Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2017
(ICMERE2017) 18 – 20 December, 2017, Chittagong, Bangladesh

ICMERE2017-PI-109

DESIGN & FABRICATION OF A SOLAR CHIMNEY POWER GENERATION SYSTEM

Istiak Ahmed [1], Md. Nesar Ali [2], Dr. Bodius Salam [3]

[1, 2] Graduate, Chittagong University of Engineering & Technology

[3] Professor, Chittagong University of Engineering & Technology

istiak.ahmed9367@gmail.com [1], nesarali455@gmail.com [2], bodiussalam@yahoo.com [3]

Abstract: *Solar power generation system is the conversion of energy from sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect. An energy crisis is any significant bottleneck in the supply of energy resources to an economy. In popular literature, it often refers to one of the energy sources used at a certain time and place, in particular those that supply national electricity grids or those used as fuel in vehicles. Industrial development and population growth have led to a surge in the global demand for energy in recent years. Most renewable energy comes either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity, and for hot water heating, solar cooling, and a variety of commercial and industrial uses. In my experiment essential elements are collector, chimney & turbine. My experiment procedure is mainly depends on the natural convection system. Around 2.6 watt power can be generated by using this experiment procedure & by applying this method in our power generation system we can reduce our national energy crisis.*

Key words: Solar power, Electricity, Photovoltaic, Collector, Chimney, Turbine, Natural Convection

1. INTRODUCTION

Electricity is the backbone of each industrial society and economy and the available energy sources for power generation can be classified in two types: conventional (non-renewable) and non-conventional (renewable). As the conventional energy sources are polluting and expensive too, there is the need of alternative energy sources. In this regard solar energy is the most promising alternative because of its abundance and pollution free nature. In modern market renewable energy depends on energy sources like heating and cooling, lighting, transportation etc. being the most abundant and well supplied form of renewable energy, a list of solar technologies are used to produce power. The solar chimney power generation system is one of them. This solar chimney power plant (SCPP), also known as solar updraft tower (SUT) has been developed in the latter half of the last century. Generally it is a solar thermal electrical power generating plant which transforms the solar energy into electrical energy through a heat transfer process. The solar chimney power plant usually operates like a hydroelectric power plant. In hydroelectric power plant water is used but in this SCPP system air is used instead of water. Solar panels are used as a collector of heat from sun. The output of solar cell depends upon the intensity of sunlight and the angle of incidence. A chimney in the middle sucks the heated air and the air passes with a velocity and this air suction is driving wind turbines which are placed in the chimney. The turbine is connected with a generator to produce current. Though the initial building cost of solar chimney power plant (SCPP) system is a little bit high, it is more effective and useful and less expensive than the conventional power generation system. So it is hoped that the project on "power generation by using solar chimney" will fulfill the demand of age.

2. LITERATURE REVIEW

A chimney turbine was envisioned as a smoke jack, and illustrated 500 years ago by Leonardo da Vinci. An animal spitted above a fire or in an oven could be turned by a vertical axis turbine with four angled vanes in the chimney updraft. In 1896, Mr. Alfred Rosling Bennett published the first patent describing a "Convection Mill". Even if in the title of the Patent and in the claims the word "Toy" clearly appears and even if in the overall description made inside the Patent it is evident that the idea was to produce small devices, in page 3 at lines 49-54 Bennett envisions much larger devices for bigger scale applications. A model of this "convection mill", built in 1919 by Albert H. Holmes & Son (London) to demonstrate the phenomenon of convection currents, is on display in the Science Museum, London. In 1903, Isidoro Cabanyes, a colonel in the Spanish army, proposed a solar chimney power plant in the magazine *La energía eléctrica*. In 1926 Prof Engineer Bernard Dubos proposed to the French Academy of Sciences the construction of a Solar Aero-Electric Power Plant in North Africa with its solar chimney on the slope of a large mountain. A mountainside updraft tower can also function as a vertical greenhouse. Based on the need for plans for long-term energy strategies, Botswana's Ministry of Science and Technology designed and built a small-scale research tower. This experiment ran from 7 October to 22 November 2005. In mid-2008, the Namibian government approved a proposal for the construction of a 400 MW solar chimney called the 'Green tower'. The tower is planned to be 1.5 kilometers (4,900 ft) tall and 280 meters (920 ft) in diameter, and the base will consist of a 37 square kilometers (14 sq mi) greenhouse in which cash crops can be grown. SUT demonstration for a school science fair was constructed and studied in 2012, in a suburban Connecticut setting. With a 7-metre stack and 100 square meter collector, this generated a daily average 6.34 mW, from a computer fan as a turbine. Insolation and wind were the major factors on variance (range from 0.12 to 21.78 mW) in output. The literature review about SCPP presents an outstanding technological development enlightening considerable advances in tis construction, operation, including its technical economic and ecological relevant facts. In contrast with other solar facilities, SCPPs can be used above and beyond power production. [1]

3. METHODOLOGY

Power output depends primarily on two factors: collector area and chimney height. A larger area collects and warms a greater volume of air to flow up the chimney. Heat is stored inside the collector area allowing SUTs to operate 24 hours a day. The ground beneath the solar collector, water in bags or tubes, or a saltwater thermal sink in the collector could add thermal capacity and inertia to the collector. Humidity of the updraft and condensation in the chimney could increase the energy flux of the system. Turbines with a horizontal axis can be installed in a ring around the base of the tower, as once planned for an Australian project and seen in the diagram above; or—as in the prototype in Spain—a single vertical axis turbine can be installed inside the chimney. Locating a tower at high latitudes could produce up to 85 per cent of the output of a similar plant located closer to the equator, if the collection area is sloped significantly toward the equator. The sloped collector field, which also functions as a chimney. [2] In our project there exists three major steps to complete our experiment. Firstly, Polythene is used as collector medium. Secondly, Solar heated air move to the chimney as hot air is lighter than cold air. Finally. The heat energy is converted into kinetic energy to run a turbine.

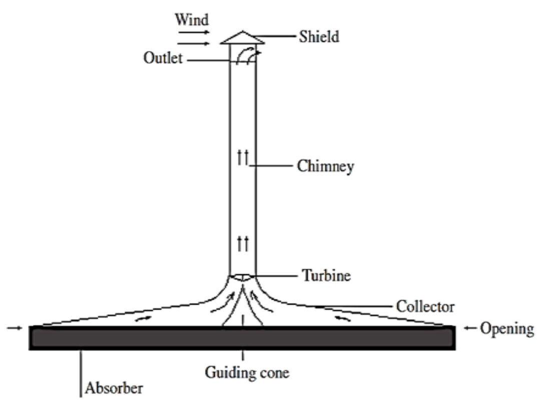

Fig 1: Solar chimney power plants (SCPP) components

The solar chimney power plant is a simple solar thermal power plant that is capable of converting solar energy into thermal energy in the solar collector. In the second stage, the generated thermal energy is converted into kinetic energy in the chimney and ultimately into electric energy using a combination of a wind turbine and a generator. So there will be three basic parts in this project. They are – collector (transparent plastic), chimney and turbine. The ground surface underneath the collector will be colored as black as the color black can absorb the solar radiant energy most. The three primary components of a solar updraft tower are the solar collector, the tower or chimney and the turbine. The following sections describe the important components, their role in the tower, and their material and construction.

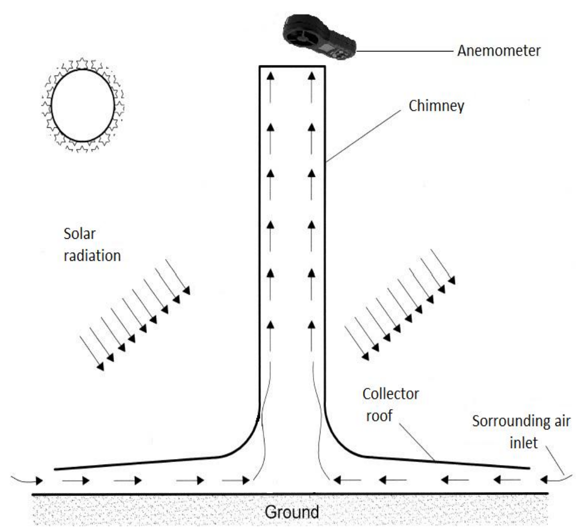

Fig 2: Design of a SCPP

The SCPP has notable advantages in comparison with other power production technologies, namely (Schlaich, 1995):

1. The collector uses both direct and diffuse radiation,

2. The ground provides a natural heat storage,

3. The low number of rotating parts ensure its reliability,

4. No cooling water is necessary for its operation,

5. Simple materials and known technologies are used in its construction and

6. Non OECD countries are able to implement such technology without costly technological efforts.

The most import part of Solar Chimney Power Plant (SCPP) is collector. The collector surface gradually rises closer to the tower, to direct the heated air towards the tower, and then curves up sharply at the base of the tower in order to transition the air flow up the tower. In our project the base length of the collector is 5 feet or 1.5 meter. The collector is in square pyramid shape. The height of the conical portion is 8 inches or 0.2 meter and total 0.35 meter including the support or legs. There are extra 4 inches extruded upward from the upper diameter which help to hold the chimney. The ground surface is painted black as black can absorb more heat than any color.

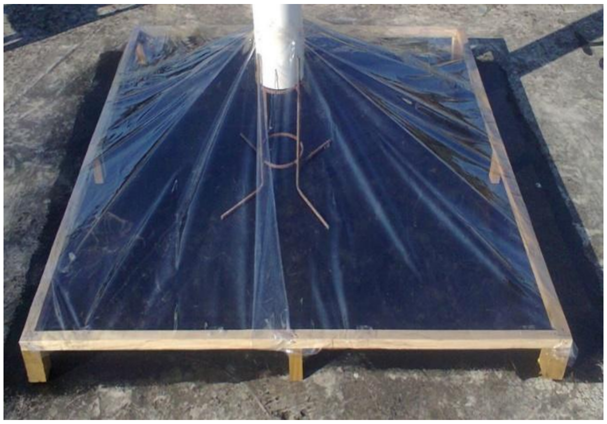

Fig 3: Base collector

On the other hand, another important part is 'chimney'. The chimney or tower of a solar updraft tower is the thermal engine of the plant. The heated air from the collector is funneled into the chimney, where the buoyancy difference between the heated air and the surrounding atmosphere creates a pressure difference that drives the air up the chimney.

Fig 4: The chimney

In our experiment, we used 6 inches diameter PVC pipe is used as a chimney. The height of the chimney is 6 feet tall because more the height more the air flow.

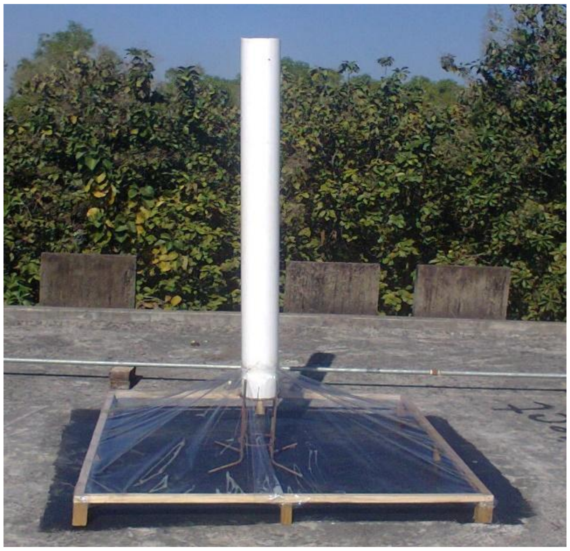

Fig 5: Prototype Solar Chimney Power Plant (SCPP)

Solar updraft towers provide another renewable power option for areas that are good candidates for solar concentrating or solar photovoltaic power generation facilities. Proposed projects have typically focused on large towers in countries with well-developed like USA, CANADA, EU and AUSTARLIA energy infrastructures. This project describes the power generation principal of solar updraft towers, their construction and operation, the technological challenges facing solar updraft towers and cost factors in the construction and operation of solar updraft towers in developing countries like BANGLADESH, INDIA, PAKISTAN, NEPAL, BHUTAN and SRI LANKA.

4. RESULTS & DISCUSSION

4.1 DATA INTERPRETATION:

Two consecutive sunny days data will evaluate our project work. Data took from two sunny days (2 Jan & 3 Jan, 2017). The velocity of air outside the chimney and inside the chimney is measured by a digital anemometer. It also shows the reading of the atmospheric temperature.

Table 1: Data took from (2/01/2017)

Time	Atmospheric Temperature °C	Anemometer reading of max^m wind velocity(m/s)	Anemometer reading of solar chimney, V (m/s)	Volume flow rate, $\dot{Q}$	Power output. P_{out} (watt)
11.10	28.1	0.3	0.6	2.3	0.4
11.20	28.1	0.3	0.8	3.07	0.98
11.30	28.2	0.4	0.9	3.4	1.37
11.40	28.4	0.4	0.9	3.4	1.37
11.50	28.7	0.4	0.9	3.4	1.37
12.00	29.1	0.5	1.1	4.2	2.54
12.10	29.4	0.5	0.9	3.4	1.37
12.20	29.7	0.5	0.9	3.4	1.37
12.30	29.8	0.5	1.0	3.8	1.9
		Avg.= 0.38	Avg.= 0.87		

Table 1: Data took from (3/01/2017)

Time	Atmospheric Temperature °C	Anemometer reading of max^m wind velocity(m/s)	Anemometer reading of solar chimney, V (m/s)	Volume flow rate, $\dot{Q}$ m^3/s	Power output. P_{out} (watt)
10.30	24.7	0.2	0.8	3.07	0.98
10.45	24.8	0.2	0.9	3.45	1.4
11.00	24.9	0.3	1.0	3.84	1.9
11.15	25.7	0.3	1.1	4.2	2.54
11.30	26.5	0.3	1.1	4.2	2.54
11.45	27.2	0.4	1.3	4.9	4.14
12.00	27.7	0.4	1.3	4.9	4.14
12.15	27.6	0.5	1.2	4.6	3.31
12.30	27.6	0.4	1.1	4.2	2.54
12.45	27.5	0.4	1.1	4.2	2.54
01.00	27.3	0.4	1.1	4.2	2.54
01.15	27.2	0.3	1.0	3.84	1.9
01.30	27.1	0.3	1.0	3.84	1.9
02.00	27.0	0.2	0.9	3.45	1.4
02.15	27.0	0.2	0.8	3.07	0.98
02.30	26.8	0.2	0.8	3.07	0.98
02.45	26.5	0.2	0.7	2.6	0.64
03.00	26.4	0.2	0.7	2.6	0.64
03.15	26.3	0.2	0.7	2.6	0.64
03.30	26.2	0.2	0.7	2.6	0.64
		Avg. = 0.29	Avg. = 0.97		

The formula of the area of a square pyramid can be found as

$A = a^2 + 2a\,(a^2/4 + h^2)^{1/2}$

Flow rate, $\dot{Q} = Av$

Mass flow rate, $\dot{m}$= density × flow rate

Power output, $\dot{P}_{out} = 0.5 \times m \times v^2$

Cross sectional area of the pipe= πr^2

Where,

a= Base length

h= height

v= Corresponding day Air velocity, ms^{-1}

Putting the standard values while project working we found out the area of a square pyramid is.

A= 3.2 m^2, from the table we can calculate that,

For 02 Jan, Q= 2.56 m^3/s, $\dot{m}$= 3.07 kg/s and $\dot{P}_{out}$= 1.2 watt

And for 03 Jan, $\dot{Q}$= 3.10 m^3/s, $\dot{m}$= 3.72 kg/s and

$\dot{P}_{out}$= 1.75 watt

Solar intensity calculation, the formula of the cross sectional area of the collector can be found as,

The required base area, $A_{s=}$ 1.58 m^2

Solar intensity =132 watt/m^2 [12]

So, incident solar energy =132*1.58 =210 watt

4.2 PERFORMANCE EVALUATION:

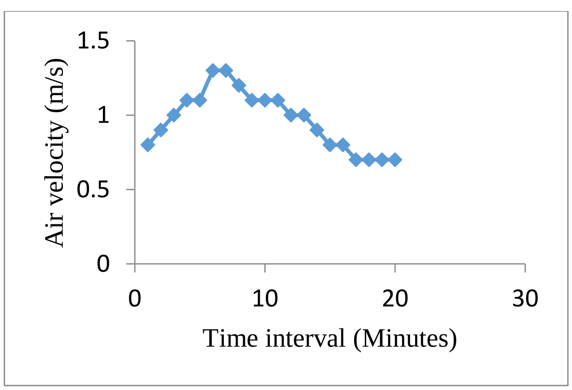

Fig 6: Time intervals vs Air velocity (m/s)

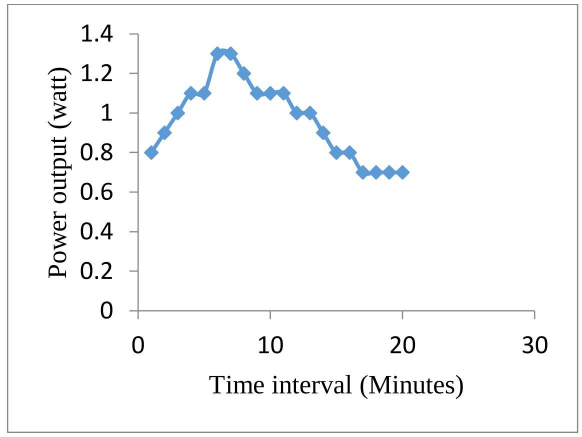

Fig 7: Time intervals vs Power output (watt)

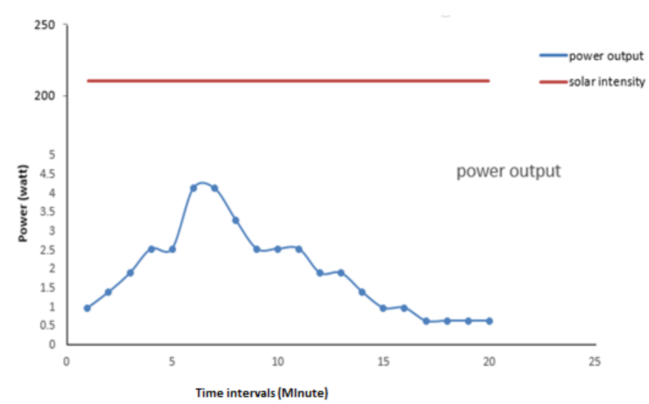

Fig 8: Comparison between Solar radiation intensity and Experimental output

4.3 DISCUSSION:

The analysis is based on the simple mathematical model expressed in theory. The result is described with some curves found in a typical day. The results presented by the curves were reasonably approaching to the expectations though there had been some deviations due to many things. Some deviations occurred due to outside wind. When outside wind flows in such a direction that opposes the hot air flow the output suddenly falls. Also the wind can be a help when it flows in the same direction or it has a component in the same direction. That's why certain volatilities were found in some curves with sudden rising and sharp falls. Thus the curves were not symmetrical or close to symmetrical with the vertical axis of 12 pm. This happened due to the greenhouse effect of the collector. When the sun started to fall from the maximum position the outside temperature started to fall. But the heat trapped inside the collector kept it warm. Also the use of black concrete i.e. concrete covered with tar as base, worked as a heat storage and provided to make a better greenhouse effect. Thus after doing this project also found out fresh source of energy which initial cost may high but its working principle and mechanism more environmental friendly. Having some experimental error but we also generate average 1.35 watt (On 02/01/2017, Average atmospheric air velocity was 0.38 m/s, solar chimney air velocity was 0.87 m/s energy and power generated was 1.2 watt and on 03/01/2017 Average atmospheric air velocity was 0.29 m/s, solar chimney air velocity was 0.97 m/s and power generated was 1.75 watt which may small but significant.

5. CONCLUSION

Solar thermal technologies have a promising future and could become an economically valuable energy sources. Solar energy has disadvantage also. Sunlight is a free and renewable source of fuel. Solar thermal energy has minimum impact on the environment. Here the solar chimney plant is next generation power producing sector. The main disadvantage of solar chimney system is it would require a larger initial capital outlay. Again it needs larger area. But government or other resourceful agencies can provide the initial cost. And solar chimney power plants are not only more effective and useful but also overall less expensive than the conventional power generation system. The next step on the development of solar chimney technology can be the construction of a solar chimney power plant with a turbine coupled with generator at chimney base. There is no ecological harm and no consumption of resources, not even for the construction. Solar chimney power plant is a truly sustainable source of energy.

7. REFERENCES

[1]https://en.wikipedia.org/wiki/Solar_updraft_tower#History

[2]https://en.wikipedia.org/wiki/Solar_updraft_tower#Design