NUMERICAL ANALYSIS ON THE PERFORMANCE OF A SMALL-SCALE SOLAR CHIMNEY POWER PLANT FOR DIFFERENT GEOMETRICAL PARAMETERS

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This report is submitted
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DECLARATION

I declare that this project report entitled "NUMERICAL ANALYSIS ON THE PERFORMANCE OF A SMALL-SCALE SOLAR CHIMNEY POWER PLANT FOR DIFFERENT GEOMETRICAL PARAMETERS" is the result of my own work except as cited in references

Signature : ....
Name : TENG MENG XIAN
Date : 7/15/2021

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of degree of Bachelor of Mechanical Engineering.

Signature : ....

Name : MOHD NOOR ASRIL BIN SAADUN ~~TENG MENG XIAN~~

Date : 7/15/2021

DEDICATION

To my beloved mother and father and friends who always support me.

ABSTACT

With the increasing demand of energy each year, Solar chimney power plant (SCPP) is considered as one of the renewable energy power plant that may replace the conventional renewable energy source such as photovoltaic (PV) cell and fossil fuel when build it right solving the energy crisis of the world. This project generally be focusing on determine the optimum size of a SCPP by investigating different geometrical parameters of SCPP using Computational Fluid Dynamics (CFD) by simulating the flow in the SCPP. The different parameters involved in this study are the chimney's height, chimney's diameter and the shape of the solar collector of SCPP. The simulation is done in Three-dimensional (3D) and a validation was made to verify the result. From the simulation, the temperature and velocity of the SCPP was examined and it is found that the higher chimney height, smaller diameter of chimney and using square collector will help to increase the performance of SCPP.

ABSTRAK

Permintaan tenaga di seluruh dunia semakin meningkat setaip tahun dan untuk mengatasi masalah tersebut loji tenaga cerobong suria (SCPP) akan digunakan kerana SCPP dapat gantikan loji janakuasa tenega berkonvensional seperti sel photovoltaic (PV) serta bahan api fosil jikalau membina dengan kriteria yang betul. Oleh itu, Project ini memberi tumpuan kepada parameter yang optimum untuk membina SCPP dengan menyiasiat parameter yang berbeza, mengunakan Computational Fluid Dynamics (CFD) untuk mensimulasikan aliran udara dalam SCPP. Parameter yang akan diuji ialah ketinggian cerobong, diameter cerobong dan bentuk pengumpul suria. Simulasi ini dilakukan dalam bentuk 3-D. selain itu, pengesahan data dilaksanakan untuk menentukan ketetapan data. Data utama iaitu, Suhu dan halaju direkodkan semasa melakukan simulasi dan didapati bahawa prestasi SCPP akan menigkat jika ketingian cerobong semakin tinggi, diameter cerobong semakin kecil dan mengunakan pengumpul suria yang berbentuk segi empat.

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LIST OF ABBREVIATION

SCPP	Solar Chimney Power Plant
PV	Photovoltaic
CFD	Computational Fluid Dynamics
DO	Discrete Ordinates
RTE	Radiative Transport Equation
Rans	Reynolds-averaged Navier Stokes

LIST OF SYMBOLS

P	=	Density of fluid (kg/m^3)
U	=	Flow velocity (m/s)
P	=	Pressure (Pa)
F	=	External Force (kg m/s^2)
μ	=	Kinematic viscosity (m^2/s)
Q	=	Heat supplied (W/m^2)
W	=	Work done by the system (kg.m^2/s^2)
σ	=	Stefan-Boltzmann constant (5.67 X 10^{-8} W/m^{2}K)
σ_s	=	Scattering coefficient of gas
a	=	Absorption coefficient of gas
n	=	Refractive index of gas
r	=	Cartesian coordinate in system (x,y,z)
s	=	Unit vector in the direction of the beam
A_{coll}	=	Collector surface area (m^2)
G	=	Solar radiation (W/m^2)
m	=	Mass flow rate of air (kg/s)
C_p	=	Specific heat capacity of air (kj/kg.K)
ΔT	=	Temperature difference (K)
n_t	=	Turbine isentropic efficiency
n_{tg}	=	Efficiency of turbine generator

ΔP_t	=	Pressure difference at turbine (Pa)
$V_{ch.max}$	=	Maximum velocity in the chimney (m/s)
A_{ch}	=	Cross-sectional area of chimney (m^2)
H_{ch}	=	Chimney Tower's Height (m)
D_{ch}	=	Chimeny Tower's Diameter (cm)
R_c	=	Solar Collector's Radius (m)
H_c	=	Solar Collector inlet's Height (m)

Chapter 1

INTRODUCTION

1.1 Background

The energy consumption around the world has been increase by 3.1% per year due to the growth of the population and technology advancement [1]. Most of the energy around the world comes from fossil fuel in the form of coal, natural gas and oil. In the United States, about 81% of its total energy come from fossil fuel and it is used on everything from vehicles to power industry and manufacturing or even heating residential houses [2]. However, human dependence over fossil fuel as primary fuel source must come to an end as in just around 47 years to come the world oil reserves will be depleted completely [3]. Therefore, it is wise to prepare for the scenario right now by investing into renewable energy sources to reduce dependence of fossil fuel.

There are many promising renewable sources that are currently under development such as solar farms, Ocean thermal energy conversion (OTEC), wave energy, etc. In Malaysia, a growing number of solar farms can be seen across the country as Malaysia received huge amount of solar energy from the sun yearly due to it located on the equator of the earth. Besides that, solar energy is considered as one of the most promising sources of clean energy due to the low maintenance cost and no emission of harmful gas. Nevertheless, among the solar technologies, solar chimney power plant (SCPP) is one of the rarer types that also gathered interest of others. The SCPP is a system that uses the wind to generate electricity. It consists of three main components, the solar collector, chimney and a wind turbine. The turbine is located at the center of the chimney and is driven by the airflow generated by the buoyancy created from the greenhouse effect inside the collector.

SCPP has many advantages due to it does not require any fuel source and can be located literally anywhere in the deserts or sun-rich plains. Besides that, SCPP can also be operated on both clear and cloudy days. Furthermore, there is also many studies to further increase the efficiency of the solar chimney power plant by creating hybrid power plant such as solar chimney power plant integrated with seawater desalination (SCPP-SD) which increases the electricity generated and also produces fresh water at the same time [4].

1.2 Problem statement

In Malaysia, SCPP is not well known and did not get much attention. Therefore, in order to educate the masses, a SCPP can be built in Malaysia. However, the SCPP build will need to be operating at maximum efficiency to attract future investor. Hence, to obtain the maximum efficiency of the SCPP, a study needs to be done in order to known what geometric parameters will affect the efficiency of the SCPP and what is the best configuration for the construction of the tower.

1.3 Objective

The objectives of this project are as follows:

1. To develop a CFD model of solar chimney using ANSYS Fluent 16.0
2. Determine the efficiency of the solar chimney power plant using different geometric parameters of the tower.
3. To identify the best configuration for the solar chimney tower

1.4 Scope of work

This study will involve only CFD analysis using ANSYS Fluent 16.0. The geometric parameters of the tower that changed were the height of the chimney, the diameter of chimney and the shape of the solar chimney collector. Besides that, this simulation on the solar chimney power plant will be assume to be carried out in perfect condition without taking consideration of external factor such as the changing position of the sun throughout the time and the changes of ambient temperature. Furthermore, the simulation will be performed in 3D.

Chapter 2

Literature Review

2.1 Introduction

Solar chimney power plant (SCPP) is a type of renewable energy power plant for generating electricity by utilizing the surrounding warm air. A simple SCPP consists of three main components, a solar collector, chimney and wind turbine. All of those main components will work together in conjunction with each other to produce air flow to power the turbine. The solar collector will be made from transparent material such as glass or semi-transparent plastic to act as a greenhouse that traps sun's energy under the solar collector and heat up the air inside the collector. Next, the chimney will serve as the thermal engine of the plant which creates suction that draws in surrounding air into the collector further increases the temperature of air while also decreasing the air density which increase the velocity of air. Finally, the turbine will act as the energy conversion for the SCPP which converts the kinetic energy of air into mechanical energy and to electrical energy which enables collection and utilization.

Besides that, there exits studies and prototype of the SCPP [5] and it is proven that this method of harvesting energy using the sun is viable as the efficiency of the SCPP will keep increases when the size and height of the solar collector and chimney increases. However, with this advantage of increasing efficiency there is also the disadvantages of increasing cost when the size of the SCPP increases. As a result, it is best to build a SCPP with its optimum parameters to prevent high cost while maintaining the highest efficiency of SCPP.

Therefore, the SCPP operates the best at places with lots of sun and on cheap flat land such as desserts or low nutrients soil. Besides that, because of SCPP is fueled by hot air, it is able to operate in the day using the sun to heat the surrounding air and also in the night where the ground releases heat absorbed by the sunlight during the day. Therefore, this give SCPP an distinct advantage over the conventional renewable energy such as Photovoltaic (PV) cell or the wind turbine as both of them only generates energy when certain requirement is met whereas SCPP are able to operate during the day and night.

2.2 Type of Study for Solar Chimney

There are 2 ways to determine the flow of a system, by performing model experiment which a smaller substitute system is directly examined and acquire data by changing the variables or using Computational Fluid Dynamics (CFD) Ansys Fluent software to simulate and predict the fluid flow, heat and mass transfer of a system. Besides that, in order to study the characteristics of fluid flows, both of the method will be used in conjunction to prove that the data collected by both of them are correct. However, building multiple substitute model in order to conduct an experiment and verify prediction is a waste of recourse, time and money as the multiple different models only have little variable changes to the data collected.

When using Computational Fluid Dynamics (CFD) Ansys Fluent software to simulate the flow of air through the solar chimney, the Navier-Stokes's equation is used to described the flow. The Navier-Stokes's equation consists of continuity, momentum and energy transport equations.

From Table 2.1, most of the previous studies did not perform experiment in order to validate their data but instead validation is done by comparing the simulation perform with past SCPP prototype experiment. As a result, several studies will have similar parameters for the SCPP in their design. For example, both Lu et.al [4] and Ali et.al [16] SCPP model have the same parameters because they validate their data using the Manzanares SCPP, mirroring the model in the process.

Table 2.1: The table of different parameters and method of experiment used by different studies.

Author	Year	Method	Parameters			Findings
Nasif et.al [6]	2019	• Simulation	Model used	3D		There exists critical point for each parameter of SCPP.
			Chimney tower Parameters	Hch (m)	Dch (m)	The best optimization of Diameter and height of SCPP's tower are 0.3 m and 3.4 m respectively.
				3.0	0.20	
			Collector Parameters	Rc (m)	Hc (m)	Further increase in height or diameter pass the critical point will loss efficiency.
				1.5	0.06	
Walid et.al [22]	2019	• Simulation • Experiment	Model used	Prototype & 3D		Geometric calculation shows that the square collector had an increase of inlet area by 11.4% when compare to circular collector.
			Chimney tower Parameters	Hch (m)	Dch (m)	The temperature of circular shape collector had higher temperature then square shape collector.
				20.0	1.0	
			Circular Collector Parameters	Rc (m)	Hc (m)	Due to an increase of inlet area of square collector which resulted in increase of 7.6% mass flow rate produces higher output power when compare to circular collector.
				-	1.25	
			Square Collector Parameters	x (m)	y (m)	
				28.5	28.5	
Haythem et.al [8]	2019	• Simulation • Experiment	Model used	Prototype & 3D		The straight shape of the chimney is change to hyperbolic.
			Chimney tower Parameters	Hch (m)	Dch (m)	It is found that by using a hyperbolic shape chimney the height of are able to increases pass the critical value of chimney height.
				2.95	0.16	
			Collector Parameters	Rc (m)	Hc (m)	With a hyperbolic chimney the efficiency of the power generated is increases by 295%.
				1.85	0.1	
Lu et.al [4]	2020	• Simulation	Model used	3D		This study replaces the absorber under the solar collector with a layer of seawater minimize energy loss.
			Chimney tower Parameters	Hch (m)	Dch (m)	Able to produce freshwater while generating electricity.
				194.6	5.08	
			Collector Parameters	Rc (m)	Hc (m)	The power generated from the SCPP is increases from 193.7kW to 224.1kW and also generating 13 ton/h of fresh water.
				122.0	1.85	
Ali et.al [16]	2020	• Simulation	Model used	3D		Combine geothermal energy with SCPP into a new hybrid system.
			Chimney tower Parameters	Hch (m)	Dch (m)	Able to produce consistent electricity throughout the day and night.
				194.6	5.08	The generated power during the night is between 3-7 kW depending on the depth of the geothermal well.
			Collector Parameters	Rc (m)	Hc (m)	
				122.0	1.85	

2.3 Chimney Tower

The chimney tower is located at the center of the collector. It acts as the SCPP's thermal engine which creates suction that draws in surrounding air into the collector and also increases the air temperature using the sun. Besides that, the chimney tower height contributes greatly to the efficiency of the SCPP. The taller the chimney, the output power also increases. However, there is also concern on building a tall chimney tower as the taller the structure is built the more vulnerable it is to external factor such as high wind velocity or other natural forces such as earthquake or flood. As a result, a chimney is usually built with reduced height but with an increase of collector area to compensate for the loss of height.

Furthermore, there is only a certain amount of height a chimney can be build and at any further will not yield any noticeable increase in efficient but the cost will be greatly increase, as more resources is needed to pour into strengthening the tower by using corrugated metal sheets or cladding cable net.

Therefore, in order to increase the SCPP efficient while limiting the height of the chimney, different shape of chimney will be utilized. For example, there is a study conducted by Haythem et.al [8] on design SCPP with hyperbolic chimney shape as shown in Figure 2.1 below.

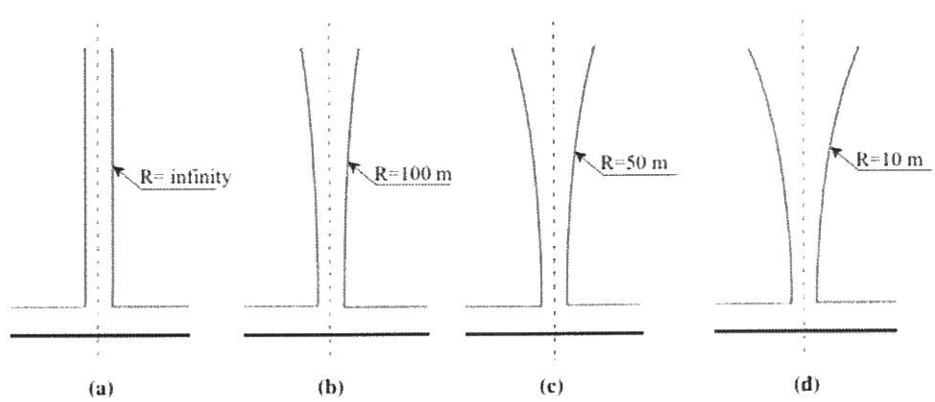

Figure 2.1: Different configurations design of solar chimney. [8]