Faculty of Engineering

DESIGN AND FABRICATION OF SOLAR CHIMNEY

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Bachelor of Engineering with Honours

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Approval Sheet

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To my beloved family

And

Future green power generation

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ABSTRACT

Non renewable energy resources will soon be exhausted, consequently leading to the world energy crisis. As this happens, non renewable energy is being replaced by renewable energy resources. This work presents the design, fabrication and performance analysis of a solar chimney power generator. Solar Chimney power generator utilize hot air rise concept in power generation. The design consists of a chimney tower built on top of a circular solar collector. These two structures are connected via a curved cave called the chimney support. Below the solar collector lays the heat absorber plates and water tubes for heat storage which is later used for night operation. An air flow director is placed below the chimney to direct the air upward which then turns the electric generator in the chimney. Solar chimney is designed to generate electric power 24 hours a day based on the hot air rise concept. The overall performance of the solar chimney is studied in this project. In this project, the fabrication method was employed. The performance of a solar chimney is dependent on the sun radiation, solar collector's size, collector glass's transparency and ground type. The night operation performance is influenced by the ground properties and water tube size. The fabrication of solar chimney involves manufacturing a structure of 4.2m in diameter and 3m in height. With this prototype design it is hope 1W of energy will be obtained.

Keyword: solar energy, wind energy, solar chimney, renewable energy

ABSTRAK

Sumber tenaga tidak dapat diperbaharui semakin kehausan sehingga mengakibatkan krisis tenaga dalam dunia. Sumber tenaga tidak dapat diperbaharui sedang diganti dengan sumber tenaga dapat diperbaharui. Kertas kerja in melapor tentang reka bentuk, pembuatan dan analisa prestasi tentang penjana kuasa “Solar Chimney”. Penjana kuasa ”Solar Chimney” berfungsi berdasarkan konsep udara panas naik. Rekabentuk penjana kuasa “Solar Chimney” mengandungi sebatang cerobong yang dibina atas pengumpul suria yang berbentuk bulat. Kedua-dua struktur ini disambung dengan satu pengambung berbentuk kon yang bernama penyokong cerobong. Di bawah pengumpul suria terletak plat penyerap haba dan tuib air untuk penyimpanan tenaga supaya boleh diguna dalam operasi malam. Sebuah penuju aliran udara diletak di bawah cerobong untuk menujukan udara ke atas supaya penjana kuasa dapat dipusing untuk penjanaan kuasa. Penjana kuasa “Solar Chimney” adalah direka supaya dapat menjana kuasa elektrik 24 jam sehari. Prestasi keseluruhan penjana kuasa “Solar Chimney” dikaji dalam kertas kerja ini. Kertas kerja ini mengguna cara pembuatan prototaip untuk menganalisa prestasi penjana kuasa “Solar Chimney”. Prestasi penjana kuasa “Solar Chimney” bergantung kepada radiasi suria, saiz pengumpul suria, mutu gelas pengumpul suria, jenis penyerap haba yang diguna, kettingian cerobong dan kecekapan penjana kuasa. Kecekapan penjana kuasa “Solar Chimney” pada waktu malam dipengaruhi oleh sifat-sifat pengumpul haba dan saiz tuib air. Penjana kuasa “Solar Chimney” yang dibina mempunyai diameter 4.2m and setinggi 3m.

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NOMENCLATURE

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p	Pressure
v	Volume
V	Wind velocity
ρ	Density [kgm^{-3}]
e	Maximal net work output (J/kg)
η	Efficiency
H	Stagnation enthalpy
b	Exponent
h	Convective heat transfer coefficient [W/m2 K]
f	Friction factor
Re	Reynolds number
Pr	Prandtl number
k	Thermal conductivity [W/m K]
d	Diameter [m]
μ	Dynamic viscosity [kg/ms]
g	Gravitational acceleration
c	Specific heat capacity [J/kg K]
k	Thermal conductivity [W/m K]
r	Radius [m]
m	Mass
Q	Heat Energy
G_h	Horizontal Global Solar Radiation [Wm^{-2}]
A	Area
$\dot{Q}$	Heat flux [W]

Prefix

Δ	Change In Value

Subscript

Hc	Chimney Height [m]
a	Atmosphere
Coll	Collector
tot	Total
tt	Circumferential component
t	Total (stagnation) or turbine
Loss	Loss
rh	Collector roof to air under collector roof
h	Air under collector roof or hydraulic
ra	Collector roof to ambient air
m	Mean
p	Pressure
Tower	Tower

Turbine	Turbine
Solar	Solar
Plant	Plant

CHAPTER 1

INTRODUCTION TO SOLAR CHIMNEY

1.0 Introduction

Solar chimney is a hybrid solar and wind power generator that converts solar energy into wind power which is later use to generate electrical power. Solar chimney stands a great potential in easing the world energy crisis issue. Its low cost and low maintenance characteristic allow it to supply energy to developing country.

Despite many available energy sources, renewable energy is getting more attention due to decrease in amount of non-renewable energy resources such as petroleum and natural gas. At the same time, demand for safer and green power source had been increasing to achieve a better and safer lifestyle.

Knowing the advantages of renewable energy resources, many researches on renewable energy resources had been carried out. Popular application on renewable energy resources available nowadays includes solar power, wind power, tidal wave power, biomass power and hydro power. However many of these applications still do not operate at an efficient state.

Solar chimney is getting attention from the society mainly because it appears to be a new generation power generator that can meets current demand. Solar chimney is fuel by solar power which is a renewable power source. It also appears to be a green power generator because it does not emit any polluted gas or chemical waste.

Solar Chimney's concept was proposed by a German author, Hanns Günther in 1931. In 1982, a fully functional model was built in Manzaranes, Spain by Schlaich, Bergerman and Partner under direction of German engineer Prof. Dr. Ing. Jörg Schlaich . This Solar Chimney is 10 metres in diameter and 195 meter tall with a maximum power output of 50kW. This solar chimney had operated for approximately 8 years before it was destroyed in a thunderstorm. Before the incident happen, optimization data had been collected from the solar chimney. These data has been licensed to EnviroMission and Solar Mission Technologies Inc. USA to manufacture solar chimney. Currently this company is planning to build a fully functional solar chimney with an output of 200MW in New South Wales, Australia by year 2008.

Solar chimney power plant consists of a circular transparent glass canopy roof raised from the ground at certain height. It has a black circular chimney tower place at the center of the power plant. It contains one or more turbo-generators at its center base. Meanwhile, black colour heat absorber is laid on the ground below the transparent glass canopy. Water tubes are place between heat absorbers to allow night time power generation.

According to Schlaich, ref [11], a Solar Chimney power plant with a solar collector of 4000 meters in diameter and a 1500 meter tall chimney will produce 600 GWh/y. Solar chimney power plant produce electrical power at both presence and absent of sun radiation. When sun radiation penetrates the glass solar collector, it heats up the heat absorbers on the ground. The heated heat absorber in turn heats the adjacent air which eventually produces temperature different and pressure different. The pressure different between ambient air and center of solar collector results air to move towards and up into the central chimney to drive the generators. At night, heat source is provided by the water tube until they are cool down. A hydroelectric generator is also place to allow electricity be generated by cooled waters, driven by gravitational pull, return towards the periphery.

1.1 Challenges of The Project

Solar chimney prototype fabricate in this project is expected to has a low efficiency. This is due to the small size solar collector. More heat will lost through the perimeter while using a small size solar collector because it has greater perimeter per area unit. On the other hand, small solar collector size is more sensitive when subject to environment wind effects. Heated air is easily blown out before they escape through the chimney tower. This reduces the prototype's efficiency.

Actual high efficient small size pressure stage power generator is not easily obtains in local market. This would require others low rotational friction power generator is to be use as a substitute while the search of actual power generator is

carried out.

Fabricating tall chimney tower is beyond possible capability of current available technology for this project. Thus a shorter chimney tower is use. This leads to lower chimney tower efficiency and eventually reduce the overall power output.

1.2 Objective of The Project

Objective of this project is to design and fabricate a solar chimney prototype for performance evaluation. This project would be among the first step for Malaysia to look into a new renewable power generation technology – solar chimney power plant, which is hopefully, will bring Malaysia to less dependent on non renewable energy resources.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The world requires more green and renewable energy resources to support growth of current society. Many methods such as photovoltaic cell, wind turbine generator, hydroelectric and geothermal had been employed to meet this demand. Besides those mentioned method, one of the latest renewable energy resources invention, named solar chimney, begins to answer the call of rising green energy demand around the world. This chapter contains literature review of many researches done previously various researchers on the solar chimney power generator. Working concept, solar chimney power plant's component characteristics and constraint are discuss in this chapter.

2.1 Solar Chimney Working Concept

Solar chimney concept is originates from the natural occurrence of hot air rises. Consider the example of the sea breeze. The sun heats both land and sea, land heats up quicker than the sea to a higher temperature. Air over the land becomes hotter than the air over the sea surface causing hot air to rise on the land. This makes the land surface a lower air pressure area compare to the sea surface. Air moves from the area of higher

pressure over the sea to the area of lower pressure over the land. The cool sea air heats up as it moves over the land and so it rises, creating a cycle. The result of this cycle is a steady wind moving from the sea to the land.

In solar chimney, heat absorber act as land in changing the sun radiation into heat. Heated heat absorber heats air above its surface and causing them to rise. This creates a pressure difference between solar collector's air and environment, causing wind to flow between these areas. Cool air enter the solar collector is slowly heated up by heat absorber. Cool air temperature rises as it move across the heat absorber. This wind energy is harvests by wind turbines located at the center of solar chimney plant. This concept is illustrated in Figure 1.

During night time, wind energy is generated by heated water tubes in daytime. Fluids in the water tube will cool down by rejecting heats into the air above it. Heats rejected from the water tube heats up the air to a higher temperature causing them to rise. This again creates a pressure difference between the solar collector air and the environment, creating wind to flow between these areas. Cool air enter the solar collector is slowly heat up by rejected heat from the water tubes and rise as it move across the solar collector. These wind energy is harvested by wind turbines to generate electricity power. This concept is illustrated in Figure 2

A solar chimney plant would imitate this same type of system that occurs in nature, but with a greater degree of control and predictability. This results in more reliable wind with a higher average wind speed.

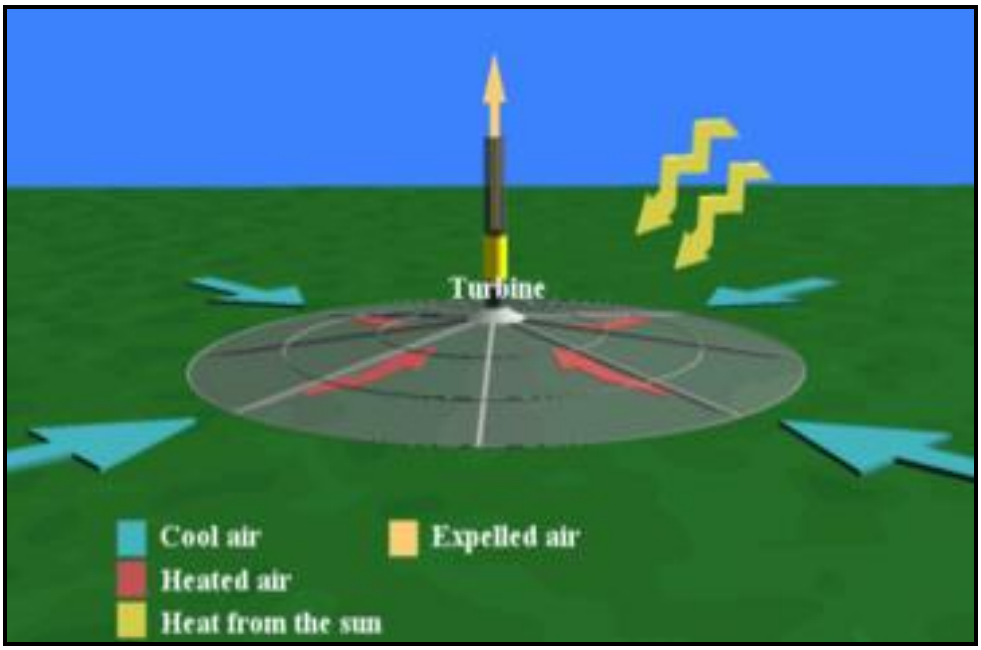

Figure 1 Solar chimney operation concept

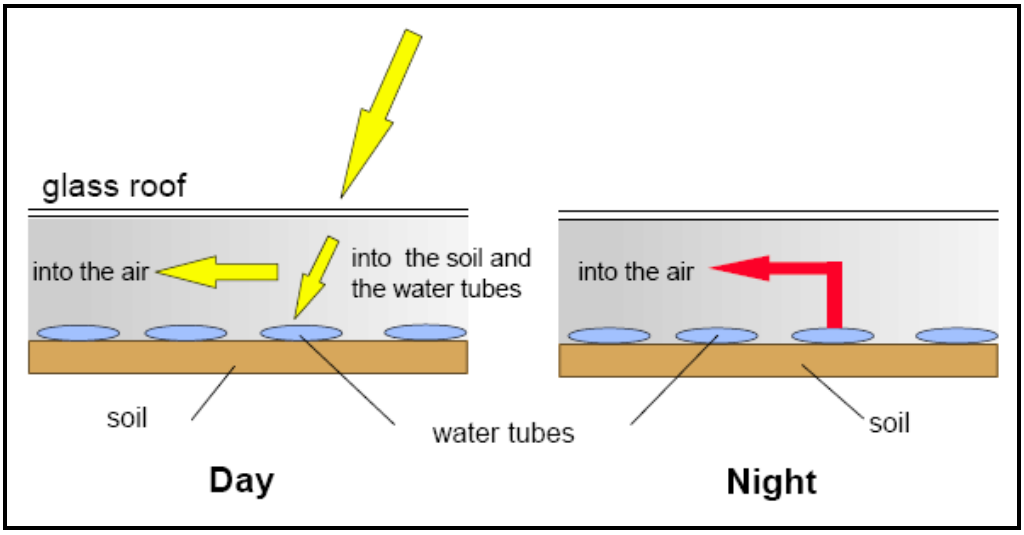

Figure 2 Principle of heat storage underneath the roof using water-filled black tubes

2.2 Solar Chimney's Structure

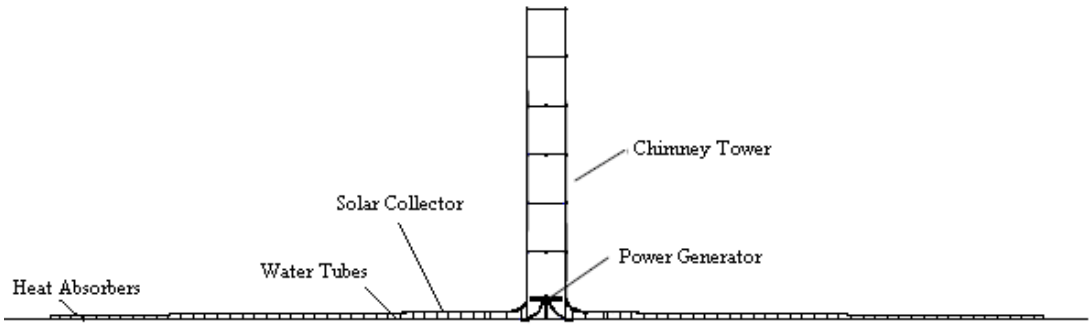

Figure 3 Solar chimney's structure

Solar chimney structure consists of 4 essential parts as illustrated in Figure 3. These parts are:

1. Chimney tower
2. Power Generator / Turbine
3. Solar Collector
4. Heat absorbers plate
5. Water Tube

2.2.1 Chimney Tower

Chimney tower acts as the key power generating structure in solar chimney power plant. Chimney tower structure approaches are well known and have been used in cooling tower for many years. It is basically a pressure tube with low friction loss. It is best built freestanding using a reinforced concrete material with its skin made of corrugated metal sheet. However, cable-net designs with cladding or membranes are also possible to use for build the skin.

Chimney tower main function is to create drawing effect in solar collector. This drawing effect is created due to occurrence of pressure different in chimney tower base and environment above the tower. It is stated in ref [18] that "a 1°C drop in temperature over every 100m facilitates the necessary updraft effect from the tower." Thus a normal chimney tower for the current available prototype was raise more than 100m from the ground.

Considering the air is separate from the surrounding atmosphere by a solid chimney structure. The pressure different all along the chimney length is eliminated. At the same time, the hot air is kept separate from the surrounding atmosphere. Thus, all elementary pressure differences at the chimney's bottom are sum up by the chimney tower. The accumulated pressure difference developed with regard to the surrounding atmosphere, amounts to

$$\Delta p_{Hc} = p_a(0) - p_{coll} \tag{1}$$

Pressure difference is linked to a maximum work output in the collector air by following equation.

$$e_{Hc} = -\int_0^{\Delta P_{Hc}} v_{coll}(p)dp \tag{2}$$

To produce pressure difference sufficient to spin the turbine, chimney tower would need to have certain height. Referring to Ref [11], a solar chimney power plant with a solar collector of 4000 meters in diameter should have an air channel length of approximate 1000 meters. The bottom end of the chimney tower should extend about