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Design and Utilization of Solar Updraft Tower for Power Generation

Bopanna K D[1], Abhay A Pai[2], Daniel Issac[3], Muhammad Sayeed M[4]

[1]*Mechanical Department, NHCE,*
[2]*Mechanical Department, NHCE,*
[3] *Mechanical Department, NHCE,*
[4] *Mechanical Department, NHCE,*

Abstract— A solar updraft tower is a power generating unit which uses solar energy in which a solar air collector plate and a central updraft tower is used to generate a solar induced air flow which drives propellers to generate electricity. ANSYS is used in order to determine the volume and the temperature variation of the air flow in the chimney. A scaled model is designed and developed with power generation capacity enough to light a conventional light bulb. The present study also investigates the influence of tower cross sectional area changes on the performance of a solar tower power plant.

Keywords — Updraft Tower, Collector Plate, Propeller, Power Generation.

1. INTRODUCTION

The worldwide interest for energy is increasing while global greenhouse gas emissions are also increasing constantly. The worldwide consumption of energy, mainly petroleum related energy is steadily growing. The worldwide total energy consumption, approximately 85% of energy is generated from fossil fuels and nuclear, just more than 13.2 % from combustible renewable & waste (Biomass both commercial and non-commercial) and hydroelectricity, while only 0.5% is supplied from other renewable energy sources. Thereby it is clear that most of our energy needs to be utilized by the earth's natural resources, as generating electricity using nuclear resources presents as a waste disposal problem.

1.1. SOLAR ENERGY

Solar radiation is considered to be one of the chief non-conventional energy resources as its availability is enormous. Solar radiation of India is even more necessary as India is a tropical country and it receives solar radiation almost all the 365 days of the year. Solar energy is a radiant light and heat from the sun that can be harnessed using a range of different technologies such as Solar Heating, Photovoltaic and Solar Thermal Energy etc. Solar energy requires the conversion of thermal energy from the sun into electric energy that can be stored in batteries. Various concepts have been studied in an attempt to harness the sun's energy.

2. INTRODUCTION TO SOLAR UPDRAFT TOWER

Solar tower, also known as solar chimney, is a solar power plant which is used to generate electricity in a large scale by converting solar energy into mechanical energy and further into electrical energy. The schematic representation of a typical solar tower power plant is sketched in Fig 2.1 where solar radiation falls on the transparent roof surface, thereby heating the air underneath as a result of greenhouse effect. Due to buoyancy effect, the heated air flow up the tower and induces a continuous flow from the perimeter towards the middle of the roof where the tower is located.

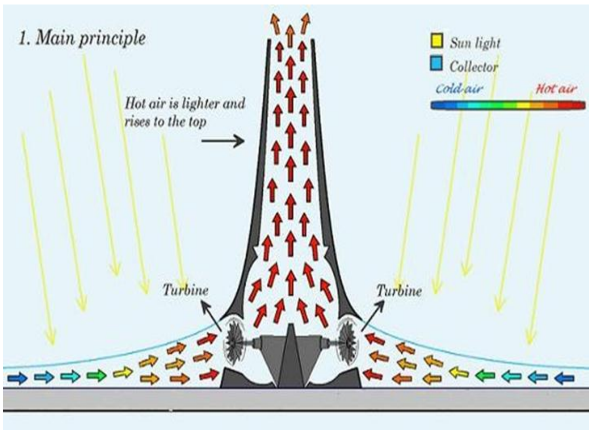


Fig 2.1: A schematic illustration of a Solar Chimney Power Plant

2.1. PARTS OF A SOLAR UPDRAFT TOWER

1. Collector Plate
2. Updraft Chimney
3. Propeller
4. Dynamo

2.1.1. COLLECTOR PLATE

The collector plate is made up of 1mm thick rectangular acrylic sheets with a length of 735mm and a breadth of 715mm. It is placed on top of a supporting frame to withstand the weight of the chimney. Acrylic sheets are rigid and have a good impact strength. They have excellent optical clarity. A clearance of 200mm is given between the collector plate and the ground for easy airflow and in order to facilitate for support structure.

2.1.2. UPDRAFT CHIMNEY

The updraft tower is made up of Aluminium and is of convergent type. The base diameter is 400mm and the upper diameter is 200mm. The total height of the chimney is 600mm. The bottom half of the chimney is cut open to facilitate flow of air to the propellers.

Fig 2.2: Collector Plate (Acrylic sheet) placed on a metal frame.

Fig 2.3: Updraft Chimney (Aluminium).

2.1.3. PROPELLER

The propeller is the rotating element in the updraft tower. It is made up of plastic so that it rotates faster and smoother. It is connected to an electric generator to generate electricity which can be stored in a battery for future uses.

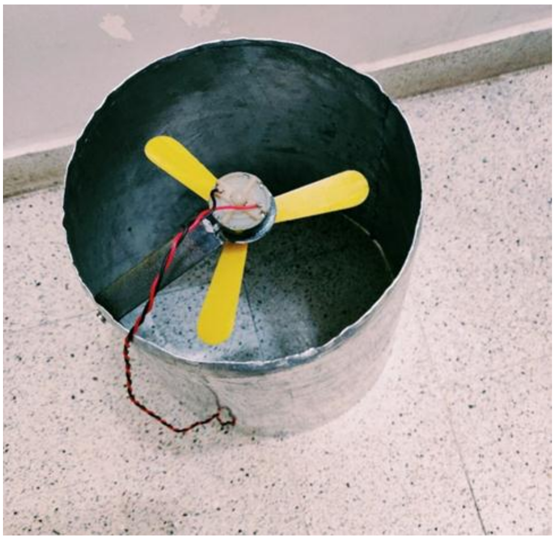


Fig 2.4: Updraft Chimney (Aluminium).

Fig 2.5: Assembled Solar Updraft Tower.

3. METHODOLOGY

3.1. CATIA Model

CATIA allows the construction of three dimensional parts from two dimensional sketches, sheet metal, forged and tooling parts up to the description of mechanical assemblies. It also provides a widespread range of applications for tool design, for both general tooling and mould and die. CATIA also provides numerous stages of product development like conceptualization (CAx), Design (CAD), Engineering (CAE) and Manufacturing (CAM).

Fig 3.1 displays the CATIA model of a convergent chimney. The chimney is converged up to a height of 600mm. The base diameter of the chimney is 400mm. The upper diameter of the chimney is 200mm. The diameter of the collector plate is 600mm. The collector plate is at a height of 200mm from the base.

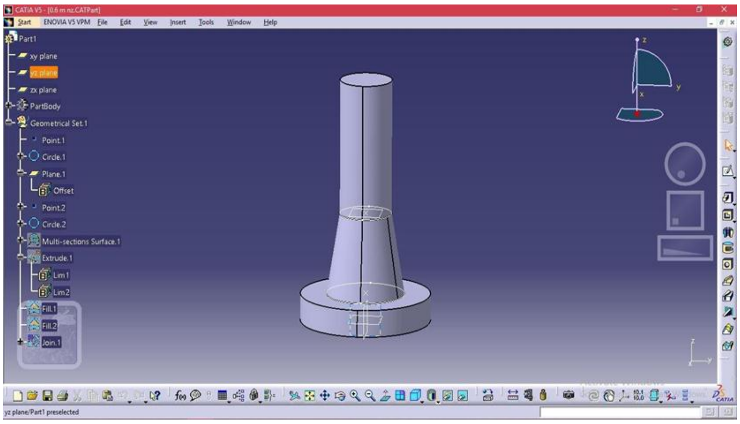


Fig 3.1: Convergent Chimney.

3.2. CASE STUDIES IN ANSYS CFX

3.2.1. CASE STUDY 1

Convergent Chimney

Temperature - 25°C

Chimney Height – 600mm

Airflow is restricted on one side.

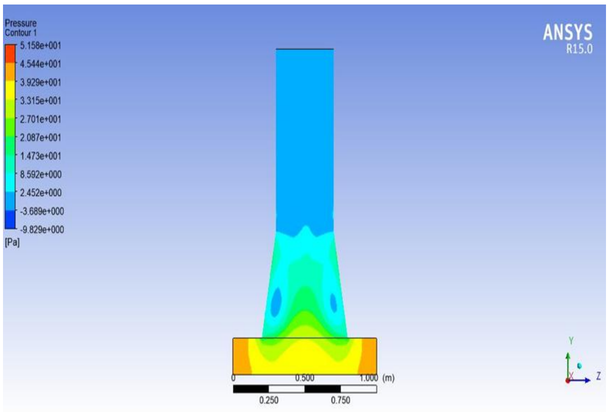


Fig 3.2: Pressure Contour

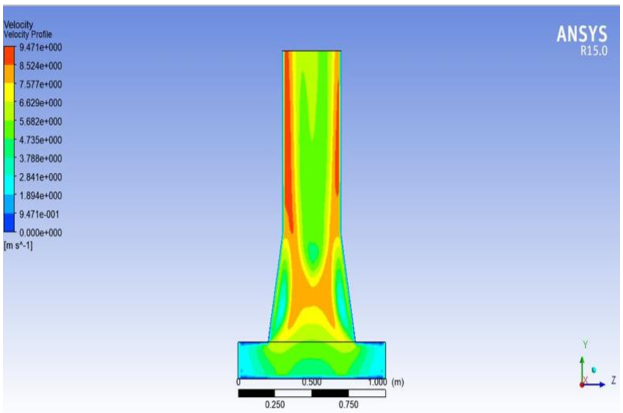


Fig 3.3: Velocity Profile

Airflow is allowed to enter only from one side.
Fig 3.2 shows that the pressure is highest at the inlet and lowest at the sides of the wall.
Maximum Pressure - 4.544e+001 Pa
Minimum Pressure - 3.689e+000 Pa

Therefore the inlet air pressure is higher than the outlet air pressure. The pressure drops at the base of the chimney.
Fig 3.3 shows that the velocity is highest at the walls and lowest at the bottom surface of the plate.
Maximum Velocity - 9.471e+000 m/s
Minimum Velocity - 1.894e+000 m/s

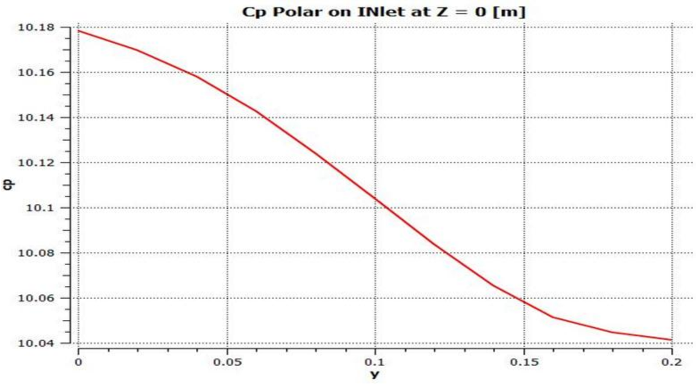


Fig 3.4: Coefficient of pressure (Cp) v/s Height of chimney (y)

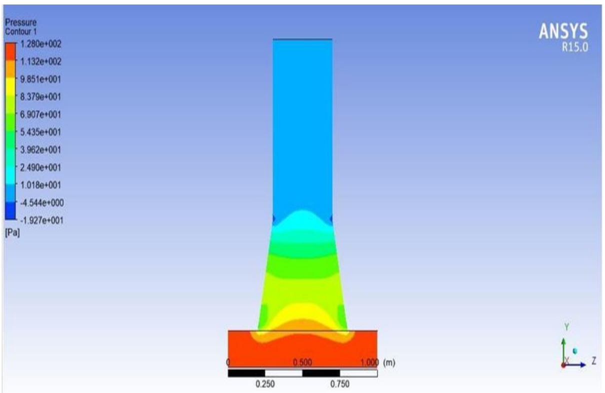
Fig 3.4 shows that the Coefficient of pressure value decreases with increase in chimney height.

3.2.2. CASE STUDY 2

Convergent Chimney

Chimney Height – 0.6m

Air is allowed to flow from all directions



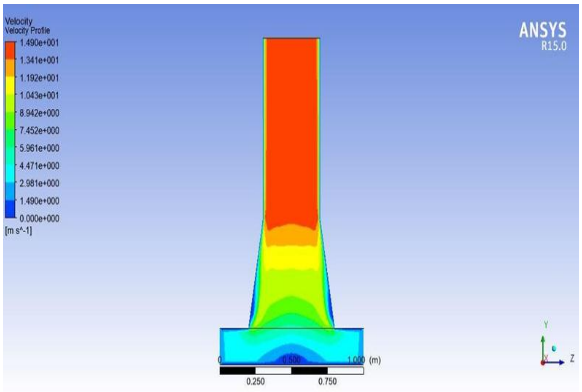


Fig 3.5: Pressure Contour **Fig 3.6: Velocity Contour**

Fig 3.5 shows that the pressure is the highest at majority of the base and lowest at the walls.

Maximum Pressure - 1.288e+002 Pa

Minimum Pressure - 1.018e+001 Pa

Fig 3.6 shows that the velocity is highest at the walls and the velocity is lowest at the sides of the base.

Maximum Velocity - 1.49e+001 m/s

Minimum Velocity - 1.490e+000 m/s

4. EXPERIMENTAL CALCULATONS AND RESULTS

4.1. FORMULAS USED

1. Mass flow rate, m = ρi * A_T * v_t (kg/s)

2. Total Pressure Difference, Δp_{tot} = g (ρo - ρi) * H_t (N/m^2)

3. Power Output, Pout = Δp_{tot} * v_t * A_{coll} (W)

Where,

ρi = Air density at tower entrance = 1.165 kg/m^3

ρ_o = Outside air density = 1.2754 kg/m^3

A_T = Area of the chimney (m^2) = $\pi (r + R) * (\sqrt{(R - r)^2 + H^2})$

A_{coll} = Area of the collector (m^2) = $(l*b) - (\pi /4 * D^2)$

v_t = Air velocity at tower entrance (m/s)

g = Acceleration due to gravity (m/s^2)

H_t = Height of the chimney (m) = 0.6m

4.2. RESULTS

1. The Mass flow rate (m) was found to be 1.877 kg/s.

2. The Total Pressure Difference (Δp_{tot}) was found to be 0.64 N/m^2.

3. The Power Output (P_{out}) was found to be = 0.7W.

5. CONCLUSIONS

- A solar tower system with variable tower flow area has been studied and its performance has been evaluated.
- Pressure, Velocity and Type of flow of air have been studied for different cases.
- For the convergent tower, the velocity at the top increases but the mass flow rate decreases in such a way that the kinetic power at the top remains the same as the constant area case.
- Mass flow rate of air is decreased when air is restricted from one side. The air tends to move in a spiral motion in the chimney thereby not being able to use it completely.

6. SCOPE OF FUTURE WORKS

- In the present work, potential of the solar updraft tower is assessed without considering the turbine to reduce the complexity.
- The primary objective of the work is to determine the shape effect of tower and therefore the height and inlet area of tower were varied and the outlet area was fixed.
- The plant can also be studied for various chimney heights.
- The higher the tower, the stronger the flow of air. The faster the turbines spin, the more electricity can be generated.
- Graphene sheets can also be used for the collector plate to increase absorption of solar radiation.

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