Experimental Evaluations of a Novel Invented Wind Turbine for Solar Chimney Power Plant

By

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14215

Dissertation submitted in partial fulfillment of

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Mechanical Engineering

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHAINICAL ENGINEERING)

Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2014

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.

(WELTSON DIUS)

ACKNOWLEDGEMENT

First and foremost, I would like to praise God the Almighty, which have helped and guided me in completing this Final Year Project Report. I would also like to express congratulations and high appreciation to my project supervisor Dr. Hussain Hammud ja'afer Al Kayiem for his supervision commitment and cooperation in creating this final year project into a successful one for me. I also would like to express my appreciation to Mr. Hassanain for the guidance and advice throughout completing this project. Not to forget our main fabricator for this project, Mr. Ho who have done a great job at fabricating the designed setup and turbine. To top everything, I am also grateful to my parents for their love and strong support during my study period.

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ABSTRACT

The power conversion unit of a large solar chimney power plant converts the fluid power, first into mechanical power, and then into electrical power. In this dissertation an experimental setup is developed to analyze the novel turbine used to harness the wind energy using a theoretical model validated with the measurement of the existing prototype in UTP. First, the solar chimney concept and the related studies on the turbine performance are introduced, and it is shown how the turbines works based on the solar chimney concept. Then, an experimental setup and turbine model is developed. The experimental procedures of the turbine analysis, testing procedure and equipment involved were being determined through numbers of literature reviews and availability of equipment inside university laboratory. Preliminary data are investigated experimentally and numerically. The aim of the experimental investigation is to further validate the findings based on the existing prototype shows that the novel turbine is capable of operating at lower than 3.5 m/s of air flow which is less than the conventional turbine which runs on average of 6.0 m/s of air flow. The methodology of this project study had been arranged accordingly from initial literature review of the subject until the experimental procedures and the analysis method was determined.

Table of Contents

Certification of Approval..ii

Certification of Originality iii

Acknowledgement iV

Abstract V

List of Figures.. Viii

Chapter 1 - Introduction 1

1.1 Background Study

1.2 Problem Statement

1.3 Objectives of the Project

1.4 Scope of Study..**2**

Chapter 2 - Literature Review..**3**

2.1 History

2.2 General Description

2.3 Principle of Operation

2.4 Types of wind turbine

2.5 Physics of wind turbine

2.6 Studies on different types of turbines **11**

Chapter 3 – Methodology **12**

3.1 Experimentation Methodology

3.2 Gant Chart

3.3 Key Milestones

3.4 Process Flowchart **15**

Chapter 4 – Results and Discussions **16**

4.1 Experimental Setup

4.2 Experimental Procedure

4.3 Experimental Apparatus

4.4 Data Collection and Analysis

4.5 Discussions **27**

Chapter 5 – Conclusions and Recommendations **28**

5.1 Conclusions

5.2 Recommendation **30**

References **31**

List of Figures

Figure 2.1: Schematic of a solar chimney power plant…………………………………..3

Figure 2.2: Temperature-entropy diagram for SUTPP…………………………………..6

Figure 4.1: Front view of the experimental setup schematic……………………………16

Figure 4.2: Top view of the experimental setup schematic …………………………….17

Figure 4.3: Actual picture of the completed setup ……………………………………...17

Figure 4.4: Top view of the experimental turbine ……………………………………....19

Figure 4.5: Side view of the experimental turbine ………………………..…………19

Figure 4.6: Experimental setup with the 3m long PVC pipe installed………………......26

Figure 5.1: Solar Chimney turbine rig schematic….……………………………..…......29

CHAPTER 1

INTRODUCTION

This chapter is all about the overview of this study which include the background, the problem statements that lead to this study, the objective or purpose to conduct this study and finally the scopes that need to be cover in this study.

1.1 Background of Study

The Solar chimney power plat or solar updraft tower (SUT) is a renewable-energy power plant for generating electricity from solar power. Sunshine heats the air beneath a very wide greenhouse-like roofed collector structure surrounding the central base of a very tall chimney tower. The resulting convection causes a hot air updraft in the tower by the chimney effect. This airflow drives wind turbines placed in the chimney updraft or around the chimney base to produce electricity. The efficiency of the tower is determined by the difference between the temperature in the collector and the temperature of the environment at the top of the tower. A 1°C drop in temperature over every 100m facilitates the necessary updraft effect from the tower. The concept ensures effective operation even on cooler days, as it is primarily dependent upon the temperature differential between the air under the collector and air at the top of the tower.

Even though this technology is simple, for it to be efficient it requires a large area of greenhouse and a very tall tower. There are currently no solar towers in use commercially. The technology got a big boost during the seventies' oil crisis in the U.S, but interest in it faded as the price of oil dropped in the eighties. Now that the price of oil is again going up, solar tower technology is again getting noticed.

1.2 Problem Statement

The solar chimney converts the solar thermal energy to wind which then operates the wind turbine to generate electricity. Traditional wind turbine requires about 6 m/s of air stream speed to operate at optimum level. This limitation prompts the construction of huge sized solar chimneys for power generation which will require massive amounts of investment.

Research solution:

Alternatively, a modified wind turbine can operate at lower air stream speed hence on this project I will conduct experimental test on several types of turbine to determine their needed air stream speed to operate.

1.3 Objectives

With regards to the problem stated, the current experiment was carried out with the following objectives:

1. To design and fabricate a model of wind turbine with radial inlet axial outlet flow.
2. To evaluate performance of the mixed flow model of the turbine by experimental measurements.

1.4 Scope of Study

The scope of the study will cover;

1. Wind energy harnessing and conversion to mechanical and electrical power.
2. Solar chimney power plant components and principle.
3. Turbine designs and configurations.
4. Turbine performance analysis.

CHAPTER 2

LITERATURE REVIEW

This chapter contains the reviews on previous researches and theories which are relevant with the present study. It mostly covers on the theory involving the solar updraft tower, the mechanical and non-mechanical parts and their respective uses, and also its relevancy with today's technology advancement. Thus, review on this section will attempt to use the useful information with regards on the issues that may arise.

2.1 History

Solar updraft tower power plant (SUTPP, also called solar chimney power plant, Fig. 2.1) is a kind of device that produces buoyancy to drive air to ascend for electricity generation (Schlaich, 1995). The concept of using a small SUT device for furnishing power first appeared in Bennett (1896)'s patent, and a household SUT device for generating electricity was proposed in a magazine by Cabanyes (1903). In 1926, Dubos proposed the construction of an SUTPP in North Africa with its tower on the slope of a high mountain (Ley, 1954).

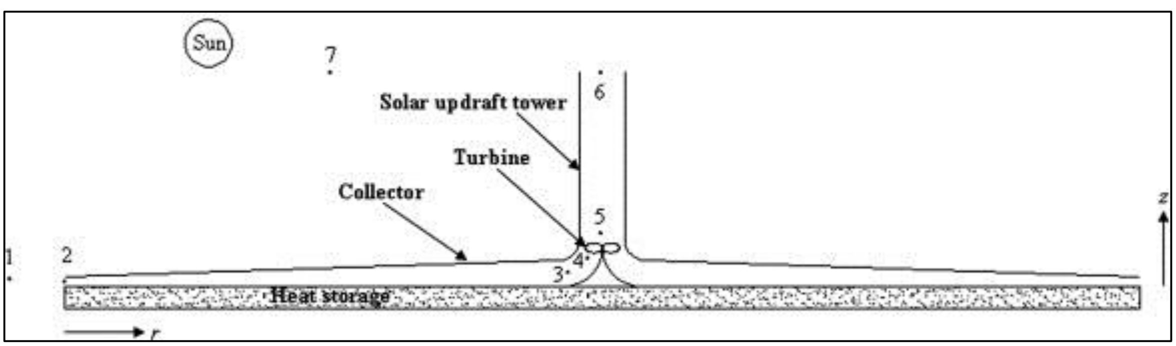


Figure 2.1: Schematic of a conventional solar updraft tower power plant (1: surroundings on ground level, 2: collector inlet, 3: collector outlet, 4: turbine inlet, 5: turbine outlet, 6: SUT outlet, 7: atmosphere at the height of SUT outlet).

Schlaich together with his colleagues built the first pilot SUTPP prototype in Manzanares, Spain in 1982 (Haaf et al., 1983 and Haaf, 1984). The pilot prototype had an SUT 194.6 m high and a collector 122 m in radius. The prototype operated with a peak power of about 50 kW for seven years from 1983 to 1989 (Schlaich, 1995). The successful operation of the prototype demonstrated the feasibility and reliability of the SUTPP technology. Since then, many researchers have shown strong interest in it and extensively studied the potential of SUTPP technology all over the world (Zhou et al., 2010b). In order to generate electricity economically, a large-area collector and a high SUT are needed for an SUTPP. Some commercial SUTPP projects have since been proposed in several countries however until now this technology has not yet been commercialized.

2.2 Description

A conventional SUTPP (Fig. 2.1) consists of a circular solar collector constructed on horizontal ground, a vertical solid SUT situated at the center of the collector, and turbine generators installed at the collector outlet or at the SUT inlet (Schlaich, 1995). In the solar collector, solar radiation passes through the transparent roof and is received by the absorber, i.e., the ground or an additional absorber laid on the ground, and thus the indoor air is heated. Some heat is stored in the absorber when solar radiation is strong during day time on sunny days. The heat is released from the absorber when solar radiation is weak during night time or on cloudy days. The density difference between the warm air inside the SUT and the ambient air creates buoyancy that acts as the driving force and is also called pressure potential. The buoyancy drives the air to flow in the collector toward the SUT base and rise in the SUT. Finally, the air current drives the turbines powering generators to generate electricity.

A solar collector consists of support columns, a framework matrix, and a transparent roof made of glass, plastic or other transparent materials. An air collector is formed when the transparent roof is suspended from the framework matrix supported above the ground by the support columns. The roof of a typical collector slowly ascends from the collector periphery to its center to guide indoor airflow with low friction losses.

Natural ground has a certain heat storage capacity, but its heat storage capacity cannot always meet the need of SUTPP operation during night time or on cloudy days. Therefore, additional heat storage systems have been proposed to help store solar energy. Since water with large specific heat capacity is a kind of cheap and effective heat storage medium, a water-filled system placed on the ground under the collector roof has been regarded as a typical additional heat storage system (Schlaich et al., 2005). The water-filled system is closed and airtight to avoid heat loss by evaporation.

The SUT situated at the center of the collector is the thermal engine of the SUTPP. The best choice for high SUT structure has been considered by civil engineers (Schlaich, 1995) to be reinforced concrete shell structure due to its long life span and favorable cost amongst many possible structural designs, although a guyed corrugated metal sheet flue was designed by Schlaich and his colleagues for the Manzanares prototype just for experimental purposes. Civil engineers (Schlaich, 1999 and Harte et al., 2013) designed high ring-stiffened thin-walled reinforced concrete cylindrical or hyperbolic shell SUTs for commercial SUTPPs.

Turbines are driven by the air current due to buoyancy to transfer fluid power to shaft power (Fluri and von Backström, 2008a). The typical SUT turbine is of the axial flow type, whose characteristics (e.g., the number of rotor blades) lie between those of wind turbine and gas turbine. Its blades are adjustable like those of wind turbine, but the air flow is enclosed just as in gas turbine, and the SUT turbine may have inlet guide vanes (IGVs) (Von Backström and Gannon, 2004). The SUT supports could be used as IGVs of the single vertical-axis turbine installed at the SUT base. Turbine configuration is the single vertical-axis, the multiple vertical-axes or the multiple horizontal-axis type (Schlaich, 1995). Turbine layout is the single-rotor layout or the counter-rotating layout with one pair of counter-rotating rotors (Denantes and Bilgen, 2006), both with or without IGVs.

2.3 Principle of operation

The energy conversion processes related to SUTPP can be demonstrated with a temperature-entropy diagram of air standard cycle analysis without considering system losses (Gannon and Von Backström, 2000) as shown in Figure 2.2. In the figure, the collector inlet area is assumed to be large enough, resulting in a small velocity of airflow at the collector inlet, and the velocity of airflow at Point 3 is assumed to be equal to that at Point 4. Process 2–3 occurring in the collector denotes that the air entering through the collector inlet from the surroundings is heated by solar radiation, its temperature and entropy increase, and the indoor air motion is accelerated, while the total pressure is kept constant inside the collector. Process 4–5 denotes that the air blows through the turbine into the SUT when the temperature and static pressure decrease slightly. This is seen as an isentropic process. Process 5–6 denotes that the air behind the turbine flows through the SUT when the temperature decreases mainly due to the negative work done by the gravitational force. This is also seen as an isentropic process. Process 6–7 denotes that the energy including kinetic energy and heat of airflow is released into the atmosphere. In the following sections, energy conversion processes related to the main components of the conventional SUTPP, i.e., solar collector, heat storage, SUT, and turbines, are discussed in detail by considering the system losses.

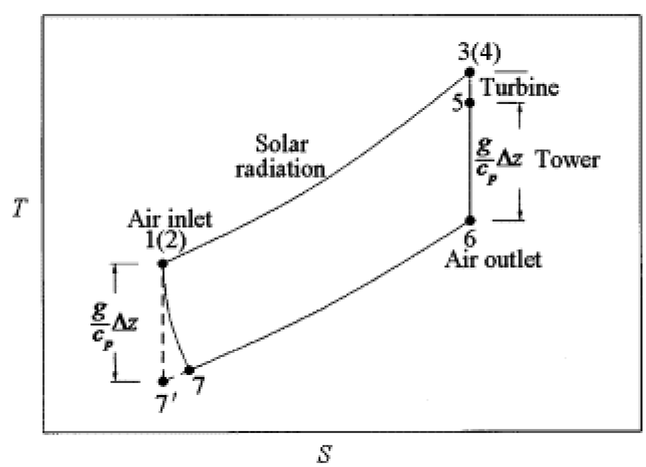


Figure 2.2: Temperature-entropy diagram of air standard cycle without system losses for SUTPP (Gannon and von Backström, 2000)

2.3.1 Solar collector

A solar collector consists of support columns, a framework matrix, and a transparent roof made of glass, plastic or other transparent materials. An air collector is formed when the transparent roof is suspended from the framework matrix supported above the ground by the support columns. The roof of a typical collector slowly ascends from the collector periphery to its center to guide indoor airflow with low friction losses.

2.3.2 Heat storage

The two main heat storage systems for SUTPPs are the natural ground system and the typical natural-additional mixed system with a closed water-filled system. The former is more convenient and cheaper but has worse heat storage capacity than the latter.

Natural ground has a certain heat storage capacity, but its heat storage capacity cannot always meet the need of SUTPP operation during night time or on cloudy days. Therefore, additional heat storage systems have been proposed to help store solar energy. Since water with large specific heat capacity is a kind of cheap and effective heat storage medium, a water-filled system placed on the ground under the collector roof has been regarded as a typical additional heat storage system (Kreetz, 1997; Schlaich et al., 2005). The water-filled system is closed and airtight to avoid heat loss by evaporation.

2.3.3 Solar updraft tower

The SUT situated at the center of the collector is the thermal engine of the SUTPP. The best choice for high SUT structure has been considered by civil engineers (Schlaich, 1995; Kra¨tzig et al., 2009) to be reinforced concrete shell structure due to its long life span and favorable cost amongst many possible structural designs, although a guyed corrugated metal sheet flue was designed by Schlaich and his colleagues for the Manzanares prototype just for experimental purposes. Civil engineers (Schlaich, 1999; Kra¨tzig et al., 2009; Harte et al., 2013) designed high ring-stiffened thin-walled reinforced concrete cylindrical or hyperbolic shell SUTs for commercial SUTPPs.

2.3.4 Turbines

Turbines are driven by the air current due to buoyancy to transfer fluid power to shaft power (Fluri and von Backstro¨m, 2008a). The typical SUT turbine is of the axial flow type, whose characteristics (e.g., the number of rotor blades) lie between those of wind turbine and gas turbine. Its blades are adjustable like those of wind turbine, but the air flow is enclosed just as in gas turbine, and the SUT turbine may have inlet guide vanes (IGVs) (Von Backstro¨m and Gannon, 2004). The SUT supports could be used as IGVs of the single vertical-axis turbine installed at the SUT base (Gannon and von Backstro¨m, 2003). Turbine configuration is the single vertical-axis, the multiple vertical-axes or the multiple horizontal-axis type. Turbine layout is the single-rotor layout, or the counter rotating layout with one pair of counter-rotating rotors, both with or without IGVs.

2.4 Types of wind turbines

There are two great classes of wind turbines: those whose rotors spin about a horizontal axis and those whose rotors spin about a vertical axis. Vertical-axis wind turbines (VAWT) can be divided into two major groups: those that use aerodynamic drag to extract power from the wind and those that use lift. The advantages of the VAWTs are that they can accept the wind from any direction. This simplifies their design and eliminates the problem imposed by gyroscopic forces on the rotor of a convectional machine as the turbine tracks the wind. The vertical axis of rotation also permits mounting the generator and drive train at ground level (Gipe, 2004). The disadvantages of this type of rotors is that it is quite difficult to control power output by pitching the rotor blades, they are not self – starting and they have low tip-speed ratio (Hau, 2000).

Horizontal – axis wind turbines (HAWT) are convectional wind turbines and unlikely the VAWT are not omnidirectional. As the wind changes direction, HAWTs must change direction with it. They must have some means for orienting the rotor with respect to the wind. In a HAWT the generator converts directly the wind which is extracted from the rotor. The rotor speed as well as the power output can be controlled by pitching the rotor blades along their longitudinal axis. A mechanical or an electronic blade pitch control mechanism can be used in order to achieve this. An important advantage for HAWT is that blade pitching acts as a form of protection against extreme wind conditions and over speed. Also the rotor blades can be shaped to achieve maximum turbine efficiency, by exploiting the aerodynamic lift to the maximum.

2.5 Physics of wind turbine

The power in the wind is the total available energy per time unit. The power in the wind is converted into the mechanical-rotational energy of the wind turbine rotor, which results in a reduced speed of the air mass. The power in the wind cannot be extracted completely by a wind turbine, as the air mass would be stopped completely in the intercepting rotor area. This would cause a `congestion' of the cross-sectional area for the following air masses (Ackerman, 2000).

The power available from wind for a vertical axis wind turbine can be found from the following formula (Castillo, 2011):

$$Pw = \frac{1}{2}\rho S V_o^3$$

Where V_o is the velocity of the wind [m/s], ρ is the air density [kg/m3], the reference density used its standard sea level value (1.225 kg/m3 at 15ºC) and S is the swept area.

The swept area can be calculated using the formula (Castillo, 2011):

$$S = 2RL$$

Where S is the swept area [m^2], R is the rotor radius [m], and L is the blade length [m].

The turbine power output can be calculated by taking direct measurements of torque and rotational speed on the generator turbine shaft (Von Backström and Gannon, 2003). The power is calculated from the product of shaft speed ω and torque τ.

$$P_{turb} = \tau\omega$$

Where P_{turb} is the turbine power output [W], ω is the angular velocity and τ is the torque.

Power coefficient, C_p, value represents the part of the total available power that is actually taken from wind, which can be understood as its efficiency (Castillo, 2011). The power coefficient can be calculated using the formula:

$$C_p = \frac{captured\ mechanical\ power\ by\ blades}{available\ power\ in\ wind}$$

$$C_p = \frac{P_{turb}}{Pw}$$

Where C_p is the power coefficient, P_{turb} is the total turbine power and Pw is the total available power in the wind.

2.4 Studies on different types of turbines

A lot of research has been done to test which types of setting would be the most optimal for the solar chimney power plant. Some of those studies are;

- *Vertical vs. horizontal shaft*: In a vertical shaft configuration the turbines are integrated in the chimney. In a horizontal shaft configuration the turbines are located around the chimney circumference with their axes perpendicular to the chimney axis. A vertical shaft configuration reduces cyclical stress on the components due to gravity but requires a thrust bearing to carry the weight of the whole rotor. For a horizontal shaft configuration the pressure after the turbine section is sub-atmospheric which makes sealing of the horizontal to vertical flow transition section necessary.

- *Single vs. multiple turbines*: A single turbine with a vertical shaft was used for the Manzanares plant. The design of the PCU was made by Schwarz and Knauss (1981). Gannon (2002) also analyzed such a configuration but for a large-scale SCPP. Its advantages are (1) the simplicity of the flow passage and (2) the small number of parts. Its disadvantages are (1) huge torque, which, in the case of a large-scale SCPP, necessitates a huge generator (2) huge size, which makes manufacturing, handling and transport difficult and (3) lack of redundancy.

- *Inlet guide vanes (IGV*s): In the Manzanares plant the turbine pressure drop was small and it was not deemed necessary to reduce the exit swirl, e.g. by means of inlet guide vanes (Schwarz and Knauss, 1981)7. In the case of a large-scale SCPP the impact of the exit swirl is much bigger. If the pitch of the IGVs is variable, they can also serve to control the plant output and to close off the turbine flow passage(s) for emergency or maintenance. Inlet guide vanes will be discussed in more detail later.

- *Counter rotating turbines*: Another way of reducing the exit swirl of a turbine is to introduce a second blade row, which rotates in the opposite direction. This approach was used for the low speed low pressure turbine in the experimental aircraft engine General Electric GE368. In commercial wind turbines counter rotating rotors have not been implemented, because the theoretical maximum power coefficient of two counter rotating rotors is only little higher than that of a single rotor (Spera et al., 1994). Nonetheless, several companies are currently developing wind turbines with counter rotating rotors with the aim of reducing the cost of electricity9. Counter rotating turbines have also been proposed for the SCPP (Denantes and Bilgen, 2006).

- *Diffuser after the turbine*: To reduce the exit kinetic energy losses while keeping the size of the turbine small, an exhaust diffuser has been proposed by various authors, e.g. by Gannon (2002). In a configuration with multiple horizontal axis turbines a diffuser could be placed directly after the turbines or in the chimney.

CHAPTER 3

METHODOLOGY

This chapter will describe on the method of experimentation and the tools that will be used to accomplish the end result, process flowchart and also key milestones that need to be followed.

3.1 Experimentation methodology

The project is aiming to scale up and test a model of new wind turbine. Hence, the activities are mainly focused on fabrication and experimental tests. Accordingly, it is possible to stage the work as:

Stage 1:

Design and fabricate a testing rig for the prototype wind turbines which have different configurations in terms of blade numbers and flow guide angles.

Stage 2:

Carry out experimental measurements and compare the results to decide the best configuration.

Stage 3:

Evaluate the results and suggest any improvements that could be made to further increase the efficiency of the turbine.

3.2 Gantt Chart

Semester 1

Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic														
Preliminary Research Work														
Experimental Setup Designing														
Fabrication of prototype												●		
Finalizing experimental procedure and collecting completed fabricated parts														

● Suggested Milestones

Process

Semester 2

Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Setting up the experimental rig														
Conducting experimentation														
Data analysis and evaluation											●			
Final Report writing														
Project Presentation														

● Suggested Milestones

Process

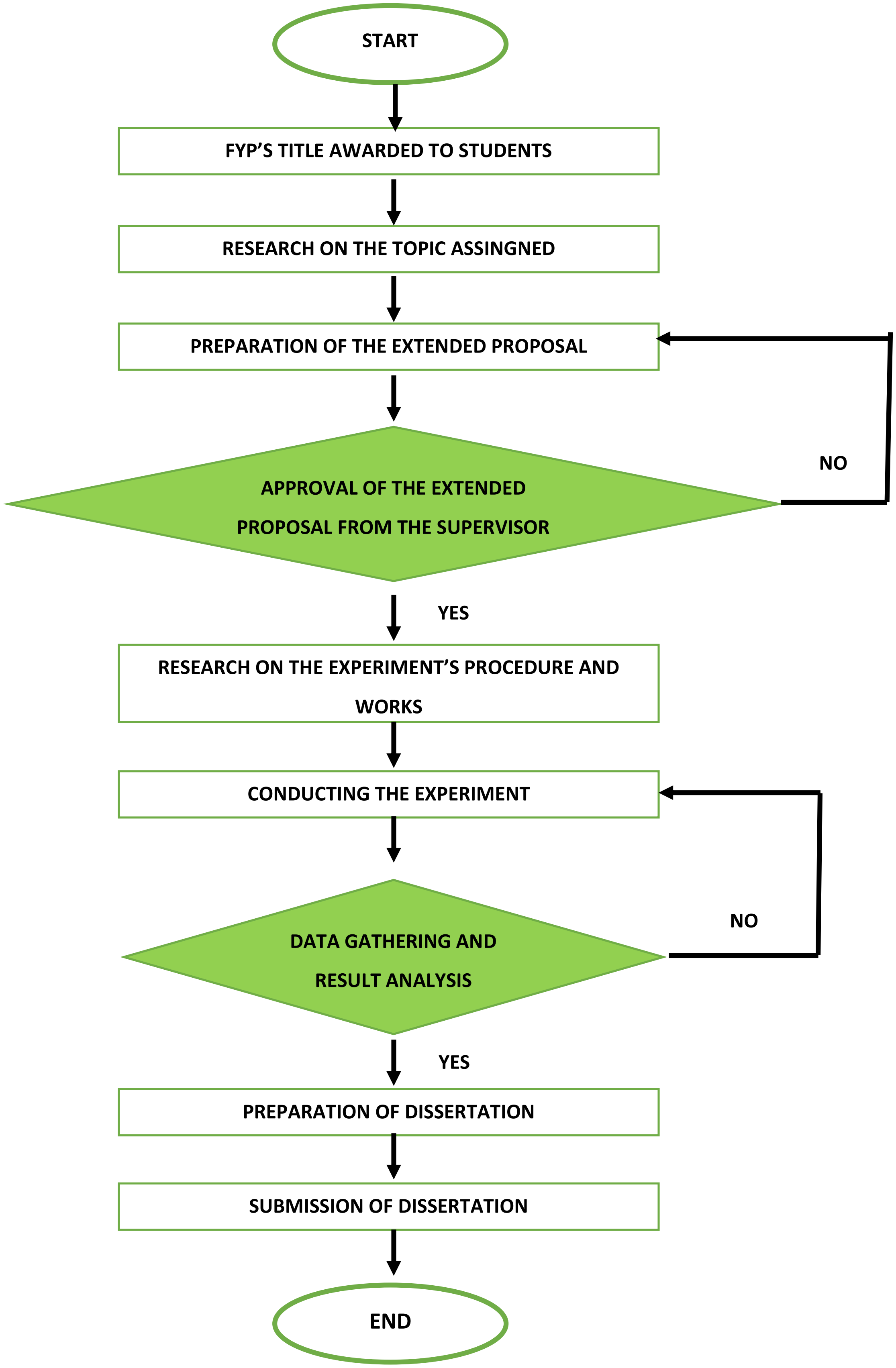
1.3 Key Progress Indicator

Table 3.1 shows the activity listed for the semesters and the percentage of the work done according to the activity.

Semester 1	Progress (%)	Semester 2	Progress (%)
Completion of research and paper work.	30%	Complete setting up experimental setup.	25%
Experimental setup design completion.	50%	Conducting experimentation and data gathering.	60%
Proposal Approval.	65%	Data analysis and report writing.	85%
Fabrication of experimental setup.	100%	Final evaluation (VIVA).	100%

Table 3.1: Key progress indicator

3.4 Process Flow Chart



CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, I will discuss further on the experimental setup and also present the data taken from the experimental testing done on the novel turbine. These findings will be analyzed and discussed in detail to see whether I have achieved my objectives.

4.1 Experimental Setup

This experiment is conducted with an up to scale model of the existing solar chimney power plant in UTP as reference. Main parts consist of solar collector, updraft tower, turbine which is the part that is tested in this experimentation, generator and fans. Figure 4.1 shows the schematics of the experiment setups;

All dimensions are in (cm).

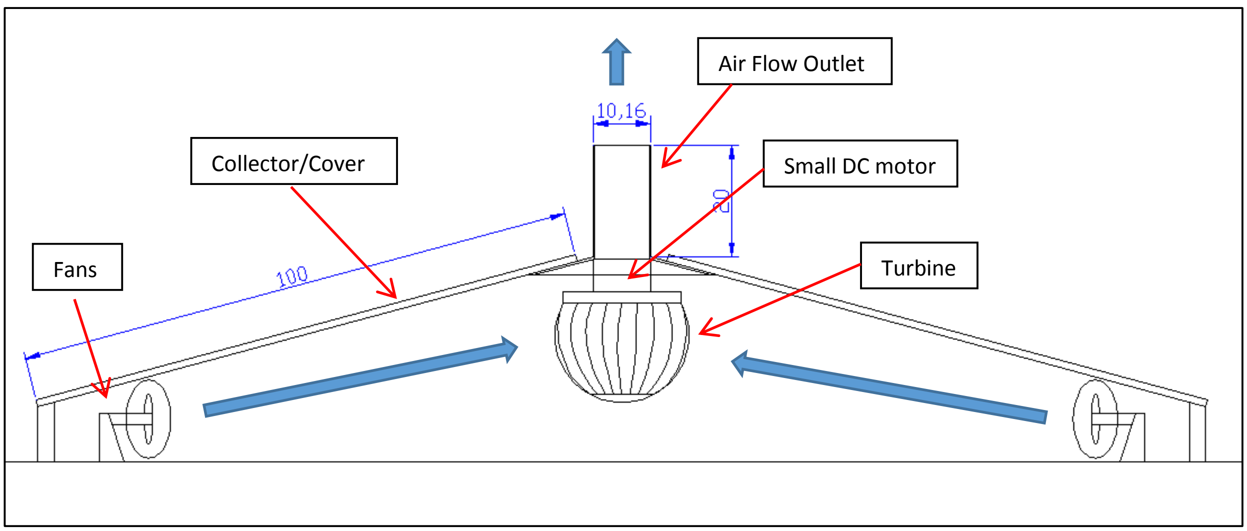


Figure 4.1: Front view of the experimental setup

Figure 4.2 shows the top view schematics of the experiment setups with the positions of the fans and Figure 4.3 shows the completed setup in the lab.

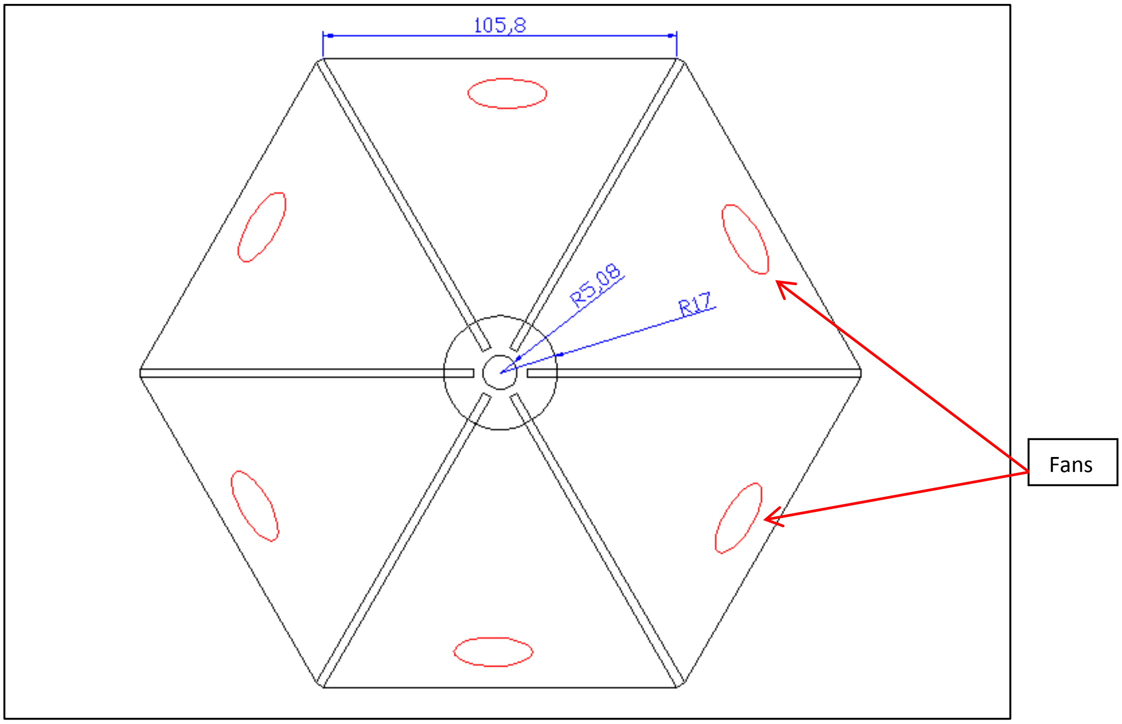


Figure 4.2; Top view of the experimental setup

Figure 4.3; the completed experimental setup

Air flow outlet

- Since we are conducting in-door experimentation the updraft tower is scaled down to only 20cm long which makes this air flow outlet. This outlet acts as a channel to flow out the air and this is where we will measure the outlet velocity.

Collector/Cover

- The collector in this experiment is not used for solar energy gathering since its in-door so the function of this collector is only to direct the air flow into the air outlet.

Fans

- Fans main function in this experiment is to replicate the air flow generated inside the solar collector in a normal solar chimney power plant. Since we are not using the buoyancy or stack effect, we will rely on these fans to generate the wind for the turbine. For this experiment we will be using 6 fans and the positions of these fans are shown in Fig. 4.2. These fans have 2 speed level with a power rating of 12V/15W.

Small DC motor

- We will be using a small DC motor to get the electrical output of the turbine. With this we can measure the torque of the turbine and thus able to do the power analysis.

Turbine

- The turbine we are using for this experiment is a type which is largely used in roof ventilation system. My aim is to find out whether its minimum operating wind speed is better than the conventional turbine used for solar chimney power plant.

- Figure 4.4 and Figure 4.5 shows the turbine used in the experiment:

Figure 4.4; top view of the turbine

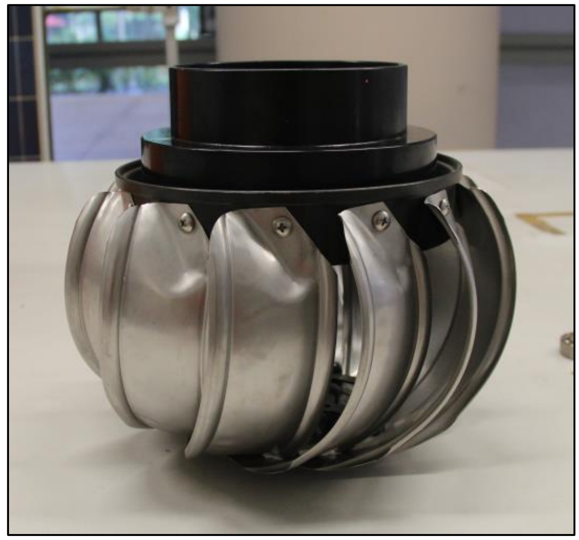


Figure 4.5; side view of the turbine

The table 4.1 below shows the design specifications of the turbine;

Roof Turbine		
Description	Value	Units
Outer Diameter	250	mm
Inner Diameter	200	mm
Aluminum Density	2700	Kg/m^3
Number of Blade	12	Pieces
Air density	1.225	Kg/m^3
Swept area of blade	630.9	mm^2
Output nozzle area	810.7	mm^2
Thickness of blade	0.8-1.2	mm^2

Table 4.1: Specifications of the experimental turbine

4.2 Experimental Procedure

The experiment procedures are as follows;

1. Setup the testing rig. Place the fans according to their respective positions with 90 cm distance from the turbine.
2. Turn on all the fans and set the fan's speed to level 1.
3. Observe the turbine and then record the outlet air velocity, wind speed just before the turbine, rotational speed of the turbine and the power generated.
4. Change the speed to level 2 and repeat step 3.
5. Move the fans forward to 55 cm and then to 20 cm distance from the turbine. Repeat step 2 to 4.

4.3 Experimental Apparatus

The apparatus used for recording the data are the anemometer for wind velocities, digital tachometer for the revolution speed and lastly the multi-meter for the voltage and current which is shown in Table 4.2.

No.	Apparatus	Name	Descriptions
1.0		Anemometer	This tool is used to measure wind velocity which for this experiment will be measuring the wind velocity at the outlet.
2.0		Digital Tachometer	This device will be used to measure the rotational speed of the turbine.

3.0		Multi-meter	This device is used to measure the electrical output of the small DC motor.
4.0		AutoCAD 2012	This will be the main designing tools. It is used to design the experiment setup.

Table 4.2: list of apparatus used

Anemometer

- Technical data of the anemometer is shown in Table 4.3:

Basic Function	Range	Resolution	Accuracy
m/s (meter/second)	0.40 ~ 45.0 m/s	0.1 m/s	± (2% + 0.1 m/s)
km/hr (kilometer/hour)	1.4 ~ 162.0 km/hr	0.1 km/hr	± (2% + 0.1 km/hr)
ft/min (feet/min)	80 ~ 8860 ft/min	0.1 ft/min	± (2% + 0.1 ft/min)
Knots (Nautical MPH)	0.8 ~ 88.0 knots	0.1 knots	± (2% + 0.1 knots)
Air flow			
CMM (m^3/min)	0 ~ 9999 m^3/min	0.001 ~ 0.1	
CFM (ft^3/min)	0 ~ 9999 ft^3/min	0.001 ~ 0.1	

Table 4.3: Technical data of anemometer

Digital Tachometer

- Technical data of the digital tachometer is shown in Table 4.4:

Basic Function	Description	
Range switching	Automatic	
Detection distance	Non-contact, 40mm to 50mm (1.58” to 19.7”)	
Resolution	Over 10000 count	
Sampling rate	0.5 to 10 times/sec	
Memory capacity	200 data sets	
Accuracy	AVG “ON”	AVG “OFF”
Up to 9999 counts	± 1 dgt	± 10 dgt
10000 counts or more	± 2 dgt	± 20 dgt
20000 counts or more (r/min mode only)	± 20 dgt	± 100 dgt
Period measurement only	± 0.5% rdg is added to above-mentioned accuracy	

Table 4.4: Technical data of digital tachometer

Multi-Meter

- Technical data of the multi-meter is shown in Table 4.5:

Basic Functions	Range	Accuracy
DC voltage	400mV/4V/40V/400V/1000V	± (0.8% + 1)
AC voltage	4V/40V/400V/750V	± (1% + 5)
DC current	400μA/4000μA/40mA/400mA/4A/10A	± (1% + 2)
AC current	400μA/4000μA/40mA/400mA/4A/10A	± (1.5% + 5)
Resistance	400Ω/4kΩ/40kΩ/400kΩ/4MΩ/40MΩ	± (1% + 2)
Capacitance	40nF/400nF/4μF/40μF/100μF	± (3% + 5)
Temperature	-40ºC to 1000ºC	± (1% + 3)
Frequency	10Hz to 10MHz	± (0.1% + 3)
Duty Cycle	0.1% to 99.9%	

Table 4.5: Technical data of the multi-meter

4.4 Data Collection & Analysis

Table 4.6 below shows the data collected from the experiment;

wind speed				RPM			
test 1	test 2	test 3	average	test 1	test 2	test 3	average
2.80	3.00	3.10	2.97	32.57	39.11	43.54	38.41
3.30	3.60	3.40	3.43	63.90	75.35	67.49	68.91
4.30	4.00	3.90	4.07	108.88	92.12	87.63	96.21
4.40	4.50	4.30	4.40	113.60	137.80	134.98	128.79
5.20	4.90	5.10	5.07	180.50	162.34	178.66	173.83
5.50	5.40	5.40	5.43	195.40	194.23	190.76	193.46

Table 4.6: Data collected from the experimentation

Based on the data collected a graph of the turbine rotational speed (RPM) against the average wind speed was plotted as shown in Figure 4.6.

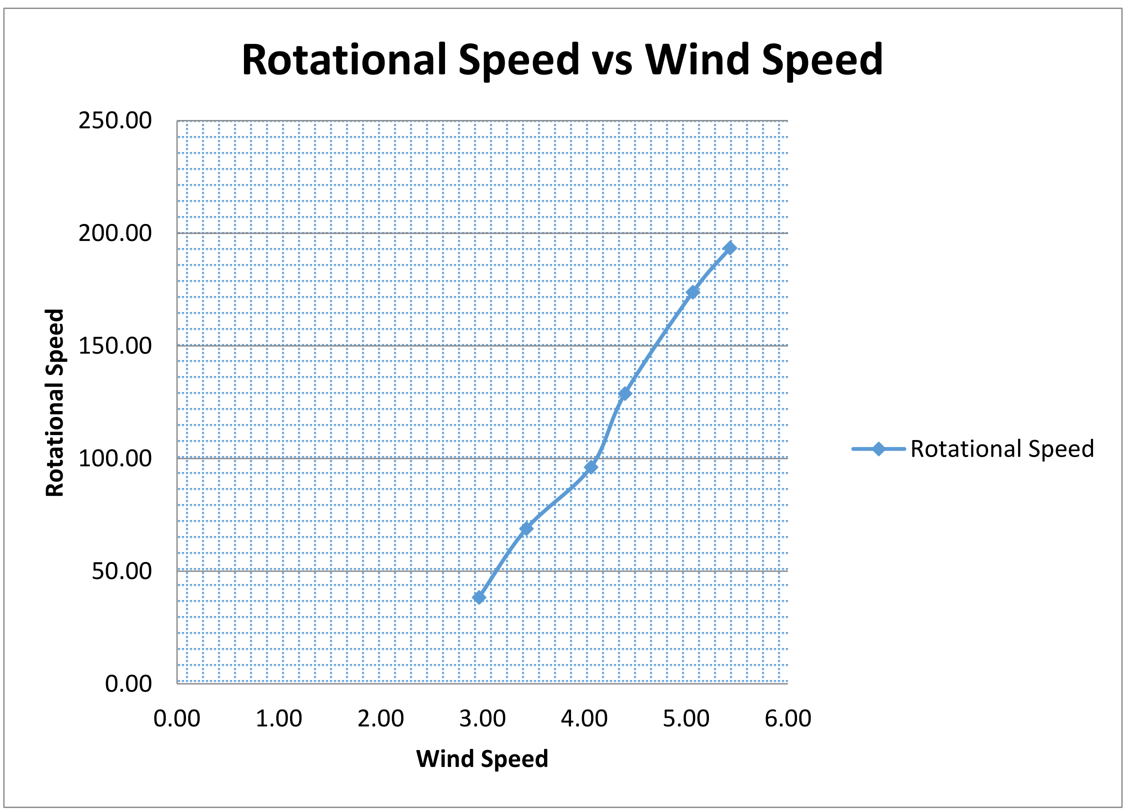


Figure 4.6: graph of turbine rotational speed vs average wind speed

From the graph we can see that the relation follows that of a normal wind turbine where, as the wind speed increases, the rotational speed also increases. This shows that the turbine rotational speed is linearly exponential to the wind speed. In the graph, the highest rotational speed is 193.46 rpm at wind speed of 5.43 m/s and the lowest rotational speed is 38.41 at wind speed of 2.97 m/s. with these findings, we can see that the turbine used in this experiment can operate at below 6.0 m/s wind speed which is proven with the lowest wind speed that induced rotation was at 2.80 m/s

4.5 Discussion

Based on the data collected and the plotted graph, we have seen that the turbine clear one of the objectives which is to be able to operate at below 6.0 m/s wind speed. In fact the turbine was able to operate at only half the optimum operating wind speed of that of a traditional solar chimney power plant turbine. This shows that the turbine possess great potential as an alternative type of turbine for low solar intensity areas or limited space areas.

Although these findings are very encouraging and positive, there are some few areas that leave some question marks to the validity of the experiment. The first and foremost is that the testing rig doesn’t exactly replicate the conditions occurring in a solar chimney power plant, more specifically the wind flow. In a normal solar chimney, the air flow comes from the sides and exits at the updraft tower and for this experimental setup the wind should flow out from the air outlet located at the middle of the rig but during the experiment I have noticed that the air flow coming out from the outlet is very small and most of the air escape to the sides.

This observation prompts me to assume that the turbine is a type of turbine that does not change the flow direction of the wind (eg. Horizontal to vertical flow) which would mean that the turbine is simply acting on the horizontal flow of the wind instead of a suction like effect in the normal solar chimney which uses the buoyancy and pressure difference to operate. Hence, to see if we can create that stack effect, we installed a 3m long PVC pipe to the outlet to check if there was any difference in the readings. Figure 4.6 shows the installed 3m PVC pipe.

Figure 4.6: Experimental setup with the installed 3m PVC pipe

The test result after installing the 3m PVC pipe shows no significant difference in the rotational speed and also the outlet air velocity. Based on this I conclude that even with the addition of the PVC pipe, the stack effect still cannot occur because there is no temperature difference in the collector and at the outlet which would imply that there is no pressure difference to make the air to flow into the outlet.

The second drawback in this experiment was that the turbine was not installed with the DC motor as generator. Due to some technicalities we were unable to install the generator in time for the testing period and hence we were not able to record the data for the power generation of the turbine.

With the data from the motor we should be able to find the torque made by the turbine and also the power generated from the rotational speed. With these extra values we can do the analysis on the power utilized by the turbine and analyze the turbine efficiency based on the utilized power and the maximum potential power in the wind. Apart from that with these data we can also evaluate the power coefficient of the turbine and compare them to other types of turbine used for solar chimney power plant.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter will conclude everything that had been done throughout the process from doing the literature reviews, preparing experimental procedure and making the report. This chapter also will provide recommendations for the future works to ensure everything will be carried out smoothly, manageable and finish on time.

5.1 Conclusion

Overall, throughout the two semesters timeline given to complete this project, the experimental setup and the experimental procedure was designed with accordance to the literature review and then the testing rig was fabricated for the turbine experimental testing. The turbine was purchased and modified to be able to be used for the solar chimney power plant and then put into testing with the fabricated testing rig. The data was recorded and analyzed which prove that the turbine used can definitely operate at below the optimal wind speed for traditional turbines.

With this I can conclude that the first and second objectives of this project which is to create an experimental setup for turbine testing and designing and fabricating of the turbine have been achieved. But as for the third objective which is to evaluate the turbine performance is only partial completed due to the lack of data especially on the motor part.

5.2 Recommendations

From the discussions earlier, we can see that there are a lot of things that need to be improved to get the best possible data from the experimental testing. First of all is to create an experimental setup that replicate the real air flow condition in the collector. One example of a setup that can do this is the setup used by Von Backström and Gannon, 2003, in their experimental research on diffuser. The configuration of the setup is shown in Figure 5.1.

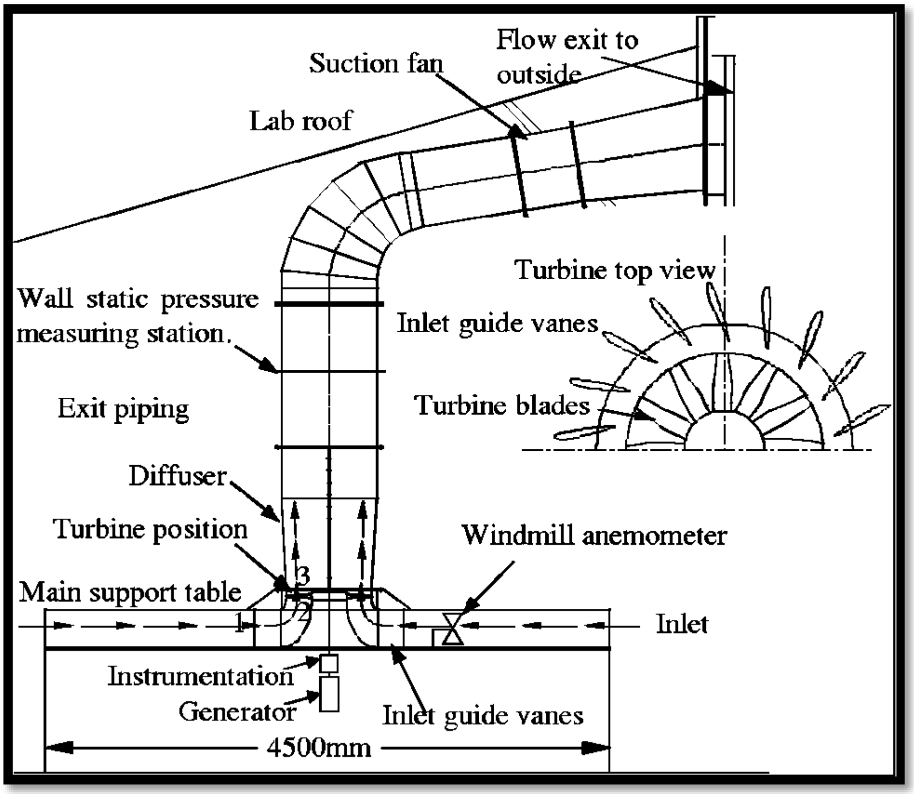


Figure 5.1: Solar Chimney turbine rig schematic (Von Backström and Gannon, 2003)

In this experimental setup, Von Backström and Gannon used a suction fan connected to the outlet to re-create the conditions in a real solar chimney. The suction fan will suck the air causing the outside air to flow into the inlet and flow towards the turbine.

One more possible solution for re-creating the solar chimney flow is by completely covering the sides of the setup to prevent air from escaping. By doing this there will be only one air outlet which is the updraft tower and this might be able to focus the air to the outlet. Though, this method is yet to be tested and proven its validity.

The second improvement we can do to the setup is to properly install the generator to the turbine. With the installation of the generator, we can do a complete performance analysis on the turbine and see if it is comparable with other types of turbine regularly used in the solar chimney power plant.

Another improvement that can be made is to use fans with higher wind speed capabilities. The fans can be like the one used in my experimental or it can be suction fans as per recommended earlier. With a more powerful fan, the wind speed range can be increased to provide with a more in-depth analysis of the behavior of the turbine under solar chimney conditions.

Most research on turbines uses wind range from 0 m/s to 20~30m/s and with a wind range of only 0 m/s to 6 m/s we are unable to do comparison with other studies based on the data collected. By increasing the range, we will be able to see whether the analysis is better than other turbine.

To sum it up, the experimental setup is still not complete in its own, there are still needs for further improvement in order to get the best possible results from the testing and also to reduce possible errors in the data collection. Even with that said, the setup has good potential to be useful in the long term to do studies on other types of turbine for the solar chimney power plant.

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