CERTIFICATION OF APPROVAL

Modification and Evaluation of Water Turbine for Power Generation

by

Dayang Fittri Noorkhairunnisa

9478

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(AP Dr. Hussain Al-Kayiem)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

November 2010

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.

____

DAYANG FITTRI NOORKHAIRUNNISA

ABSTRACT

Due to falling of the fossil-based fuel, renewable energy becomes one of the most important sources of energy. Yet the demand is still low but expected in the future, the demand will be increase. With the advantage of new technology and expertise, the renewable energy field is expanding. The targets for renewable energy field are more than beyond fossil-based fuel due to unlimited sources. This paper describes the study taken to determine the 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 rotor. The rotor is specifically designed for this application and is a modified version of the Savonius wind rotor. This device can be used to generate small scale of electricity. This report is divided into 6 chapters. First chapter describes on the introduction of the project that will cover the project background, problem statements, significance of the project, objectives and scope of studies. Second chapter focuses on the literature review. These include the latest energy extraction from raindrops, rainwater harvesting systems in Malaysia, rainwater distribution in Malaysia, household electricity consumption and also Savonius rotor. This followed by the third chapter, methodology which elaborates on how the project is carried out, the planning involved, milestones and also tools needed for the project. Later, fourth chapter explains on the project development which in this case on how selection of the rotor geometry, materials, fabrication is being done. Outcomes of the experiment are described in the fifth chapter while sixth chapter covers the conclusion and recommendations to improve the rotor for future studies. The 2 sections onwards are references and ended with appendices.

ACKNOWLEDGEMENT

First and foremost, alhamdulillah to Almighty Allah, who grants me to complete this project within the given time frame. I would like to express my greatest appreciation to my supervisor, Dr. Hussain Al-Kayiem for his guidance and support throughout this project. I am deeply grateful for his advice, encouragement and patience throughout the period. I have very much benefited from his professional and personal advices in making this project successful.

Secondly, I would like to thank the Department of Mechanical Engineering of UTP especially all the lab's technicians for their assistance from the beginning until the completion of the project. The thanks extend to my fellow colleagues for their helping hand and willingness to help me to do the lab works, for their jokes in the happy times that make this project become easier and valuable.

To all individuals who helped me in any way but whose names are not mentioned here, I sincerely thank you all for the endless support, guidance and patience. I hope all the things that I learned here will be useful in my education and life in the future at large.

Last but not least, sincere appreciation to my beloved family for their moral support in completing my project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Renewable energy is clean and less or minimizes the pollution and environment effect due to non-toxic characteristics. One of the latest energy harvesting techniques is converting the mechanical energy from falling raindrops into electricity that can be used to power sensors and other electronics devices. This project focuses on the small generating electricity through the falling raindrops which is rain. To uncover the available sources in Malaysia, research is conducted to signify whether the rain capture in Malaysia is significant in proceeding with the project.

The advantage of this project is that it can help contribute to overcome the drawbacks of depleting of fossil-based fuel. Rain power is a renewable energy source which can be developed and improved to extract the energy and help supporting the energy demand. This project mainly for small scale electric power generation based on the flowing of the rainwater, which can be installed in the house area to generate electricity and run few house equipments.

However, in the application of generating electricity from rain, the available head and flow rate is too low for usage of Pelton, Francis, Kaplan or other types of hydraulic turbomachine. This study focus on the performance of the modified Savonius rotor that mounted in a horizontal position in extracting energy from falling raindrops. In other words, stream of rainwater will be the working fluid. Further developments and modifications were made to the rain rotor design to suit the rain application. Development of this project can be used to complement other electricity generating systems.

1.2 PROBLEM STATEMENT

As the world is becoming more advanced in technology, more energy is being used to keep up with the changing requirements. At the current rate at which energy is being used, the world will shortly come to an end of fossil fuels, the primary energy resource. Fossil fuels provide around 66% of the world's electrical power, and 95% of the world's total energy demands including (heating, transport, electricity generation and other uses). Coal provides around 28% of energy, oil provides 40% and natural gases provide about 20% [1]. A concern is that the fossil fuels are being used up at an increasing rate, and that they will soon run out. If these fossil fuels were to run out now there would not be a suitable replacement for them that is equally as efficient at producing the same amount of energy. The world use of fossil fuels has nearly doubled every 20 years since 1900. This is a particular problem for oil because it is also used to make plastics and many other products and soon there will be no longer enough oil to continuously meet the demands for it.

Renewable energy is any source of energy that can be used without depleting its reserves. The targets for renewable energy field are more than beyond fossil-based fuel due to unlimited sources. One of the most important reasons is to overcome global warming issue and also green house effect due to fossil-based fuel in use. Renewable energy is clean and less or minimizes the pollution and environment effect due to non-toxic characteristics.

The target for this project is to be used to complement other electricity generating systems. This study focus on the performance of the modified rotor that mounted in a horizontal position in extracting energy from harvested falling raindrops. Further developments and modifications were made to the rain rotor design to suit the rain application.

1.3 SIGNIFICANCE OF PROJECT

The advantage of this project is that it can help contribute to overcome the drawbacks listed. Considering the context in which to examine renewable energy sources, it is the priority to fairly consider the ways in which energy is used and the scale of its use, looking at the various problems associated with the current use of fossil and nuclear fuel, their effects on the environment problems of sustainability and social problems. Rain power is a renewable energy source which can be developed and improved to extract the energy and help supporting the energy demand. This project mainly for small scale electric power generation based on the flowing of the rainwater, which can be installed in the house area to generate electricity and run few house equipments.

1.4 OBJECTIVE

The objectives of this project are to:

- Redesign and modify the water turbine to suit rain application.
- Fabricate the modified water turbine.
- To conduct detailed measurement to evaluate the performance of the turbine.
- Test the performance of the water turbine in generating power from rainwater.

1.5 SCOPE OF WORK

The project will cover the characteristics of Malaysia's weather focusing only on the rain conditions, these would include the obtaining information on the annual rainfall rate and distribution in Malaysia.

The scope of the studies is the limited resources of fossil fuel as the main energy source and the importance of renewable energy generation such as rain powered generator with a modified water turbine. Current energy extraction techniques from rain would also be studied. Also, mathematical calculation in terms of testing the performance of this rainwater energy extracting by water turbine included.

The analytical method would be based on the results given while the numerical method would be based on formulas formulated with alterations according to on-site conditions. The fabricated rain rotor arrangement would be placed outdoors. It will be installed and connect to stream of flowing water to simulate the continuous rain supply.

CHAPTER 2

LITERATURE REVIEW

2.1 HARVESTING RAINDROP ENERGY

Scientists from CEA/Leti-Minatec, an R&D institute in Grenoble, France, have recently developed a system that recovers the vibration energy from a piezoelectric structure impacted by a falling raindrop [2]. The system works with raindrops ranging in diameter from 1 to 5 mm, and simulations show that it's possible to recover up to 12 milliwatts from one of the larger "downpour" drops.

They believe that the physics of how a raindrop impacts a surface is not fully understood. However, to build a rain energy harvesting system, the important part is to estimate the recoverable energy during the impact. When a raindrop impacts a surface, it produces a perfectly inelastic shock. The amount of energy generated by the impact can then be estimated using a mechanical-electric model.

To capture the raindrops' mechanical energy, the scientists used a piezoelectric material that converts mechanical energy into electrical energy. Piezoelectricity is the ability of some materials (notably crystals and certain ceramics, including bone) to generate an electric field or electric potential in response to applied mechanical stress [3]. The effect is closely related to a change of polarization density within the material's volume. If the material is not short-circuited, the applied stress induces a voltage across the material.

When a raindrop impacts the 25-micrometer-thick the material, the polymer starts to vibrate. Electrodes embedded in the material are used to recover the electrical charges generated by the vibrations. The group experimented with raindrops of different sizes, falling heights, and speeds. They found that slow falling raindrops generate the most energy because raindrops falling at high speeds often lose some energy due to splash.

Figure 2.1: Piezoelectric band structure at the bottom [2]

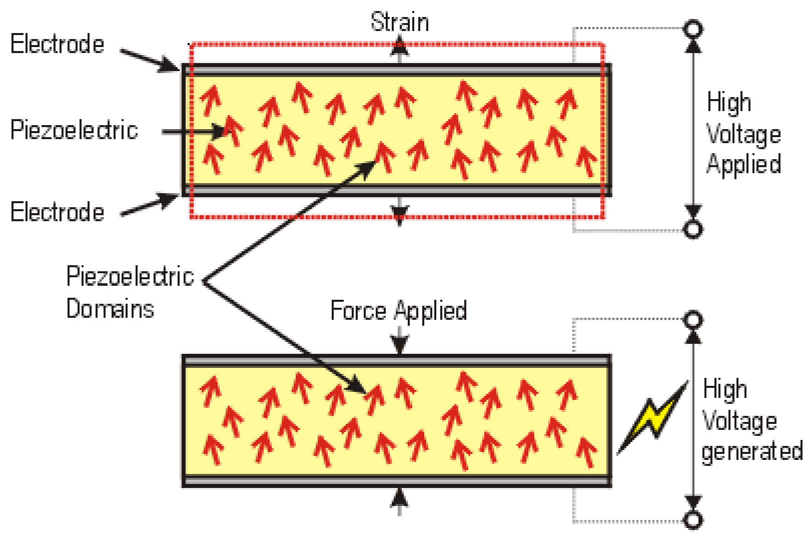


Figure 2.2: Illustration of working principle of piezoelectric material

2.2 RAINWATER HARVESTING

Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, the land surface or rock catchments. Commonly used system are constructed of three components that is catchments area, collection device and conveyance system.

The Malaysian government has recognized that rainwater harvesting contribute toward National Water Conservation Policy [4]. It has made a commitment to revise the guidelines for installing a Rainwater Collection and Utilization System in the Ninth Malaysian Plan within a period of 2006 – 2010. Encouragement from the government through various means of awareness program and incentive has increased the number of rainwater harvesting system in various building types.

In the present study, a rainwater harvesting system was installed in the faculty of engineering, University Putra Malaysia, Malaysia [5]. The system is composed of the catchment (roof), gutter, pipe, steel tank and treatment unit. The catchment area is $150m^2$. From 20 different rain events, the collected volume of the rainwater from different events ranges between $0.17m^3$ and $2m^3$. The daily water consumption is monitored for one month and compared with the collected rainwater volume. The volume of collected rainwater is found to be adequate to meet the non-potable uses. In a tropical country like Malaysia it is easy to collect $2m^3$ in a single rain while $10m^3$ are collected annually in Zambia, Africa from a roof of almost of the same size.

The study has been done to determine urban runoff at study area and analysis the effectiveness of rainwater harvesting system at residential area in controlling urban surface runoff [6]. The study area is a residential area located in the upstream part of Sungai Klang river basin called Taman Wangsa Melawati. The surface runoff must be controlled from upstream to avoid flood at downstream. National Hydraulic Research Institute of Malaysia (NAHRIM) does the research for one unit double storey house at this area. There are 242 units the double storey house in this area. The roof area for one unit double storey house is $60m^2$. The data collection from this study is rainfall data (13 August 2007 - 1 October 2007) and water level data (11 August 2007 - 11 October 2007). From this study, percentage reduction of surface runoff is 24.37 % if 242 units double storey house at this area use the rainwater harvesting system. This study proves that rainwater harvesting system is an effective solution to controlling surface runoff in Taman Wangsa Melawati, Kuala Lumpur.

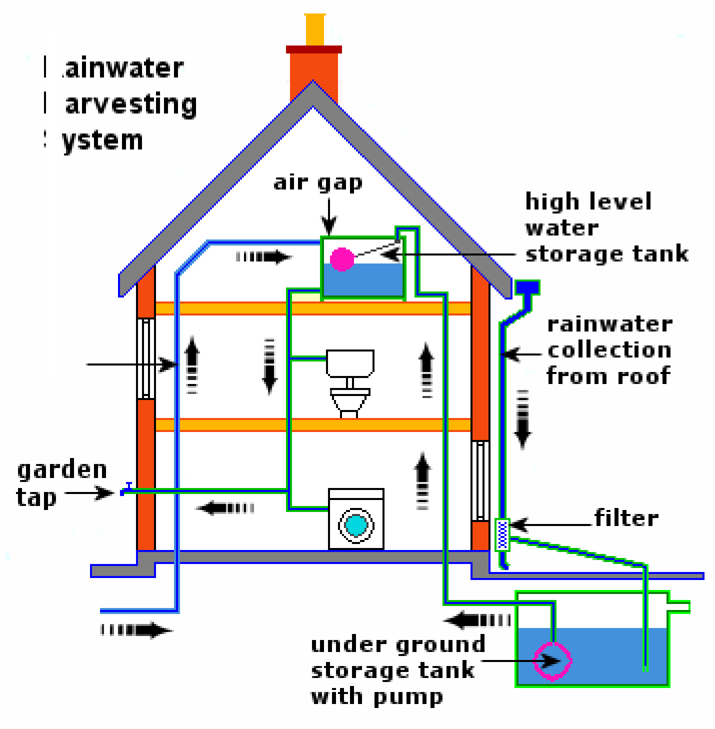


Figure 2.3: Rainwater harvesting system

2.3 RAINWATER DISTRIBUTION

The characteristic features of the climate of Malaysia are uniform temperature, high humidity and numerous rainfalls [7]. During the northeast monsoon season, the exposed areas like the east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah experience heavy rain. On the other hand, inland areas or areas which are sheltered by mountain ranges are relatively free from its influence. It is best to describe the rainfall distribution of the country according to seasons.

2.3.1 Seasonal rainfall variation in Sabah and Sarawak

The seasonal variation of rainfall in Sabah and Sarawak can be divided into five main types:

i) The coastal areas of Sarawak and northeast Sabah experience a rainfall regime of one maximum and one minimum. While the maximum rainfall occurs during January in both areas, the occurrence of the minimum rainfall differs. In the coastal areas of Sarawak, the minimum rainfall occurs in June or July while in the northeast coastal areas of Sabah, it occurs in April. Under this regime, much of the rainfall is received during the northeast monsoon months of December to March. In fact, it accounts for more than half of the annual rainfall received on the western part of Sarawak.

ii) Inland areas of Sarawak generally experience quite evenly distributed annual rainfall. Nevertheless, slightly less rainfall is received during the period June to August which corresponds to the occurrence of prevailing south-westerly winds. It must be pointed out that the highest annual rainfall area in Malaysia may well be at the hill slopes of inland areas.

iii) The northwest coastal areas of Sabah experience a rainfall regime of which two maximum and two minimum can be distinctly identified. The primary maximum occurs in October and the secondary one in June. The primary minimum occurs in February and the secondary one in August. While the difference in the rainfall amounts received during the two months corresponding to the two maximum is small, the amount received during the month of the primary minimum is substantially less than that received during the month of the secondary minimum. In some areas, the difference is as much as four times.

iv) In the central parts of Sabah where the land is hilly and sheltered by mountain ranges, the rainfall received is relatively lower than other regions and is evenly distributed.

v) Southern Sabah has evenly distributed rainfall. The annual rainfall total received is comparable over central part of Sabah. The period February to April is, however slightly drier than the rest of the year.

2.3.2 Seasonal rainfall variation in Peninsular Malaysia

The seasonal variation of rainfall in Peninsular Malaysia is of three main types:

i) Over the east coast states, November, December and January are the months with maximum rainfall, while June and July are the driest months in most districts.

ii) Over the rest of the Peninsula with the exception of the southwest coastal area, the monthly rainfall pattern shows two periods of maximum rainfall separated by two periods of minimum rainfall. The primary maximum generally occurs in October to November while the secondary maximum generally occurs in April to May. Over the north-western region, the primary minimum occurs in January to February with the secondary minimum in June to July while elsewhere the primary minimum occurs in June to July with the secondary minimum in February.

iii) The rainfall pattern over the southwest coastal area is much affected by early morning "Sumatras" from May to August with the result that the double maxima and minima pattern is no longer distinguishable. October and November are the months with maximum rainfalls and February the month with the minimum rainfall. The March - April - May maximum and the June -July minimum rainfalls are absent or indistinct.

Throughout the first decade of October 2009, most places in Peninsular Malaysia recorded normal to above normal rainfall except for most areas in Selangor, Negeri Sembilan, Malacca and some places in west of Pahang that showed much below normal to below normal rainfall [8]. Over east Malaysia, most places experienced above normal rainfall except eastern of Sabah that showed below normal to normal rainfall. However, some places in west of Sarawak showed much above normal rainfall The Map of Rainfall Total (mm) indicates that Peninsular Malaysia together with Sarawak had rainfall of 70 to 200mm, elsewhere in the country shown 10 to 50mm of rainfall amount. However, some places in west of Sarawak had precipitation more than 200mm during this period. The highest total rainfall of 219mm was recorded at Kuching, Sarawak where all 7 days period were raining. On the average, most places in Malaysia recorded 4 and 6 to 8 raindays. In the wet areas 6 to 7 raindays were recorded whereas 1 and 9 raindays were recorded in other areas.

2.4 HOUSEHOLD ELECTRICITY CONSUMPTION

The data that were used were gathered from Centre of 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 [9].

Table 1.1: Cetdem Estimation (2004) of Energy Consumption for a Typical Urban Household [9]

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%
Water Heater	2.7	360	972	5.4	14%
Washing Machine	2.2	540	1188	6.6	17%
Iron	1	180	180	1	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%
Air Conditioner	1	1440	1440	8	21%
Fluorescent Lamps 18w	0.032	288	9.216	0.0512	0%
Fluorescent Lamps 18w	0.192	288	55.296	0.3072	1%
Vacuum Cleaner	0.3	96	28.8	0.16	0%
Total	8.729	17064	6980.1	38.8	

It was interesting to note in the Cetdem survey, that most of the households have similar energy consumption of approximately 6,000-7,000 kWh per year, with the exception of bungalow type household (bungalow have higher energy consumption). The Cetdem surveyed data showed rather similar energy consumption between terrace house and apartment in urban area. Based on the available data, the average household electricity consumption was computed to be approximately 2200 kWh/yr per household in Malaysia.

The following assumptions were then made to correspond income level to availability of a particular electrical appliance in a household. The assumption made in Table 2.2 below was best 'guesstimate' without any available surveyed data to refer to.

Table 2.2: Assumed equivalent of household owning a particular type of electrical appliances. [9]

Electrical Appliances	Assumed Household Monthly Income Level to Own the Appliance (RM)	% of household above the income level (2005)
Refrigerator	Above 2000	62%
Rice Cooker	Above 1000	82%
Water Heater	Above 3000	44%
Washing Machine	Above 3000	44%
Dryer	1% of population	1%
Iron	Above 1000	82%
Fan	Above 1000	82%

Television	Above 1000	82%
Radio	Above 1000	82%
Air-conditioned night-time	Above 4000	28%
Air Conditioner daytime	1% of population	1%
Lighting	Above 1000	82%
Vacuum Cleaner	Above 4000	28%
Computers	Above 3000	44%

The estimate in Table 2.2 seems conservative, however, this assumption would have estimated that the average household consumption in Malaysia to be 3400 kWh/yr instead of 2200 kWh/yr as shown by TNB data. It is 1,200 kWh/yr more than the TNB's average household consumption. A reduction of 35% on the assumption of the percentages of household having the appliance is necessary to calibrate the model to the TNB's average household consumption of 2200 kWh/yr. In short, Table 2.2 has over estimated by 35%.

2.5 SAVONIUS ROTOR

The Savonius rotor has the following advantages over the other conventional wind turbines such as simple and cheap construction, acceptance of wind from any direction thus eliminating the need for reorientation, high starting torque and relatively low operating speed (rpm). The above advantages may not outweigh its low efficiency and make it an ideal economical source to meet small scale power requirements, especially in the rural parts of developing countries. The concept of the Savonius rotor was based on the principle developed by the German aircraft engineer Anton Flettner in the 1920s [10]. Savonius used a rotor which was formed by cutting the Flettner cylinder into two halves along the central plane and then moving the two semi cylindrical surfaces sideways along the cutting plane so that the cross-section resembled the letter "S."

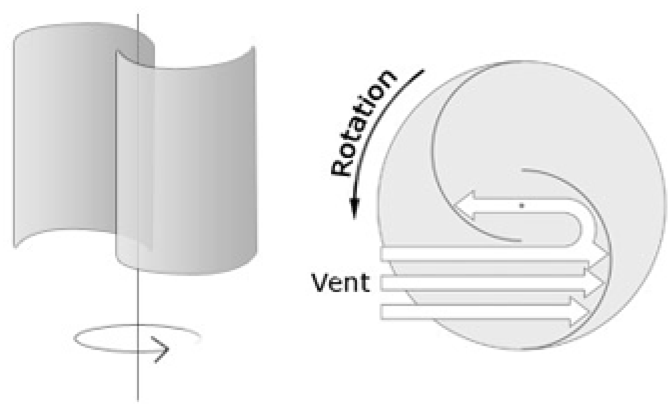


Figure 2.4: Savonius rotor

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

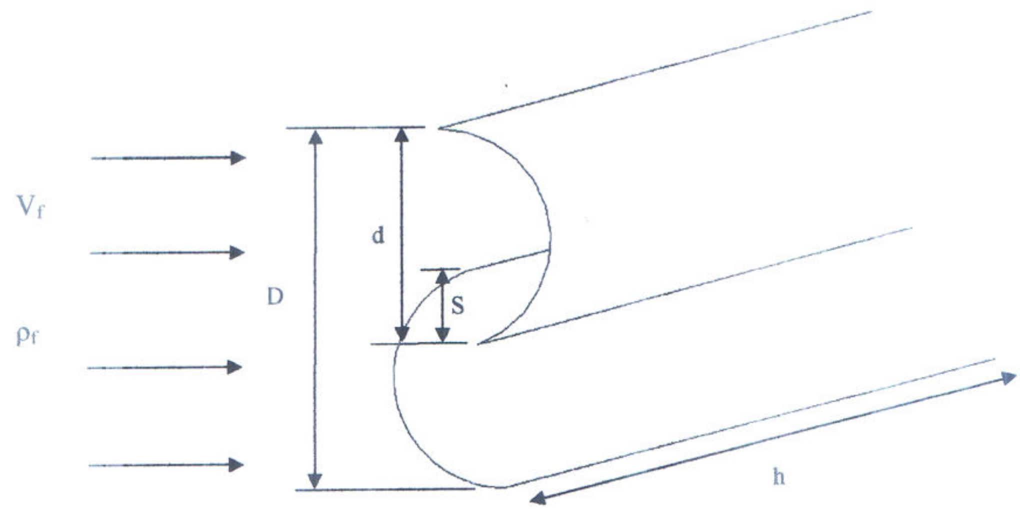


Figure 2.5: Geometry of savonius rotor

CHAPTER 3

METHODOLOGY

This Final Year Project is experimental study conducted in the laboratory. The methodology structured is very important in order to achieve the stated objective within the time frame. In addition to that, findings of the project must be relevant to the current situation and able to be applied in industries.

This section consists of project analysis where it involves data and information gathering, rain rotor modification and redesign, plus experimental analysis.

3.1 PROJECT ACTIVITIES

The activities involved in developing the project consist of:

i. Information gathering:
   - Previous studies on rain power generation.
   - Current rotor design available and specifications.
   - Materials specification.

ii. The parts that selected for the model (prototype) for experimental analysis consist of:
   - Blades
   - Disc

iii. Development of the rain rotor.
   - Redesign the current rotor that convention in industry.
   - Analytical calculation.

iv. Model fabrication.

v. System implementation & testing. (Experimental Analysis)

3.2 PROTOTYPE BASED-METHOD

The prototype-based methodology is governs as the development methodology. Figure 6 shows the diagram of the methodology.

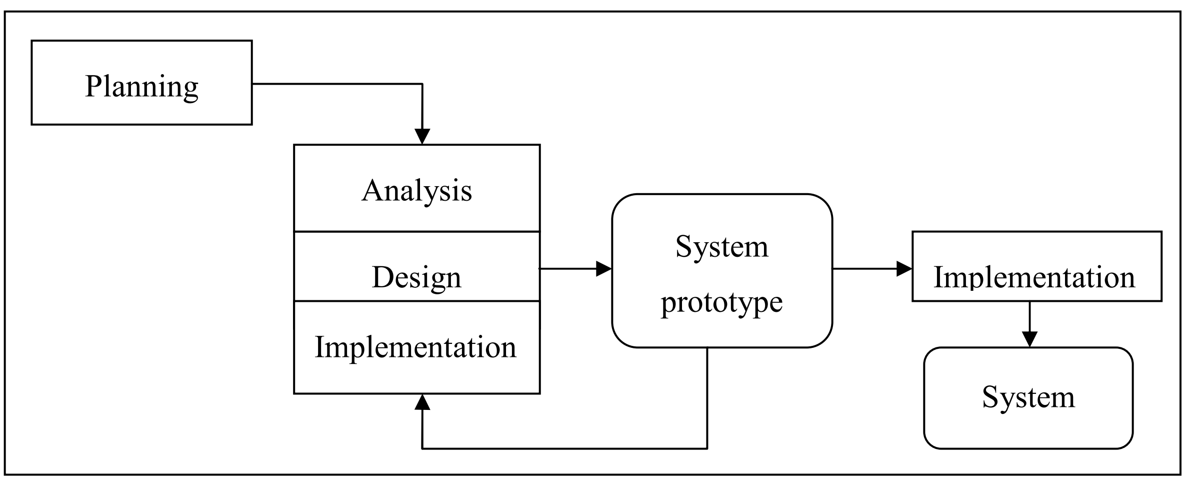


Figure 3.1: Prototype-based Method

3.2.1 Planning

The planning phase is the fundamental understanding on the project development. A study regarding the area involves are heavily conducted. In this phase, the work flow or execution chart has been developed to summarize the whole project outline.

Firstly research, collect and summarized data and experimental studies related to water turbine and renewable energy. Literature sources such as experimental studies, journals and reference books regarding rain utilization, rain power and power generation also contribute information to this project.

The general sequence of methodology is shown in Figure 3.2.

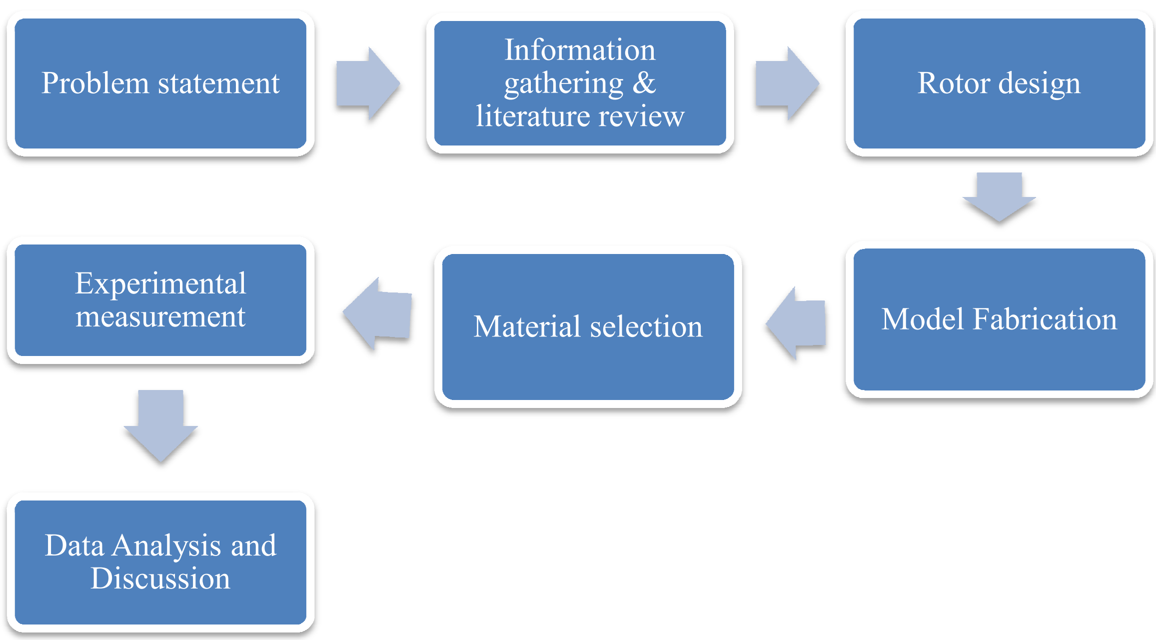


Figure 3.2: Methodology Flow Chart

3.2.2 Analysis

The structures of project include the theoretical calculations and experimental measurement.

i. Theoretical Analysis

The theoretical analysis focuses on study regarding related equations such as Bernoulli's Equation and power generated from fluid are used to determine the theoretical parameters. The theoretical jet velocity, torque, rotation speed and the power generated can be calculated.

ii. Experimental Measurement

Testing of the model is conducted in order to get the actual power generated by the turbine. The findings of the experiment will be used to compare with the theoretical value calculated before.

3.2.3 Design

Next will be the turbine redesign and modification for better performance and higher power generated. The modifications will posses newer features in terms of number of blades, blade arrangement and blade design. A step-by-step redesign process will produce the final drawing of the turbine and it would be use to fabricate the rotor prototype.

The design phase focuses mainly on the rain rotor of the prototype.

i. Prototype creation.

This is the part where after the research and analysis of the previous studies had been settled, and then only the design of the model is conducted. The model is very important in order to carry out the experimental analysis and meet the objectives of the project itself.

3.2.4 Implementation

Finally, after prior research, analytical calculation and redesign processes, and experimental of the rain rotor will be fabricated. For this final stage, the actual system is being built, installation is being made and testing is being done. In this stage, the findings of the rain rotor performance will be critically analyzed in order to compare the result with the theoretical value calculated before and come out with the conclusion.

From this experiment, the rotational speed, torque and power generated can be determined. Therefore, this would provide the necessary information and performance data of the turbine when it is operated.

3.3 REQUIREMENTS

The tools and equipment which are required in this Final Year Project are a Windows based PC together with the programs such as Microsoft Office and Autocad which is used in redesign and modification process. Measuring device needed basically will be required during experimental analysis. In this project, digital tachometer (Figure 3.2) and digital torquemeter (Figure 3.3). Also required depending on the research as well as from the internet and other references.

Figure 3.3: Digital Tachometer

Figure 3.4: Digital Torquemeter

CHAPTER 4

PROJECT DEVELOPMENT

4.1 ROTOR DESIGN

The rain wheel design is based on the conventional Savonius rotor design. However, 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 optimal design. The final design will be able to give a suitable design that would capture the most amount of rainwater per unit blade area to achieve greater performance.

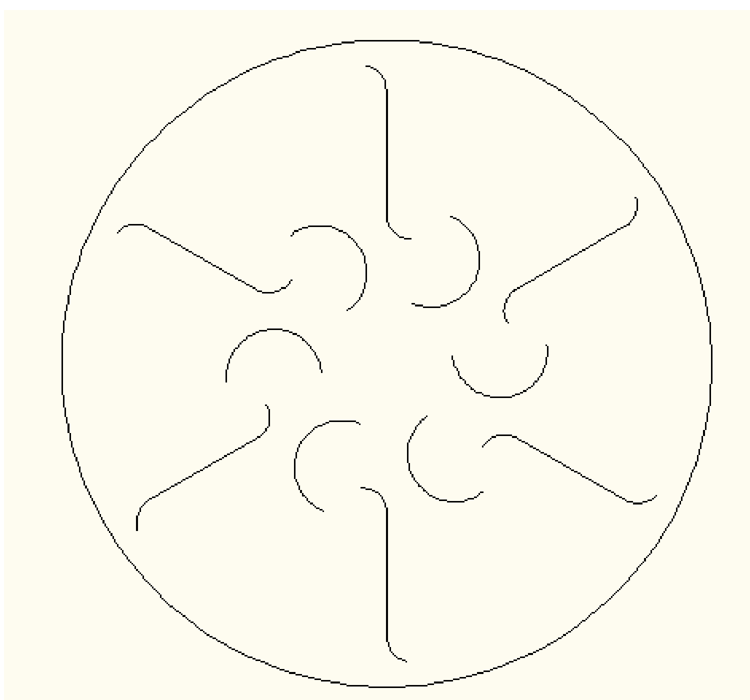


Figure 4.1: Final design

Figure 5.1 is the final design for this rain rotor. The outer blades plus accompanying inner blades are considered as 1 blade unit so the total number of blades is 6. 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.

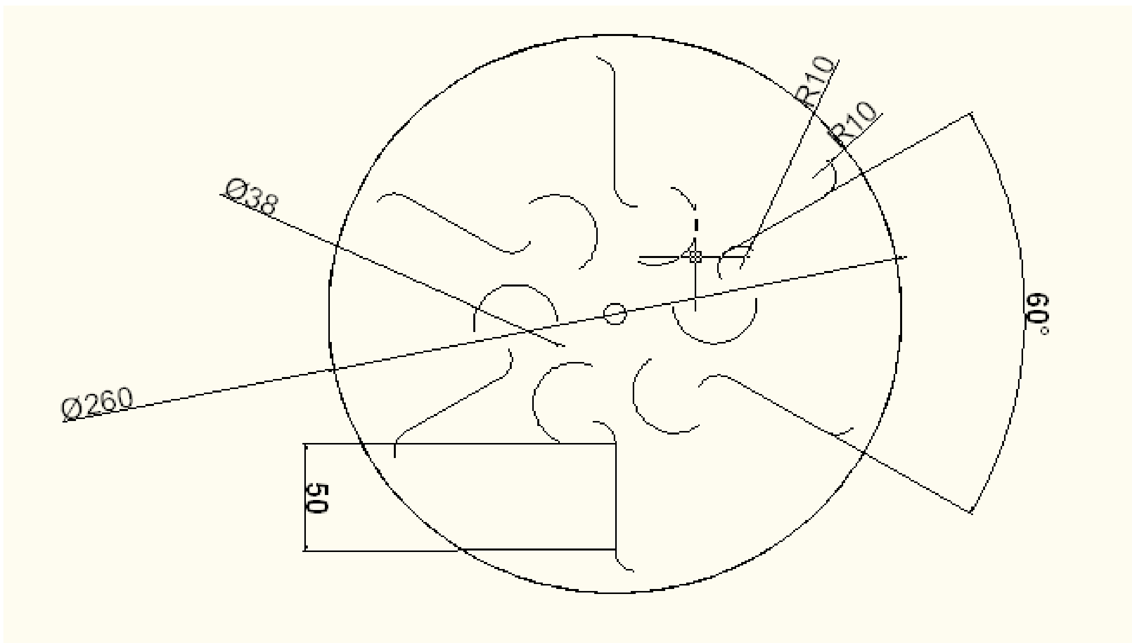


Figure 4.2: Cross section view with dimensions in millimetres (mm)

Based on the blade configuration in Figure 4.1, the dimensions for the rain wheel prototype was determined (Figure 4.2).

4.2 THEORETICAL ANALYSIS

i) Flow discharge

The discharge through the nozzle, Q from an inlet height H at pressure P is given by:

$$H = P/\rho g \tag{1}$$

$$Q = A_n V_1 \quad (2)$$

Where A_n is the nozzle opening area.

The velocity in the inlet of the nozzle can be predicted from the equation below:

$$V_1 = C_v \sqrt{2gH} \quad (3)$$

Hence,

$$Q = A_n C_v \sqrt{2gH} \quad (4)$$

Where C_v is the nozzle flow coefficient.

ii) Volume Analysis

Considering the rotor rotating in an anti-clockwise direction with an angular velocity, ω due to the combined action of an incident water jet and a clockwise resisting moment,τ.

The velocity of the incident jet is given by:

$$V_{r_1} = V_r - U \quad (5)$$

$$V_{r_1} = V_r - \omega R \quad (6)$$

Where R is the radius of the wheel.

Since the incident and emergent jets are both exposed to atmospheric pressure, the magnitude of the emergent jet will be only slightly less than the frictional resistance which can be allowed for by introducing a frictional resistance coefficient K_1 so that:

$$V_{r_2} = K_1 V_{r_1} \quad (7)$$

The jet will be deflected so that the emergent jet is at an acute angle, θ to the incident jet. The change in the component of relative velocity in the plane of the wheel will be:

$$\Delta V_r = V_{r_1} + V_{r_2} \cos\theta \tag{8}$$

$$\Delta V_r = V_{r_1} (1 + K_1 \cos\theta) \tag{9}$$

$$\Delta V_r = (V_1 - U)(1 + K_1 \cos\theta) \tag{10}$$

Which can be written as:

$$\Delta V_r = (V_1 - U)(1 + c) \tag{11}$$

Where

$$c = K_1 \cos\theta \tag{12}$$

iii) Power Output

Using the force-momentum equation, the force, F exerted by the water jet is given by:

$$F = \rho Q \Delta V_r \tag{13}$$

The torque induced by the rotational shaft of the wheel is then:

$$T = FR \tag{14}$$

$$T = \rho Q \Delta V_r R \tag{15}$$

And the power output W_{out} is:

$$W_{out} = \tau\omega \tag{16}$$

$$W_{out} = \rho Q \Delta V_r U \tag{17}$$

Substituting for ΔV_r gives:

$$W_{out} = \rho UQ (V_1 - U) (1 + K_1 \cos \theta) \quad (18)$$

iv) Efficiency

The input hydraulic power, W_{in} to the rotor is the product of the inlet pressure and flow rate.

$$W_{in} = PQ \quad (19)$$

$$W_{in} = \rho gHQ \quad (20)$$

The efficiency of the rotor is:

$$\eta = W_{out} / W_{in} \quad (21)$$

$$\rho = U\Delta V / gH \quad (22)$$

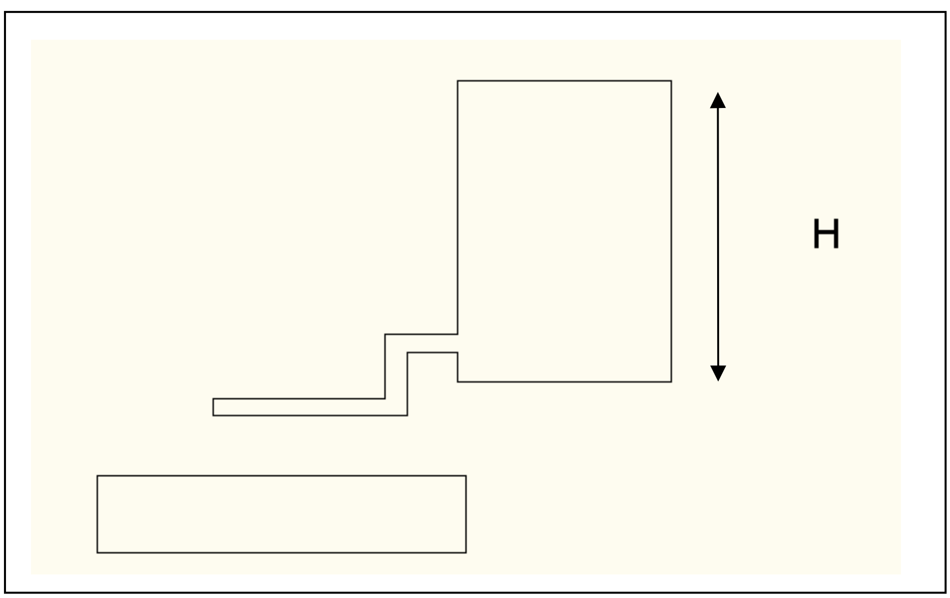


Figure 4.3: Tank arrangement

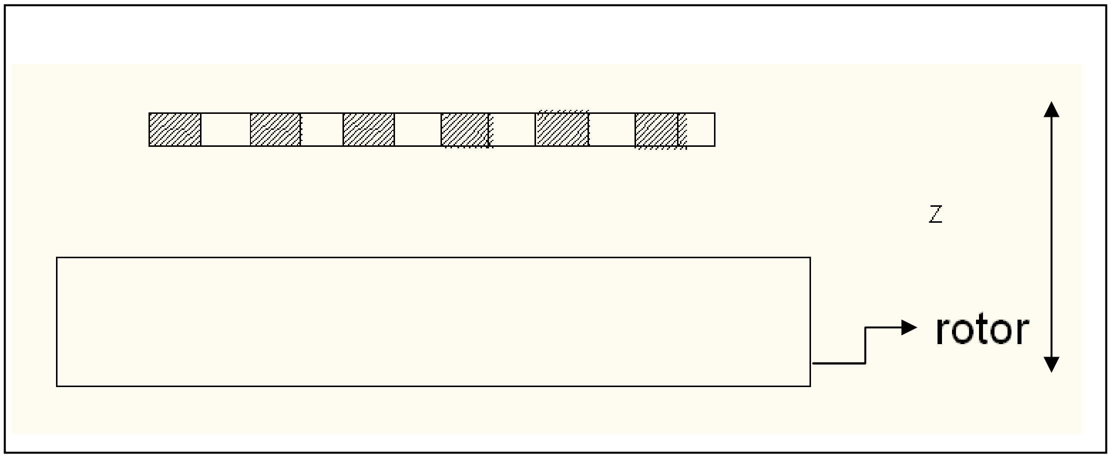


Figure 4.4: Rotor configuration

From the theory and Figure 5.3 and 5.4, calculation below is performed in order to calculate the rotor performance.

A_{flow} is take from the hatch pattern area in Figure 5.4.

Q_{theo}=V*A_{flow} (23)

Q_{theo}= f(H) *A_{flow} (24)

Where C_D is the discharge coefficient.

$Q_{out} = C_D * \ Q_{theo}$ (25)

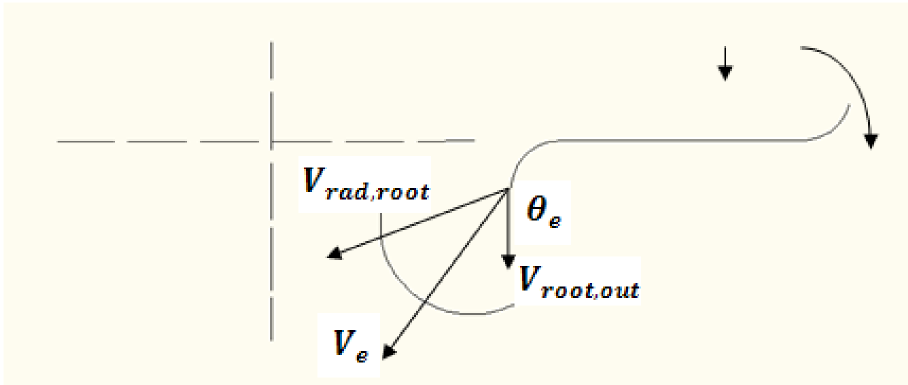


Figure 4.5: Vector Analysis

$$V_e = \sqrt{{V_{rad,root}}^2 + {V_{root,out}}^2 - 2V_{rad,root}V_{root,out}Cos135°} \quad (26)$$

$$\theta_e = Sin^{-1}(\frac{V_{root,out}}{V_e}\mathrm{Sin}135°) \quad (27)$$

4.3 MATERIAL SELECTION

The materials to be used would be based on several criteria such as resistance to corrosion, resistance to wear, cost and several other factors. Part of the rotor to be considered in this material selection process would be the end – plates, turbine blades and shaft also the water tank.

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 in significant 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 pipe per unit and if mass production is 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.

From Table 4.1, the table is converted into matrix data in Table 4.2. Table 4.2 shows the strong candidates and rating of those materials within the specifications in Table 4.5. The rating is from 1-5, where 1 means the lowest possibility of it to meet the criteria while 5 means the highest score for the specific material to meet the criteria (which explained in Table 5).

Table 4.2: Material Selection Matrix

Material	Corrosion resistance	Wear resistance	Lightweight	Cost	Ease of machinability
Aluminium	4	4	5	4	4
PVC	5	4	4	4	4
Perspex	5	4	4	4	3

CHAPTER 5

RESULTS & DISCUSSION

5.1 ANALYSIS OF RESULT

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

- Diameter, D=0.26 m
- Height, H=1.0 m
- Area, A= D*H = 0.26 m^2
- Water Flow Rate, Q = 5.88 x 10^{-4} m^3/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 $C_T = \frac{T}{\frac{1}{2}*\rho*{V_j}^2*A*\frac{D}{2}}$
- Tip Speed Ratio (TSR), λ, is evaluated by the formula, $\lambda=\frac{\omega D}{2V_j}$
- Power Coefficient C_p is evaluated from $C_p = \lambda\, C_T$

Table 5.1: Rotational speed, torque and power at different water levels

Water Level (m)	Rotational Speed (rpm)	Torque (N.m)	Power (W)
0.7	207.42	0.293	6.364
0.6	109.36	0.221	2.531
0.5	86.64	0.249	2.213
0.4	69.80	0.237	1.732
0.3	61.00	0.219	1.399
0.2	56.42	0.217	1.282

Table 5.2: Value of torque coefficient, tip speed ratio and power coefficient at different water levels

Water Level (m)	Torque Coefficient, C_T	Tip Speed Ratio, λ	Power Coefficient, C_p
0.7	0.15	8.2	1.185141149

0.6	0.11	4.3	0.471305603
0.5	0.12	3.4	0.420702052
0.4	0.12	2.7	0.322598109
0.3	0.11	2.4	0.260510827
0.2	0.11	2.2	0.238750694

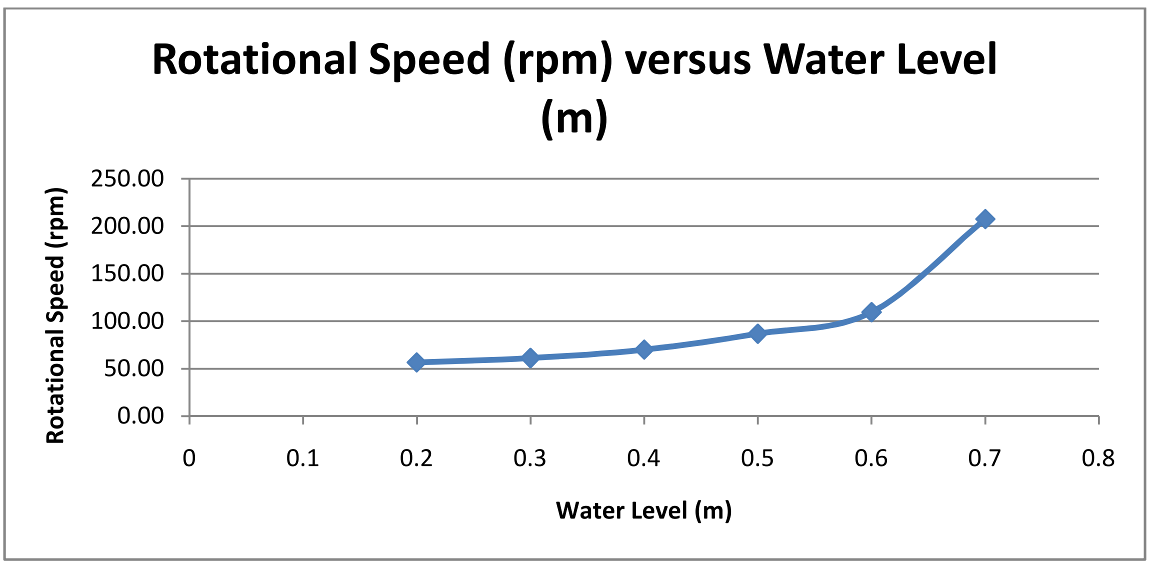


Figure 5.1: Rotational speed versus water level

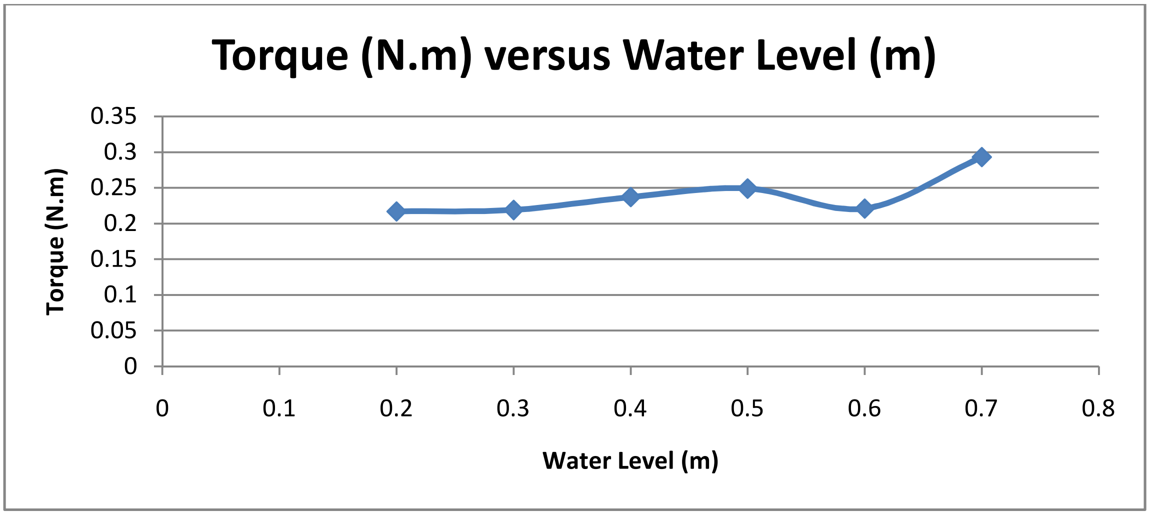


Figure 5.2: Torque versus water level

Figure 5.1 and Figure 5.2 shows that as the water level increases, the torque value and rotational speed also increase. The maximum value occurred at water level equals to 0.7 m.

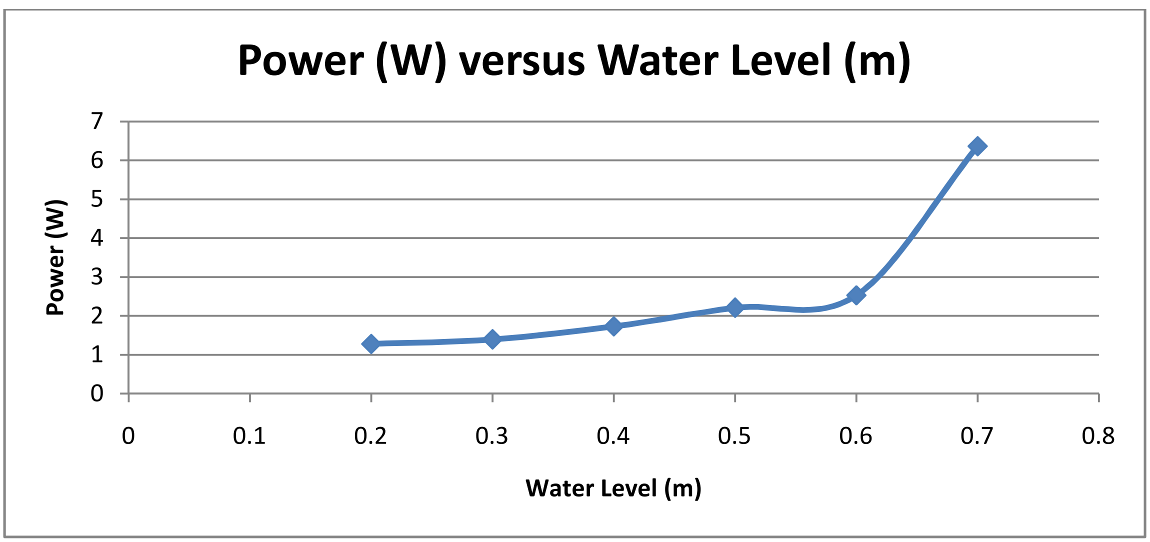


Figure 5.3: Power versus water level

Eventually as showed in Figure 5.3, maximum power produced is at maximum water level at 0.7 m. In this case, obviously as shown in Figure 5.1 and Figure 5.2 that maximum torque and maximum rotational speed occur at water level at 0.7 m. The higher the torque and rotational value, the higher the power extracted from the rotor.

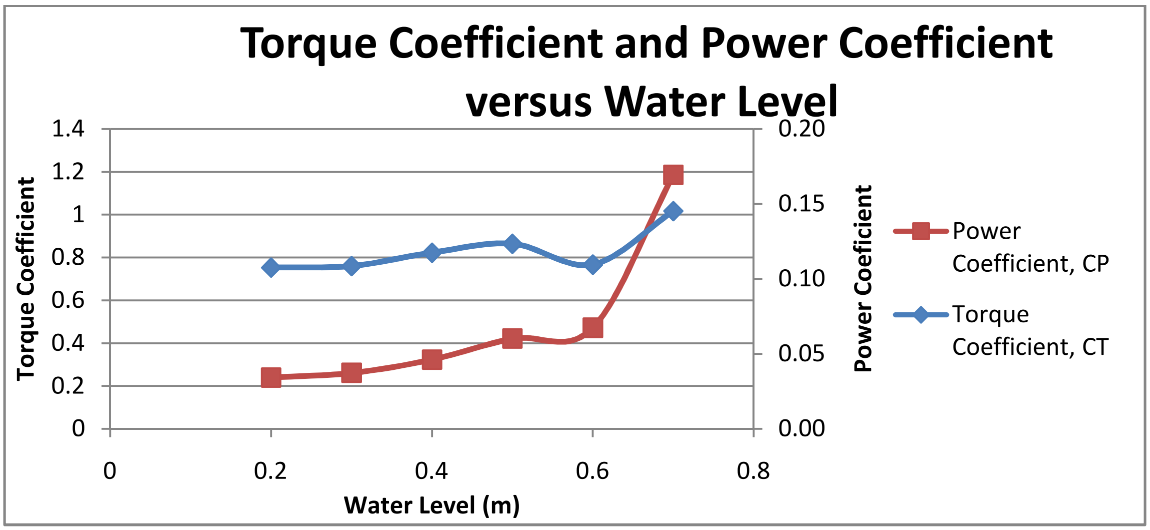


Figure 5.4: Torque coefficient and power coefficient versus water level

As shown in Figure 5.4, overall performance of the rotor was low but still higher than previous studies. This is to be expected, considering that blade was partly due to the limitation on speed imposed by the water flow that used to rotate the rotor and partly to the lower than expected tip speed ratio range.

But the significant finding was that the performance increased by redesign the rotor and improved the performance. This is consistent with the findings of Table 5.1. The data points appear to be mainly due to the difficulty in maintaining a steady speed, which was anticipated. It was difficult to hold the speed which corresponds to anticipated power.

Flowing water is directed on to the blades of a turbine runner, creating a force on the blades. Since the runner is spinning, the force acts through a distance (force acting through a distance is the definition of work). In this way, energy is transferred from the water flow to the turbine. The intention is that assembly will be motored to a suitable site and moored in moving water where the current velocity will not be controllable but should be steady over the duration of a test. It is reasonable to expect that with further optimization of the geometry, still higher efficiencies could be achieved.

There are few factors which influence the results were obtained. Since the experiment is done in the lab, the wind factor can be neglected. But the water splash when it strikes the rotor caused a lot of kinetic energy loss. The amount of water strikes the rotor produces only a small amount of torque. Apart than that different pressure distribution along the length of the pipe gap causes the water to flow more at one end only instead of uniform water sheet. This eventually will affect the RPM readings of the rotor. The shaft at the same time also affect the rotor rotation due to it's' weight. Since the shaft in this case is quite heavy, higher torque and higher RPM is required to rotate the rotor.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The rotor, which operate in a manner design from a wind turbine, are a relatively new technology which can generate power from flowing water with very little environmental impact. Geometry of the turbine has several potential advantages. The maximum efficiency of energy conversion of the energy incident on the swept area of an open turbine, since a suitably shaped blades can draw in flow from a larger area and increase the available pressure drop across the turbine, generating more power than previous studies.

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 problems 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 6.364 W.

6.2 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 area. Friction losses 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.

Also, the weight of the shaft. The rotor rotational speed seems being affected by the shaft's weight, thus it is strongly recommended that the shaft's weight is reduced. By lighter weight, less torque needed to rotate the rotor, therefore the rotor's RPM reading increases. These two significant increases will contribute to higher power generated from the rotor. For further development, the weight must be lightweight especially the shaft and the blades in order to make sure the increasing of the rotational speed.

REFERENCES

[1]The Depletion of Fossil Fuels, http://www.annesley.sa.edu.au/amep/energyconservation_solarenergy/depletion%20of%20energy%20research%20paper.htm

[2] Guigon, Romain, Chaillout, Jean-Jacques, Jager, Thomas, and Despesse Ghislain.(2008). Harvesting raindrop energy: theory" and "Harvesting raindrop energy: experimental study. *Smart Mater. Struct.* 17 015038-9.

[3] Holler, F. James; Skoog, Douglas A; Crouch, Stanley R (2007). *Principles of Instrumental Analysis* (6th ed.). *Cengage Learning. p. 9.* ISBN 9780495012016.

[4] Rainwater Harvesting, http://www.myhomepalm.com/rain-harvesting-malaysia/rain-water-harvesting.html

[5] Mohammed, Thamer Ahmed and Mohd. Noor, Megat Johari Megat and Ghazali, Abdul Halim (2007). ALAM CIPTA, International Journal on Sustainable Tropical Design Research & Practice, 2 (1).*Checking the Adequacy of Rainwater Harvesting System for Housing and Landscaping.* pp. 19-26. ISSN 1823-7231.

[6] Ahmad Faisal Bin Mohamad (2007). Project Paper. Special Collection University Malaysia Pahang. *Effectiveness Of Rainwater Harvesting System In Controlling Surface Runoff At Taman Wangsa Melawati, Kuala Lumpur,* TD418 .A36 2007 rs Thesis

[7] General Climate of Malaysia, http://www.met.gov.my/index.php?option=com_content&task=view&id=75&Itemid=1089

[8] 10-Day Agromet Bulletin. *Weather Review for Agricultural Users of Malaysia.* 1st-10th October 2009.

[9] K Tang, March 2005 *Energy Efficiency in Residential Sector.* http://www.eib.ptm.org.my

[10] Savonius Wind Turbines. http://www.reuk.co.uk/Savonius-Wind-Turbines.htm

APPENDIX A

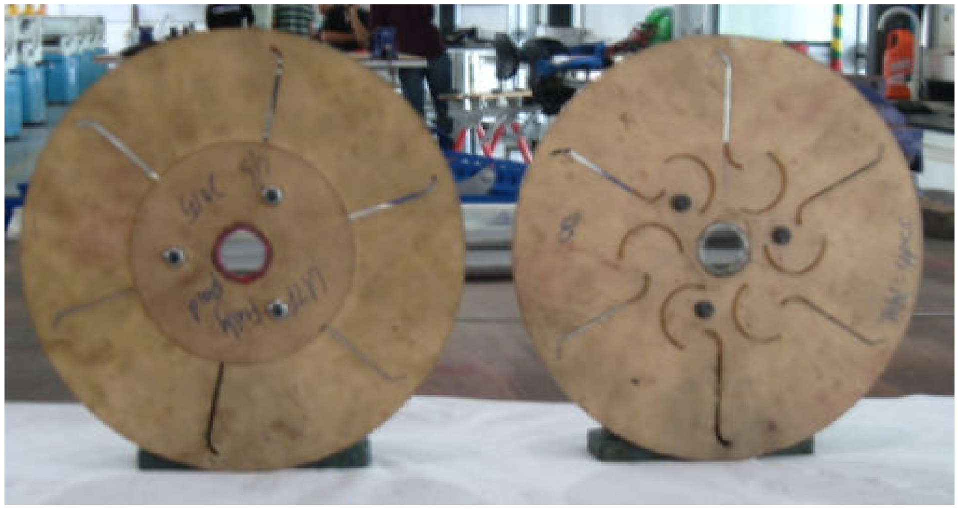
Gantt Chart for FYP 1

Activities	FYP 1													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic														
Submission of Form 01 (Title Proposal)														
Preliminary Research Work • Literature Review • Methodology														
Submission of Preliminary Report														
Seminar 1														
Project Work														
Submission of Progress Report • Project Description and Progress														
Seminar 2														
Project Work Continues • Redesign Rain Rotor														
Submission of Interim Report Final Draft														
Oral Presentation														

APPENDIX B

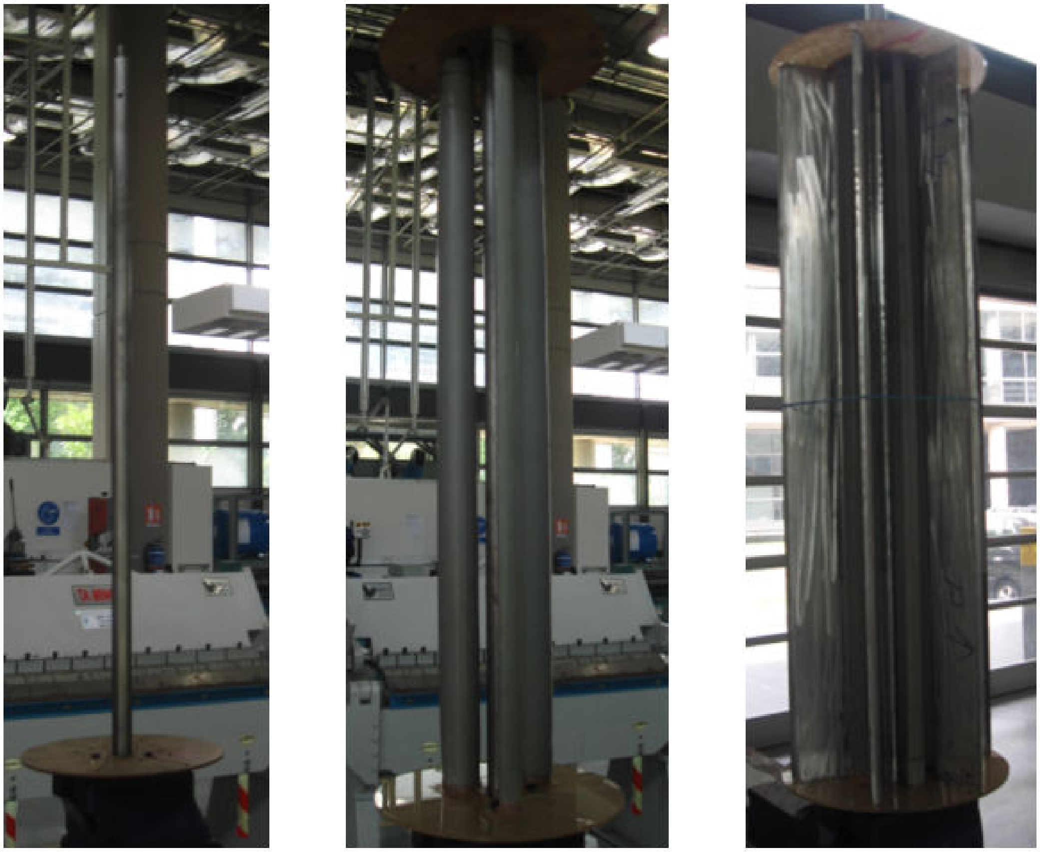
Gantt Chart for FYP 2

Activities	FYP 2														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continue • Finalize design and fabrication of rain rotor															
Submission of Progress Report 1															
Project Work Continue • Data gathering and Analysis • Experimental Analysis															
Submission of Progress Report 2															
Seminar															
Project Work Continue • Results and Findings • Data Analysis and Discussion															
Poster Exhibition															
Submission of Dissertation (soft bound)															
Oral Presentation															
Submission of Project Dissertation (hard bound)															

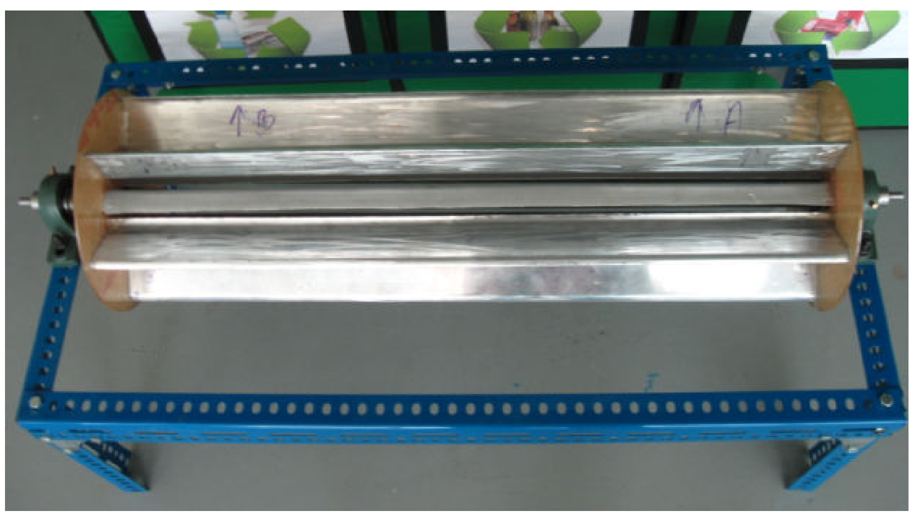


Rotor Disc

Ball Bearing for Shaft Rotation



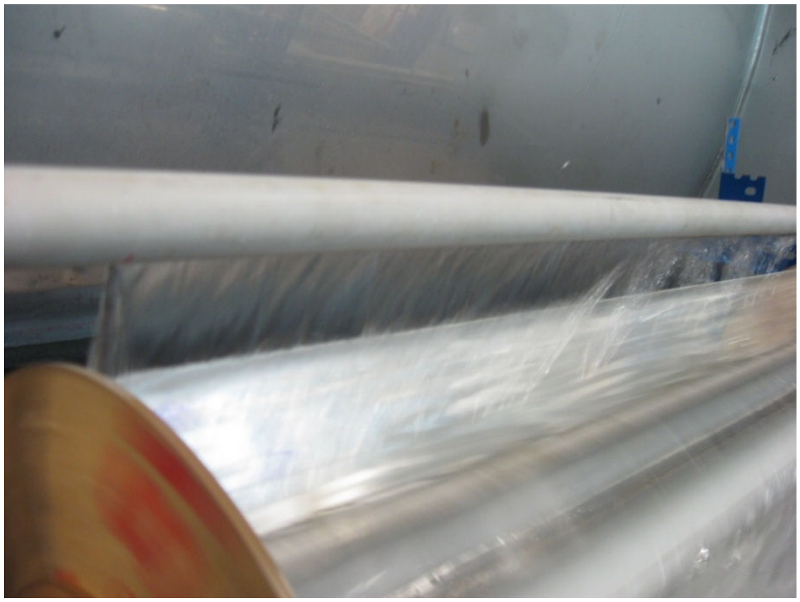
Rotor assembly process



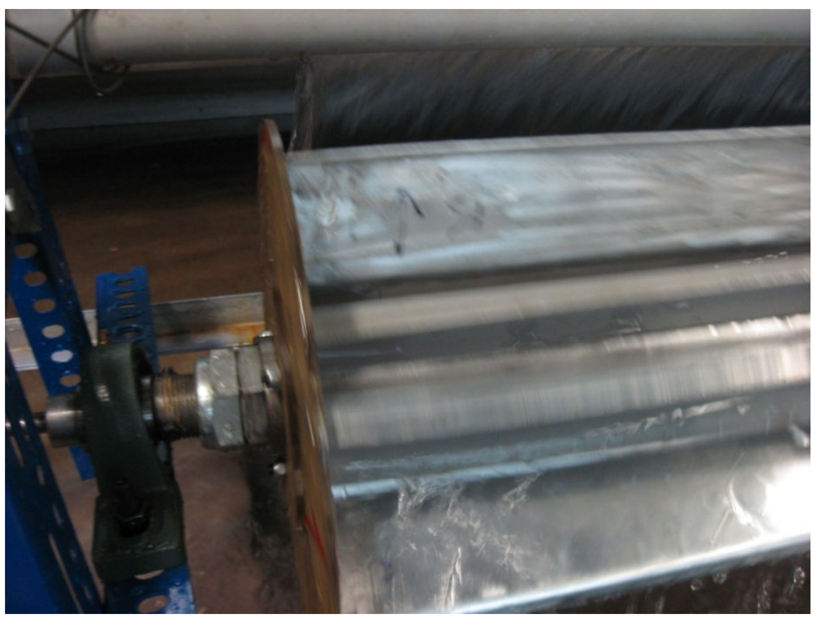
The completed rotor

Prototype arrangement

Accumulated water in the tank



Water stream



Water stream