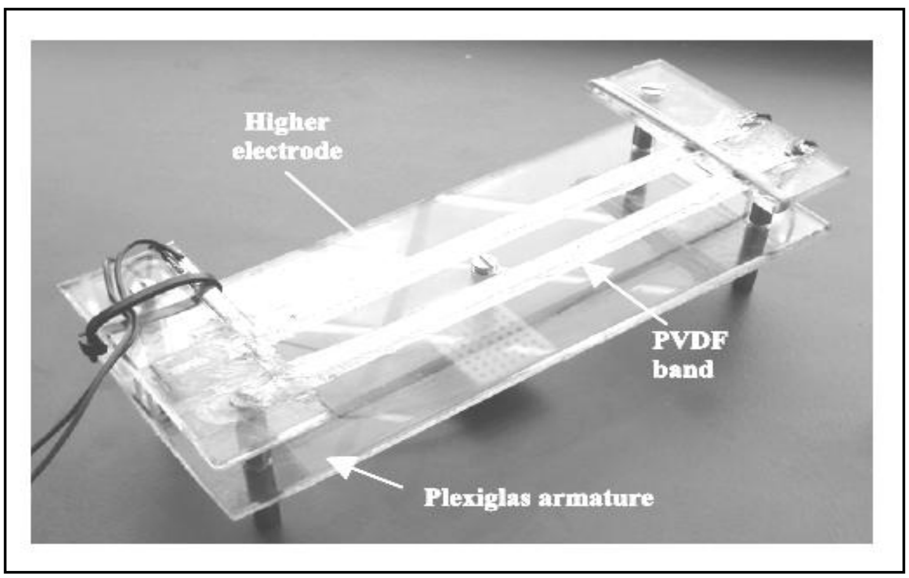


Figure 2.5: Mechanical system embedding the PVDF bands [2]

Results of this study showed that the quantity of electrical energy that can be recovered is approximately 1 nJ of electrical energy and 1 μW of instantaneous power using raindrops. This is the worst case scenario; however, simulations show that it would be possible to recover 25 μJ and 12 mW from a downpour drop.

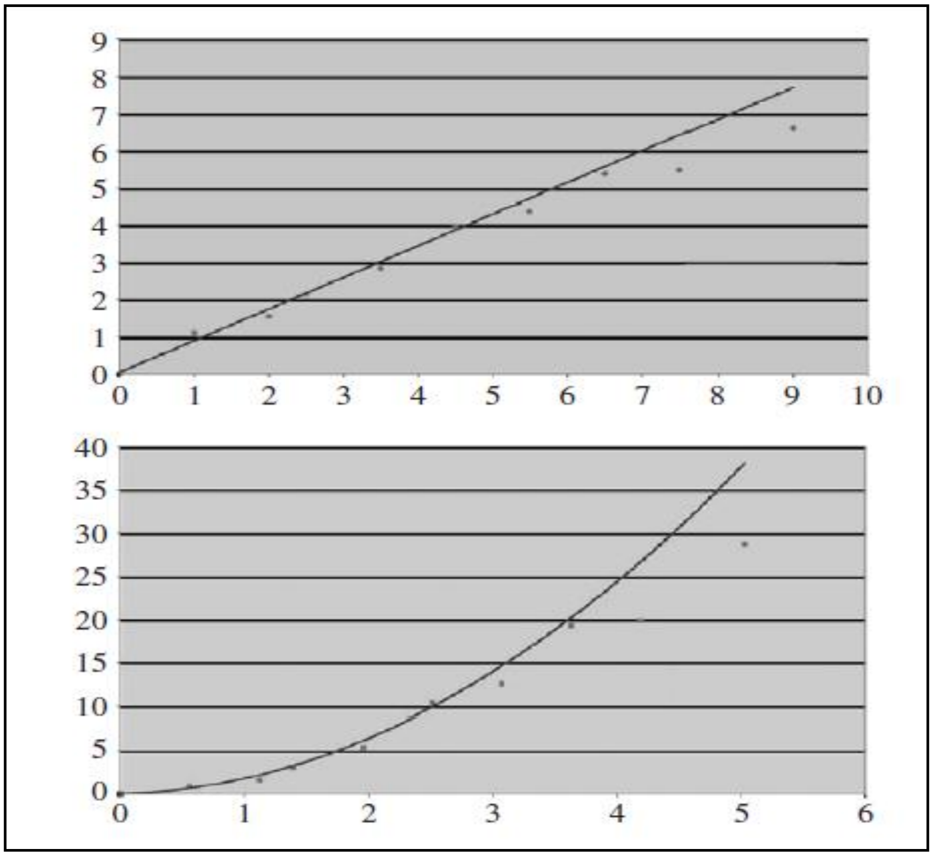


Figure 2.6: Voltage (in V at the top) and energy (in nJ at the bottom) as a function of the mechanical energy (in µJ) of the drop impacting the 25 µm thick PVDF [2]

2.3 Residential Electricity Consumption

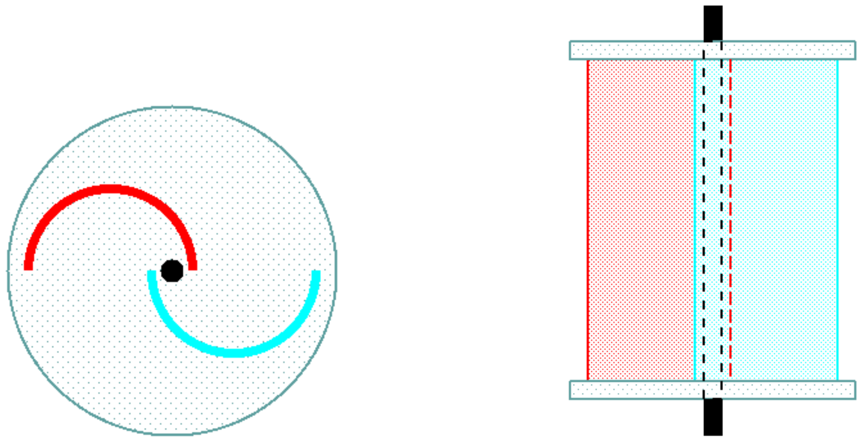
The current national average energy consumption per household is low compared to the energy consumption of a typical urban household. But this is about to change as the nation progresses towards 2020. The estimated total energy consumption for a typical urban household is 8.73 kW [3]. This data was gathered from the Centre for Environment, Technology and Development Malaysia (Cetdem), Tenaga Nasional Berhad (TNB)'s average energy household consumption based on household income, distribution of household income and household growth rate published in official documents. However, if only the basic electrical items were considered (such as rice cooker, fan, lamps, etc.), the total energy consumption would be 1.53 kW.

Table 2.1: Cetdem estimation (2004) of energy consumption for a typical urban household [3]

Item	**kW**	**hrs/yr**	**kWh**	**kWh/m2/yr**	**%**
Refrigerator	0.3	8760	2628	14.6	38%
Rice Cooker	0.65	360	234	1.3	3%
Fan	0.045	3600	162	0.9	2%
Television	0.06	1080	64.8	0.36	1%
Radio	0.25	72	18	0.1	0%
Fluorescent Lamps 18w	0.032	288	9.216	0.0512	0%
Fluorescent Lamps 18w	0.192	288	55.296	0.3072	1%
Total	**1.53**	14448	3171.312	17.6184	

2.4 Savonius Wind Turbine

This wind turbine is a type of vertical axis wind turbine (VAWT), modeled after a design by the Finnish engineer S.J. Savonius in 1922. His idea was to mount two half-cylinders on a vertical shaft. It was simple to build, and could accept wind from any direction. The cross – section of this rotor resembles the letter "S".



(a) (b)

Figure 2.7: A Savonius rotor (a) Top view, (b) Front view [9]

However, it was somewhat less efficient than the more common horizontal axis turbine. It typically has an efficiency of only around 15% - i.e. just 15% of the wind energy hitting the rotor is turned into rotational mechanical energy [4]. The reason for the difference has to do with aerodynamics. Horizontal axis turbines have blades that create lift to spin the rotor, whereas the vertical axis design we are using here operates on the basis of drag—one side creates more drag in moving air than the other, causing the shaft spin. VAWTs have simple structure and installation. Their rotation speeds are low and torque is high [5]. The speed of the Savonius rotor cannot rotate faster than the speed of the wind and so they have a tip speed ratio (TSR) of 1 or below. Therefore, Savonius type VAWT turns slowly their high starting torque enables the rotor to run at any wind velocity.

Savonius wind turbines are being used for electricity generation but are most useful for small scale domestic electricity generation. Other applications would be for pumping water and grinding grain for which slow rotation and high torque are essential.

Figure 2.8: A Sovanius wind turbine [10]

The geometry of a Sovanius rotor is as below. The dimensions are denoted by “D”, “d”, “S” and “h” where D = diameter of rotor, d = diameter of rotor blade, S = rotor overlap and h = rotor axial length. V_f and ρ_f represents the velocity and density of the fluid.

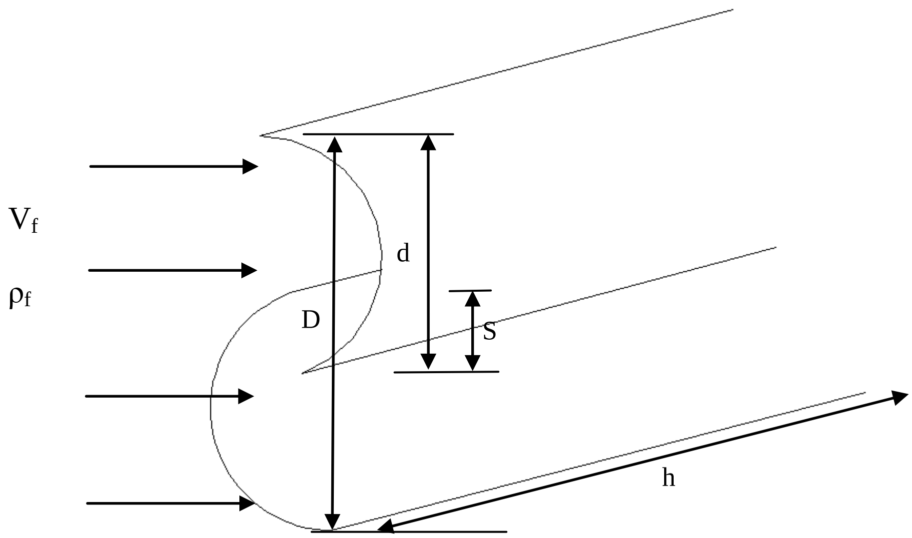


Figure 2.9: Geometry of a Sovanius rotor

2.5 Double Stage Savonius Rotor

The double stage (sometimes referred to as two stage) Savonius rotor has 2 parts or stages, with blades in the individual stages oriented orthogonally to one another. This design eliminated the presence of dead spots when the blades are aligned with the wind and rotor fails to start on its own [12]. The advantages of this design is that is has a low torque variation and produces the highest power coefficient [11].

Figure 2.10: Double stage Savonius rotor

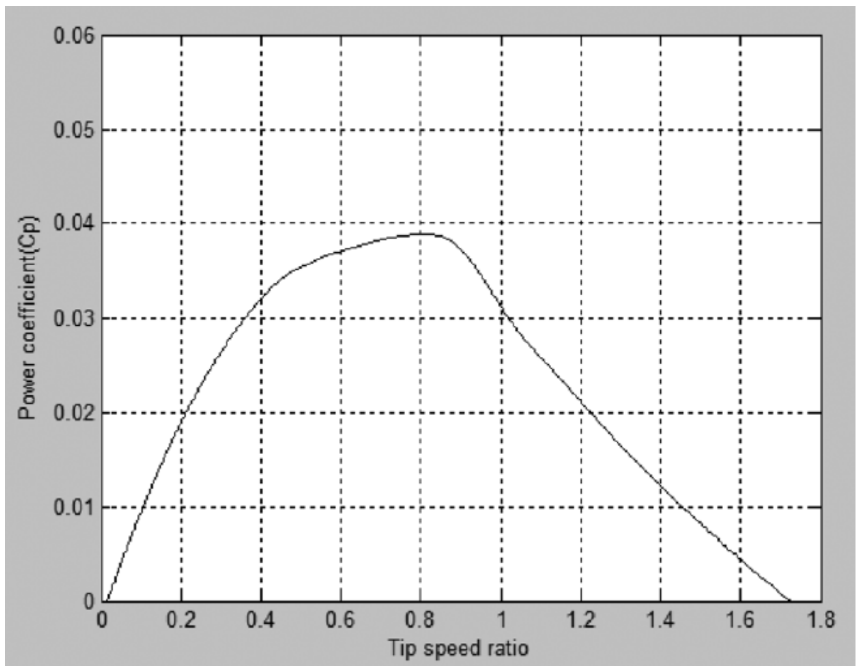


Figure 2.11: Graph of power coefficient versus tip speed ratio of a Single Stage Savonius rotor

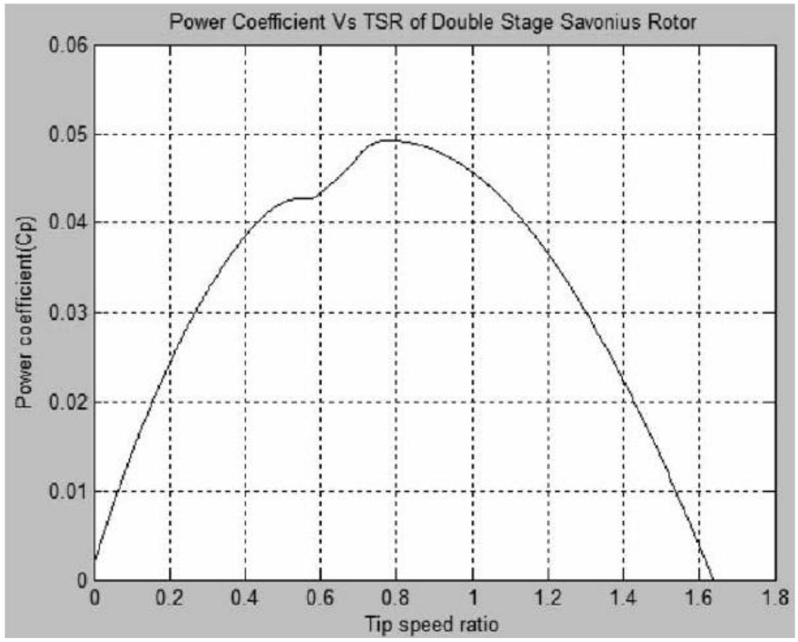


Figure 2.12: Graph of power coefficient versus tip speed ratio of a Two Stage Savonius rotor

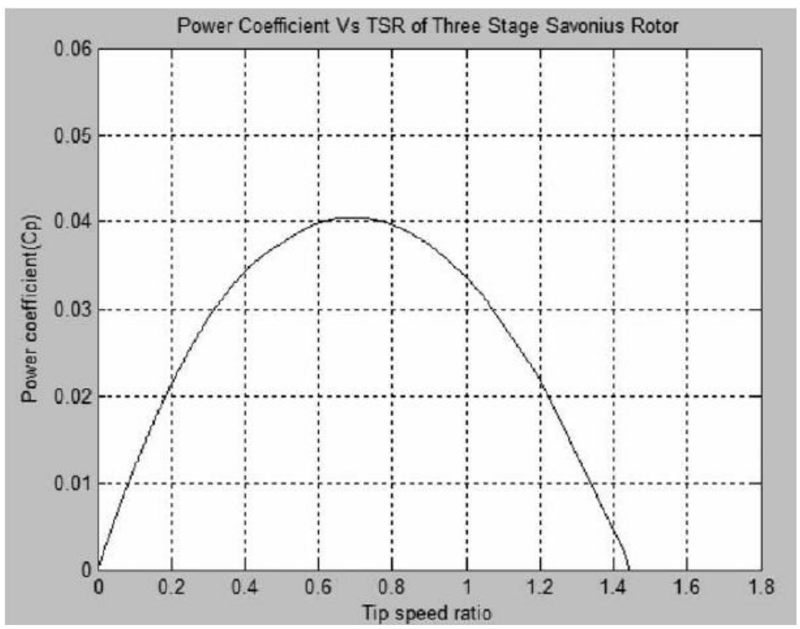


Figure 2.13: Graph of power coefficient versus tip speed ratio of a Three Stage Savonius rotor

CHAPTER 3

METHODOLOGY

This chapter consists of the project execution steps: data and information gathering, rain rotor design and experimental model preparation plus the work flow chart.

3.1 Data and Information Gathering

Preliminary research has been conducted regarding the rain conditions in areas in Malaysia and on raindrop information. Online search of experimental studies on raindrops provided data on raindrop sizes and their respective fall speeds. Rain distribution and annual rainfall rate for Malaysia was obtained from the Malaysian Meteorological Department. Literature sources such as experimental studies, journals and reference books regarding rain utilization and rain power also helped add information to this project.

3.2 Rain Rotor Design

For this application, the conventional Savonius rotor would be modified. The modified Savonius rotor will possess newer characteristics in terms of blade arrangement, number of blades and blade design. A step – by – step design modification process will produce the final drawing of the rotor. This drawing would be used to fabricate the rain wheel prototype.

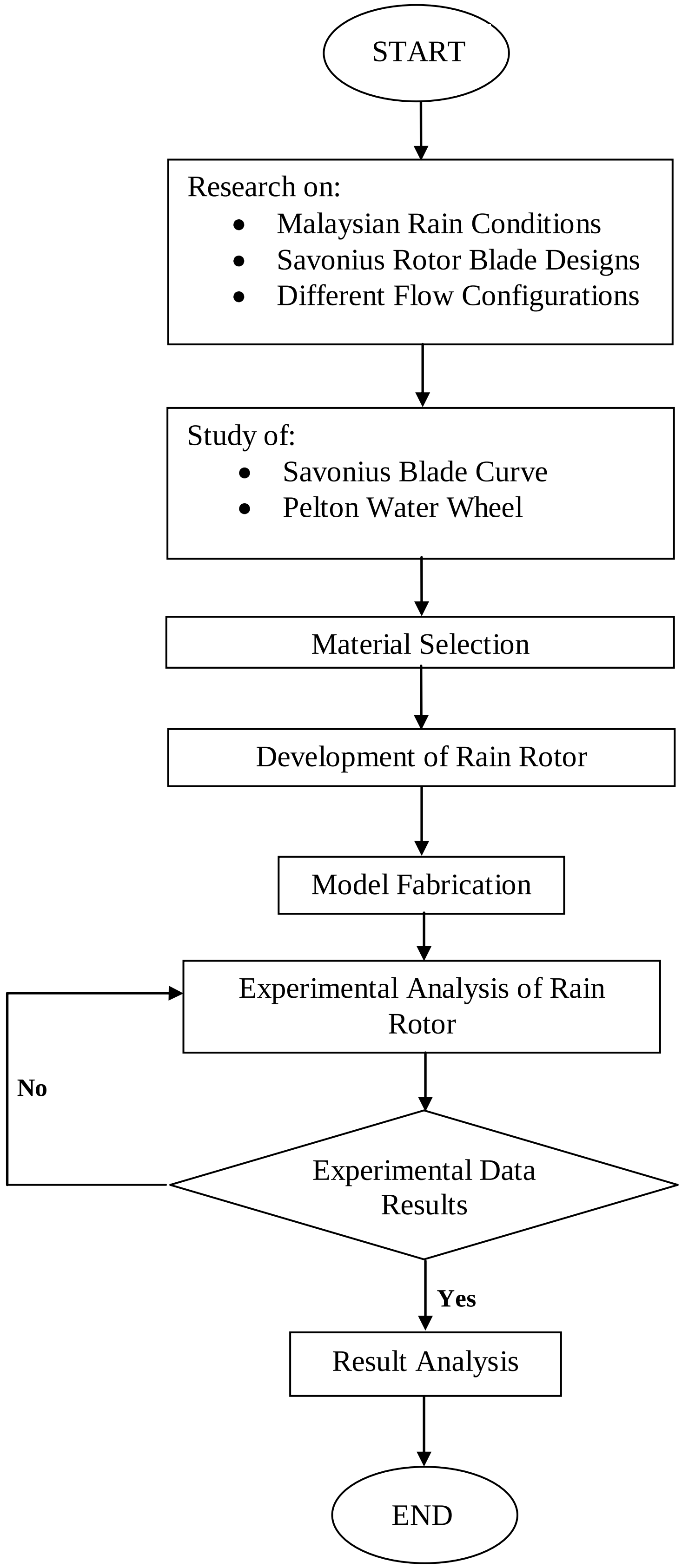
3.3 Experimental Model Preparation

Based on prior research, analytical calculations and design drawing, an experimental model of the rain rotor will be fabricated. This experimental model would be used to determine the actual performance of the turbine.

3.4 Analysis of Results

From the experimental analysis, the rotational speed, torque, power and coefficients of torque and power can be determined. This would provide the performance data of the turbine when in operation.

3.5 Work Flow Chart



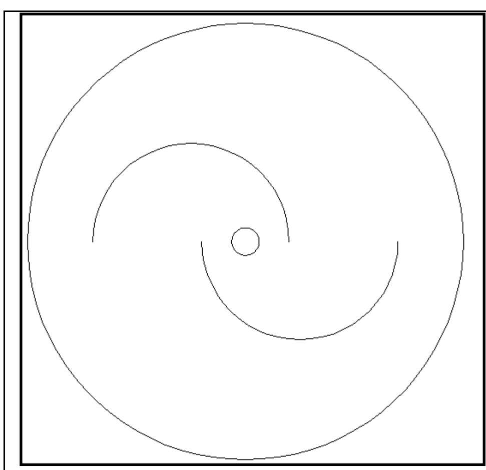
CHAPTER 4

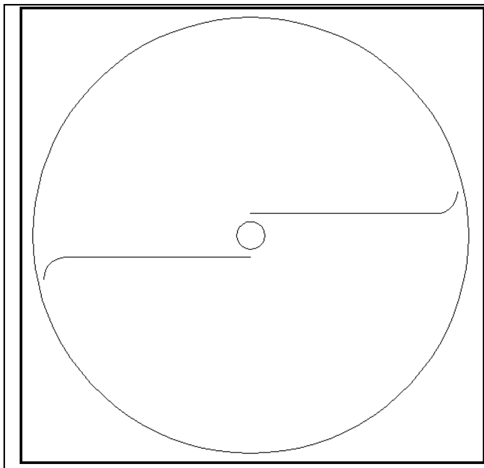
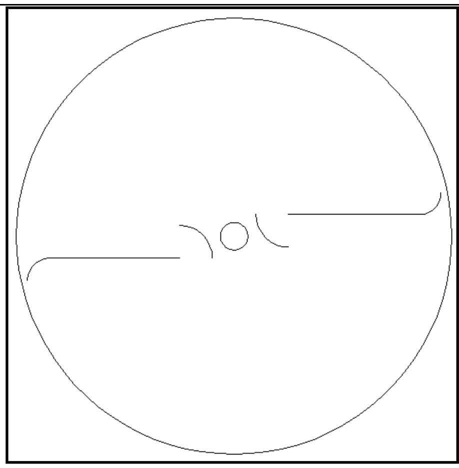
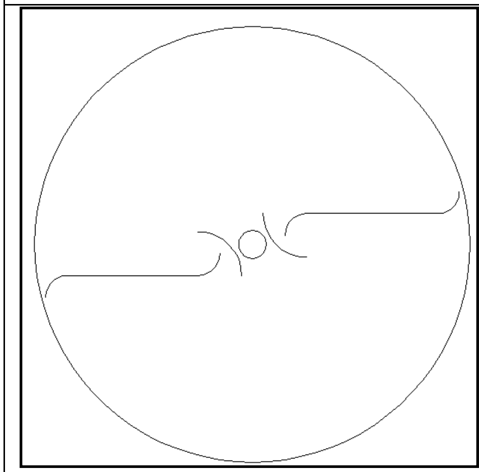
RAIN ROTOR DEVELOPMENT

The design criteria for the rain wheel prototype will consider the blade configuration, choice of geometry, and material selection.

4.1 Blade Configuration

This rain rotor design is based on the conventional Savonius rotor design. However, since the conventional design has been modified to suit this application. The design of the blades was modified and the modification was a step – by – step process to achieve the final design. The final design is believed to be the most suitable design that would capture the most amount of rainwater per unit blade area to achieve greater performance.

	<u>Configuration 1</u> • Conventional Savonius rotor design. • 2 half – cylinders form the shape of an "S".

	Configuration 2 • A straight blade followed by a 90 degree tip curvature.
	Configuration 3 • The straight section of the blade (outer blade) has been shortened. • Curvature at tip is maintained. • A 90 degree curved blade is added at the inner part (inner blade).
	Configuration 4 • The straight section has been shortened even more. • Another curvature (opposite side and direction) has been added to the outer blade. • The inner blade is maintained.

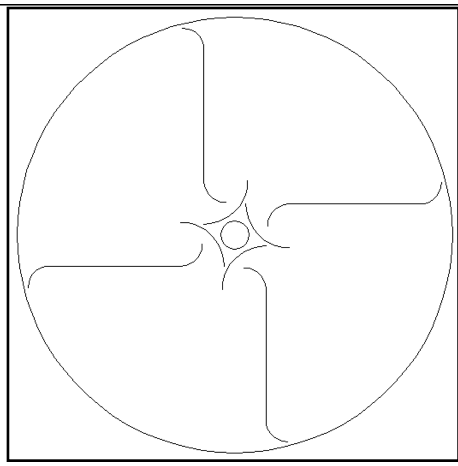
	<u>Configuration 5</u> • Using the design of Configuration 4, another 2 blades are added. • Total number of blades is 4.

Figure 4.1: Step – by – step design development

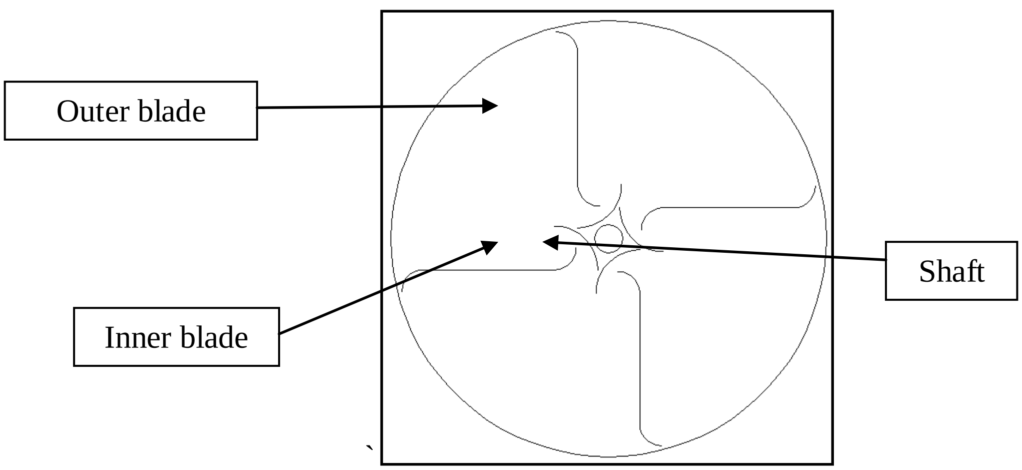


Figure 4.2: Final design

Configuration 5 is the final design for this rain rotor. The outer blades plus the accompanying inner blades are considered as 1 blade unit so the total number of blades is 4. The outer blades are curved at the tip to facilitate rainwater flow from the roof to the blade whereas the curvature at the inner section is to direct the flow to the curved inner blades. The combination of these two blades will give the rain rotor a consistent torque in only one direction.

4.2 Choice of Geometry

Based on the blade configuration in Figure 4.2, all the dimensions for the rain wheel prototype was determined.

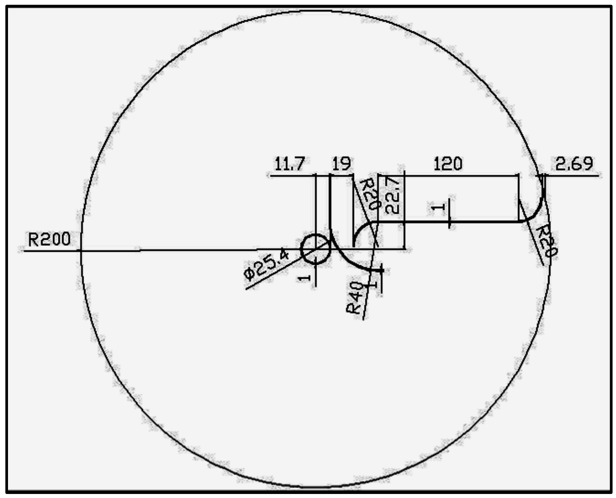


Figure 4.3: Cross section view with dimensions in milimetres (mm)

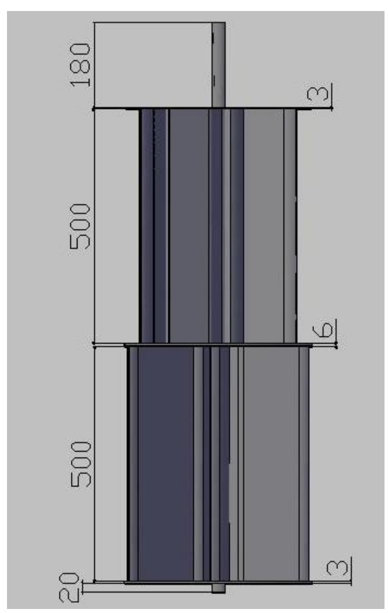
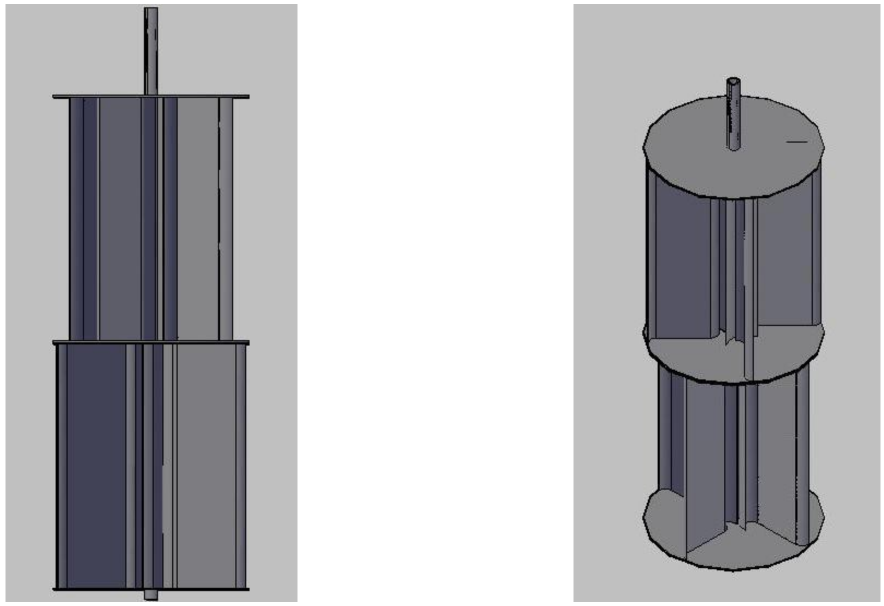


Figure 4.4: Front view with dimensions in milimetres (mm)



(a) (b)

Figure 4.5: 3D view of final design (a) Front view, (b) Isometric view

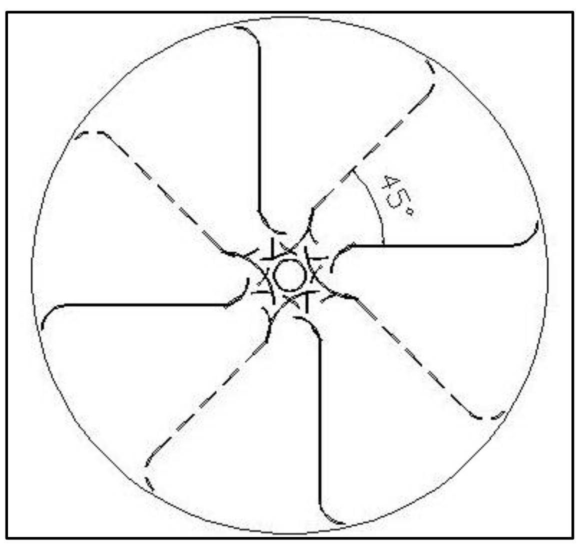


Figure 4.6: View from the end – plate

As seen in Figure 4.5 and Figure 4.6, one unit of the rain rotor consists of two sections. Each section has 4 blades, 45 degrees offset.

4.3 Material Selection

The choice of material is an important part of the design process. After the suitable materials have been selected then the fabrication process can begin. The materials to be used would be based on several design criteria such as resistance to corrosion, resistance to wear, cost and several other factors. Parts of the rain rotor to be considered in this material selection process would be the end – plates, turbine blades and shaft.

Table 4.1: Material selection criteria

Criteria	**Description**
Corrosion resistance	The working fluid for this rotor is rainwater. Rainwater plus oxygen in the air would contribute to corrosion of ferrous materials. Therefore, the materials used must be resistant to corrosion.
Wear resistance	The rain rotor would be placed outdoors and thus being constantly subjected to the elements. It would have to withstand the conditions brought by the rain and sun for many years.
Lightweight	The material used has to be lightweight. This would enable the rain rotor to be large in size relative to its weight. Less amount of torque is needed to rotate the rotor.
Cost	Being low in terms of cost would be a major advantage. Low material costs would decrease the cost price per unit and if mass production in applied, the unit cost price could be further reduced.
Ease of machinability	Materials that are easy to be machined using conventional

	and common machining tools would reduce the manufacturing cost. Time to produce each unit would also be faster.

Based on the material selection criteria in Table 4.1, a few materials have been selected. The type of materials and their application to the rain rotor arrangement is summarized below.

Table 4.2: Selected materials

Part	Material and Specifications
End – plates	Perspex • Thickness: 3 mm
Rotor blades	Aluminum • Thickness: 1 mm
Shaft	Hollow Aluminum Pipe • Diameter: 1.0 in. (25.4 mm)
Water Tank	Perspex • Thickness: 3 mm
Stand	Iron with water resistant coating

CHAPTER 5

ANALYTICAL MODEL

Related equations such as the Bernoulli's Equation and water power equation are used to determine the theoretical parameters. The theoretical jet velocity, torque, rotation speed and the water power can be calculated. A vector analysis is also conducted to show that a curved blade is better than a straight blade based on the exit velocity.

5.1 Calculations to Determine Water Power

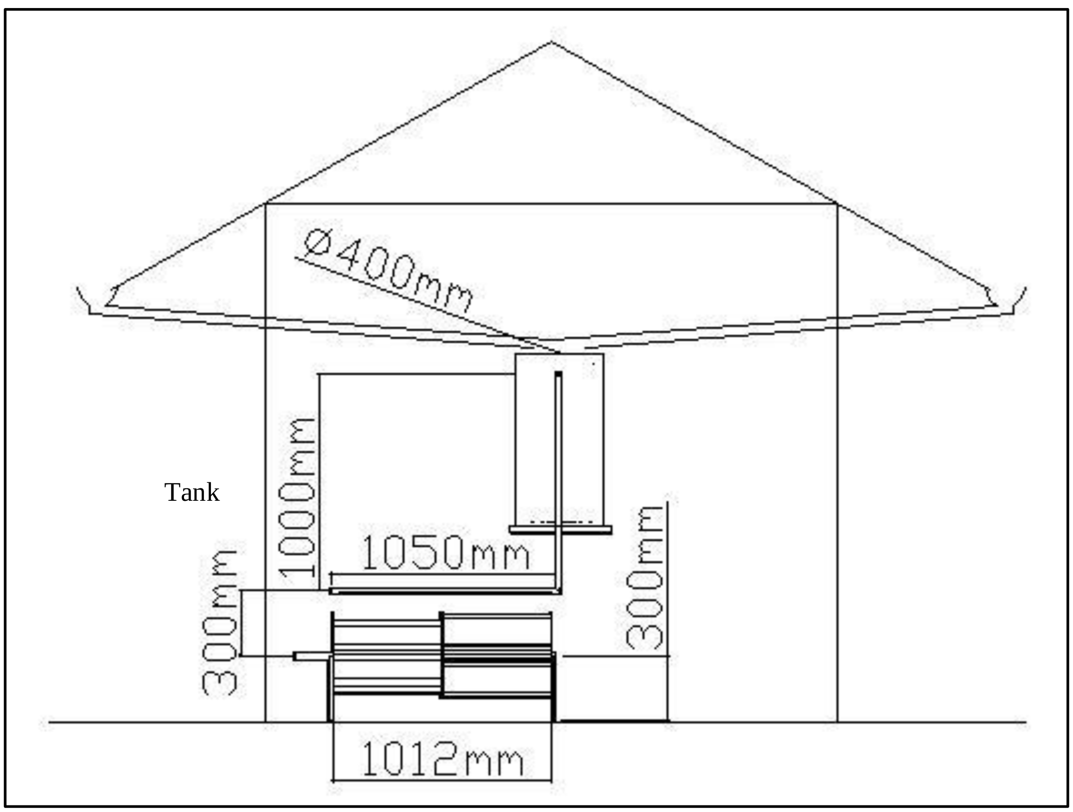


Figure 5.1: Tank and rain rotor arrangement (units in milimetres)

5.1.1 In Tank

By Bernoulli's Equation:

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2$$

$$\frac{V_2^2}{2} = g \cdot \Delta z \longrightarrow \Delta z = 0.7m$$

$$V_2 = V_j = \sqrt{2 \cdot g \cdot \Delta z}$$

$$= \sqrt{2(9.81)(0.7)}$$

= 3.706 m/s

5.1.2 Water Power, P_w

$$P_w = \rho_w \cdot g \cdot Q_w \cdot H_1$$

$$= \rho_w \cdot g \cdot A_j \cdot V_j \cdot H_1 \qquad \textbf{(1)}$$

$$P_w = T \cdot \omega$$

$$= F \cdot r \cdot \omega$$

$$= \dot{m} \cdot \Delta V \cdot r \cdot \omega$$

$$= \rho_w \cdot A_j \cdot V_r \cdot V_r \cdot r \cdot \omega$$

Where $\Delta V = V_r = V_j - V_{vane}$
For optimum performance, $V_{vane} = 0.46V_j$
Thus, $\Delta V = V_r = V_j - 0.46V_j = 0.54V_j$

So $P_w = \rho_w \cdot A_j \cdot (0.54V_j)^2 \cdot r \cdot \omega$ **(2)**

Set **(2) = (1):**

$$\rho_w \cdot A_j \cdot (0.54V_j)^2 \cdot r \cdot \omega = \rho_w \cdot g \cdot A_j \cdot V_j \cdot H_1$$

$$\omega = \frac{g \cdot H_1}{(0.54)^2 \cdot V_j \cdot r}$$

$$= \frac{9.81(1.0)}{(0.54)^2(3.706)(0.18)}$$

= 50.43 rad/s

5.1.3 Rotation Velocity, V_{rot}

Take r_{in} = 0.18 m

r_{out} = 0.05 m

$$V_{rot} = \omega \cdot r$$

$$V_{rot.in} = \omega \cdot r_{in} = 50.43(0.18) = 9.077\ m/s$$

$$V_{rot.out} = \omega \cdot r_{out} = 50.43(0.05) = 2.522\ m/s$$

From **(2)**

$$T = \rho_w \cdot A_j \cdot (0.54V_j)^2 \cdot r$$

$$= 1000\ kg/m^3 \cdot (0.004 \cdot 0.94)m^2 \cdot (0.54 \cdot 3.706)^2\ m^2/s^2 \cdot 0.18m$$

$$= 2.7106\ N \cdot m$$

5.1.4 Theoretical Power

$$P_w = T \cdot \omega$$

$$= 2.7106\ N \cdot m\ \cdot 50.43\ \text{rad/s}$$

$$= 136.70\ W$$

Taking the efficiency to be 0.80,

$$P_w = 136.70\ \cdot 0.80$$

= 109 W

5.2 Vector Analysis

5.2.1 Without Curved Root

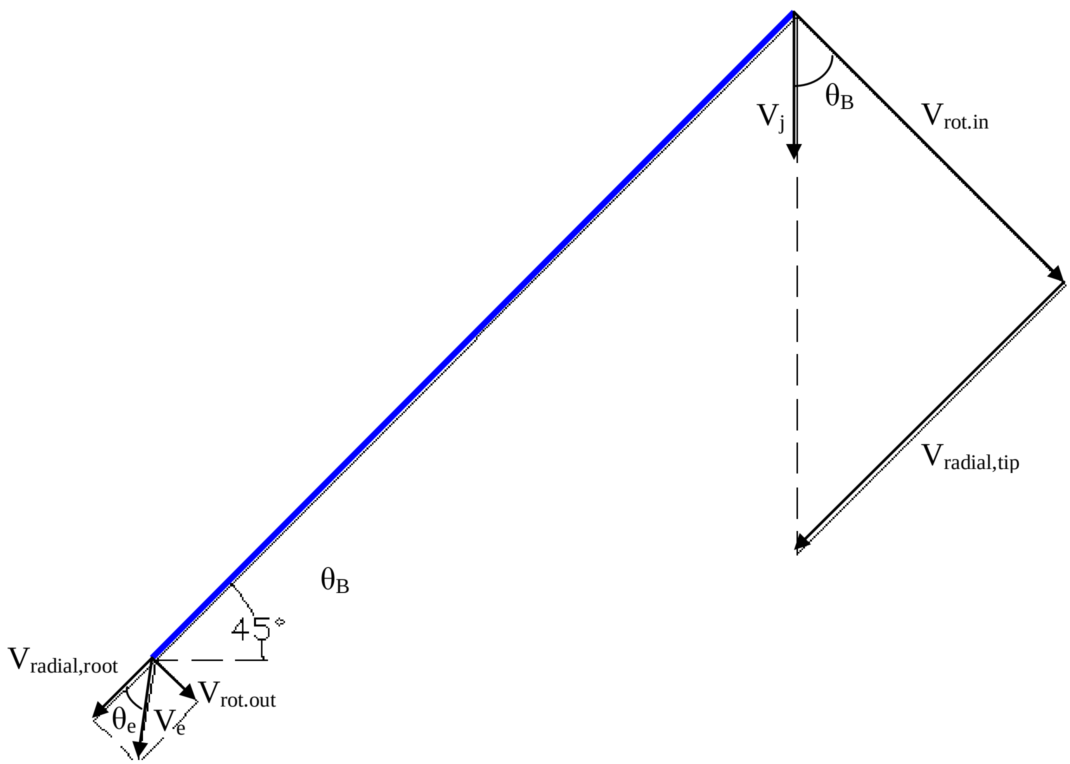


Figure 5.2: Rotor blade without curved root

Vj	= Velocity of jet	= 3.706 m/s
ω	= Angular velocity	= 50.43 rad/s
$V_{rot.in}$	= Rotation velocity (in)	= 9.077 m/s
$V_{rot.out}$	= Rotation velocity (out)	= 2.522 m/s
θ_B	= Angle of rotor blade	
V_e	= Exit velocity	
θ_e	= Exit angle	

$$V_{radial,tip} = V_{rot.in} \tan \theta_B$$

$$V_{radial,root} = 0.9\ V_{radial,tip}$$

$$V_e = \sqrt{V_{radial,root}^2 + V_{rot.out}^2}$$

$\theta_e \qquad = tan^{-1}(\frac{V_{rot.out}}{V_{radial,root}})$

Table 5.1: Exit velocity for various angles (without curved root)

θ_B (degrees)	$V_{radial,tip}$ (m/s)	$V_{radial,root}$ (m/s)	V_e (m/s)	θ_e(degrees)
45	9.077	8.169	8.550	17.15
40	7.617	6.855	7.304	20.18
30	5.241	4.717	5.348	28.02
20	3.304	2.973	3.899	39.54
10	1.601	1.440	2.904	53.94
0	0	0	0	0

5.2.2 With Curved Root

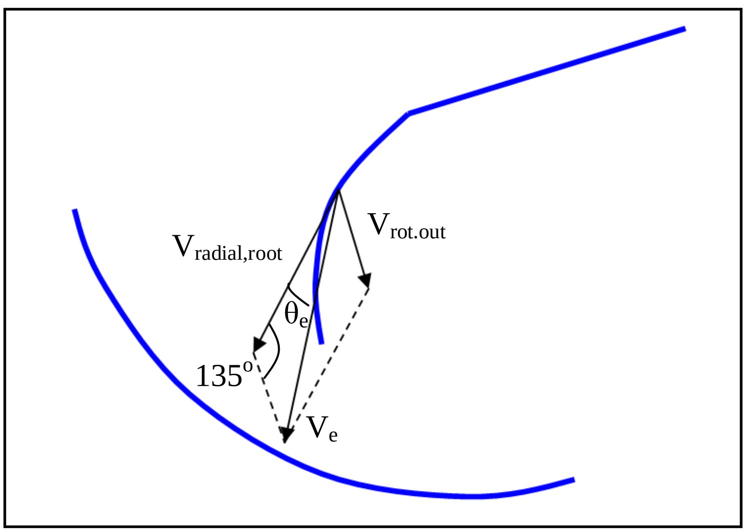


Figure 5.3: Rotor blade with curved root

$$V_e \qquad = \sqrt{V_{radial,root}^2 + V_{rot.out}^2 - 2V_{radial,root}V_{rot.out}\cos 135^o}$$

$$\theta_e \qquad = \sin^{-1}(\frac{V_{rot.out}}{V_e}\sin 135^o)$$

Table 5.2: Exit velocity for various angles (with curved root)

θ_B (degrees)	$V_{radial,tip}$ (m/s)	$V_{radial,root}$ (m/s)	V_e (m/s)	θ_e(degrees)
45	9.077	8.169	10.11	10.158
40	7.617	6.855	8.82	11.663
30	5.241	4.717	6.740	15.34
20	3.304	2.973	5.080	20.53
10	1.601	1.440	3.684	28.83
0	0.000	0.000	2.522	43.98

From the comparison as seen in Table 5.1 and 5.2 of the exit velocity (V_e), the rotor with the curved root gives a higher exit velocity.

CHAPTER 6

RESULT AND DISCUSSION

6.1 Analysis of Result

The experiment has been conducted under normal conditions at room temperature and atmospheric pressure. Tap water was used to fill the tank to simulate the accumulated rainwater for the purpose of experimentation. The findings of the rain rotor performance are presented. The result, test variables and test calculations are shown below.

- Diameter, D = 0.36 m
- Height, H = 1.0 m
- Area, A = D*H = 0.36 m^2
- Water flow rate, Q = 5.88133x10-4 m^3/s
- Jet velocity, V_j = 0.34596 m/s
- Rotational speed (RPM) was measured using a digital tachometer
- Torque (T) was measured using a digital torque meter
- Torque coefficient, C_T is evaluated by the formula $C_T = T / [{}^1/_2 * \rho * V_j^2 * A * ({}^D/_2)]$
- Tip speed ratio (TSR), λ, is evaluated by the formula $\lambda = \omega D / 2V_j$
- Power coefficient C_p is evaluated from $C_p = \lambda\ C_T$

Table 6.1: Rotational speed and torque at different water levels

Water Level (m)	Rotational speed (RPM)	Torque (N.m)	Power(W)
0.7	94	0.284	2.7956
0.6	147	0.267	4.1101
0.5	173	0.243	4.4023
0.4	173	0.245	4.4385
0.3	172	0.233	4.1967
0.2	172	0.211	3.8005

From Table 6.1, the RPM reading at water level 0.7m was low (94 RPM) and then it suddenly increased to a value of 147 RPM. The reason for this low RPM reading initially is because the rotor has only just started to rotate. This condition is referred to as the starting condition where the RPM starts at a low value before gradually increasing and then starts to stabilize at 173 RPM. As the amount of water decreases, the RPM also decreases slightly.

Table 6.2: Value of torque coefficient, tip speed ratio and power coefficient at different water levels

Water Level (m)	Torque coefficient, C_T	Tip speed ratio (TSR), λ	Power coefficient C_p
0.7	0.0732	5.1216	0.3751
0.6	0.0689	8.0093	0.5515
0.5	0.0627	9.4259	0.5907
0.4	0.0632	9.4259	0.5955
0.3	0.0601	9.3714	0.5631
0.2	0.0544	9.3714	0.5099

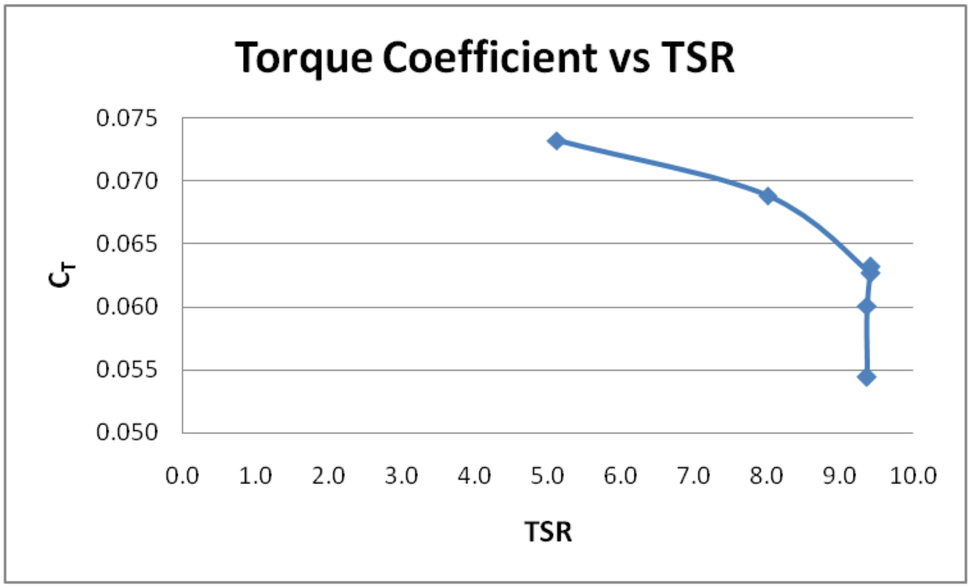


Figure 6.1: The torque coefficient versus tip speed ratio

Figure 6.1 shows that torque coefficient decreases as the TSR increases. The reason for this is because of the decreasing value in torque as the water level decreases. The maximum torque coefficient occurs at TSR of 5.1216.

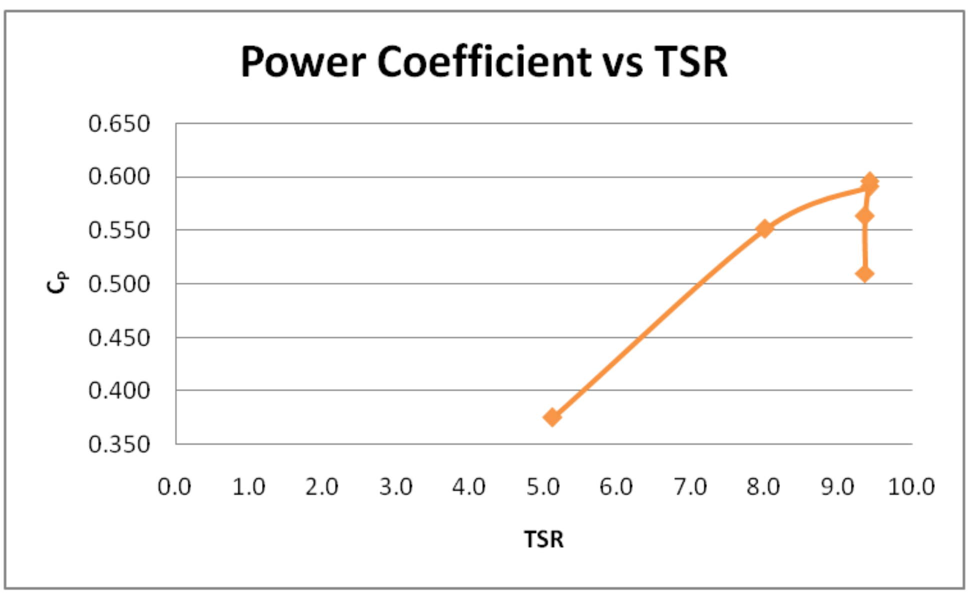


Figure 6.2: The power coefficient versus tip speed ratio

Figure 6.2 shows that the power coefficient increases with TSR at the beginning, and then it decreases. This is due to the rotational speed which increases, remain constant then decrease in value. The maximum power coefficient occurs at TSR of 9.4259.

There are a few factors which influence the results that were obtained. Different pressure distribution along the length of the pipe gap causes the water to flow more at one end only instead of a uniform water sheet. A non – uniform water sheet will strike the rain rotor more at one section which does not fully utilize the whole rain rotor. A lot of kinetic energy is lost here. The amount of water that strikes the rotor produces only a small amount of torque. By increasing the gap size at the pipe, more volume of water will strike the rotor thus creating a higher torque. Another factor is due to the wind which blew on the rain rotor. The wind will cause the rain rotor to spin in the opposite or same direction and this will affect the RPM readings of the rotor.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The modifications added to the conventional Savonius rotor will enable it to rotate in one direction only. This is achieved as rainwater flows inward from the outer blades towards the inner blades, which will then direct the flow away from the shaft. Any problem of reverse rotation can be avoided. The approach taken along this project will ensure that the design is fully functional for the experimentation process. From the experimental analysis, the maximum amount of power that can be produced is 4.44 W.

7.2 Recommendations

A few recommendations have been proposed to improve the results obtained from the experimental analysis and to increase the performance of the rain rotor.

The use of an overhead water tank with a gap at the base of the tank is recommended. This is to replace the current configuration of using pipes connected to the base of the tank to discharge the water. Direct water discharge from the tank to the rain rotor would enable a uniform sheet of water to strike the rain rotor blades, thus fully utilizing the whole rotor area. Friction loses could also be reduced due to the elimination of the pipes and pipe fittings. The tank can also be designed to hold larger volumes of water and installed at a higher position above the rain rotor to give it more head. However, if the pipes are to be maintained, instead of a long gap, holes can be made along the pipe with decreasing diameter to produce a more uniform water sheet.

For the purpose of experimental analysis, it is recommended that the flow be made steady before measurements (RPM and torque) are taken. This will be done by having a continuous supply of water into the tank as the measurements are being taken.

Since the rain rotor is affected by the wind, the rotor is recommended to be placed in a closed enclosure with an opening at the top for the water to flow into. This can help reduce the affect of wind to the performance of the rotor.

REFERENCES

[1] Ellias Saidin, 2008, "Review of Rainwater Harvesting," *The Ingenieur,* Vol.40

[2] Romain Guigon, Jean-Jacques Chaillout, Thomas Jager and Ghislain Despesse, 2008. *Harvesting raindrop energy: experimental study*. Smart Mater. Struct. 17 015039. CEA-LETI-MINATEC, France.

[3] C.K Tang, March 2005, "Energy Efficiency in Residential Sector,"< http:// www. eib.ptm.org.my>

[4] Savonius Wind Turbines, <http://www.reuk.co.uk/Savonius-Wind-Turbines.htm>

[5] Sargolzaei J. 2007. *Prediction of the power ratio and torque in wind turbine Savonius rotors using artificial neural networks*. WSEAS International Conference on Renewable Energy Sources, Arcachon, France, October 14-16, 2007. Ferdowsi university of Mashhad, Iran.

[6] Lance Turner, *Making a simple Savonius wind turbine*. <http://www.macarthurmusic.com/johnkwilson/MakingasimpleSavoniuswindturbine.htm>

[7] <http://www.kjc.gov.my/english/publication/mwb.html>, January 2009.

[8] Yunus A. Cengel and John M. Cimbala, 2006, *Fluid Mechanics – Fundamentals and Applications,* Mc. Graw Hill

[9] SeaSteading-Homesteading the High Seas: Wind Power, <http://gramlich.net/projects/oceania/seastead1.html >

[10] A Homemade Water Pumping Wind Turbine, <http://www.icestuff.com/~energy21/savonius2.htm >

[11] Md. Nahidul Islam Khan, M. Tariq Iqbal, Michael Hinchey, and Vlastimil Masek. *Performance of savonius rotor as a water current turbine.* Memorial University, Canada.

[12] V.J. MODI, N.J. ROTH and M.S.U.K. FERNANDO, 1983, "Optimum-configuration studies and prototype design of a wind-energy-operated irrigation system," *Journal of Wind Engineering and Industrial Aerodynamics* 16 (1984) 85-96

APPENDIX A

Gantt Chart (Final Year Project I)

No.	Activity	Week 1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Selection of Project Topic	■	■								MID SEMESTER BREAK					
2	Allocation of Project Topic to Student		■													
3	Research on Rain Conditions in Malaysia		■	■	■											
4	Research on Water Turbines			■	■	■										
5	Research on Savonius Wind Turbines				■	■	■									
6	Research on Rain Power Utilization					■	■	■								
7	Submission of Preliminary Report (First Draft)				■											
8	Submission of Preliminary Report				■											
9	Design of Rain Rotor							■	■	■						
10	Submission of Progress Report								■							
11	Seminar 1								■							
12	Design of Rain Rotor (Continued)											■	■	■		
13	Submission of Interim Report														■	
14	Oral Presentation															■

■ Completed Tasks

APPENDIX B

Gantt Chart (Final Year Project II)

No.	Activity	Week 1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Material Selection										MID SEMESTER BREAK					
2	Analytical Calculations for Water Power															
3	Submission of Progress Report 1															
4	Vector Analysis of Rotor Blade															
5	Submission of Progress Report 2															
6	Seminar															
7	Poster Preparation															
8	Submission of Poster															
9	Experimental Analysis															
10	Engineering Design Exhibition															
11	Experimental Analysis (continued)															
12	Submission of Dissertation (final draft)															
13	Oral Presentation															
14	Submission of Dissertation (hard bound)															

Completed Tasks

APPENDIX C

Rain Prototype Pictures

Rain Rotor

Water Tank

Prototype Arrangement

Prototype Arrangement

Water Stream