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Design, Fabrication and Testing of Solar Updraft Tower

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Abstract: Solar Updraft Tower is a green energy power plant that generates electricity by harnessing the energy of sunlight using the principle of 'green-house effect'. The Solar Updraft Tower consists of a collector made up of transparent material used in green-house, an updraft tower or solar chimney for generating the air-flow by principle of 'stack effect' and turbine unit driven by the air-flow. Our main aim is to bring out a new, clean and green energy provision which have minimal effect on environment.

Keywords: Solar Updraft Tower, Green energy power plant, Green-house effect, Solar chimney, Stack effect

I. INTRODUCTION

India is one of the countries which rely on renewable sources of energy to meet its current energy requirement. In the electricity sector, from the total installed power capacity 34.4% are account for renewable energy. But the current energy sources are not enough to fulfill our future requirements. So we need a sensible technology which is simple, reliable and accessible by even less developed countries. Solar Updraft Tower (SUT) is the best technology which meets these conditions appropriately. Solar updraft tower uses green-house effect and updraft of air to generate electricity. It consists of collector solar tower (chimney) at its centre and a turbine complied with generator at the junction of the tower and the collector.

Collector consists of a glass or plastic stretched horizontally several meters above the ground on a rigid frame. Main purpose of it is to heat up the air using green-house effect.

Tower is the plants actual thermal engine. Due to stack effect, it allows the high pressure air to come in contact with the ambient atmosphere air. It is built up with concrete and a rigid structure able to hold the outside loads of air at upper heights. Mechanical output is derived using turbine units and generator.

II. DESIGN METHODOLOGY

A. Functional Principle

As the air heat up inside green-house based collector, its density decreases and it tends to moves up allowing a radial flow of fresh air from outer perimeter in the collector. This hot air tends to move outside through the tower with higher velocity as the diameter of collector is much lesser than collector. Thus the solar radiation causes a constant updraft in the tower. The energy contained in the updraft is converted into mechanical energy by pressure staged turbines and into electrical energy by conventional generators.

B. Theory

The power output of the solar updraft tower can be calculated as the solar energy, Q_{solar} , multiplied by the respective efficiencies of collector, tower and turbine(s):

$$P_{\text{output}} = Q_{\text{solar}} * \eta_{\text{coll}} * \eta_{\text{tower}} * \eta_{\text{turbine}}$$

Where,

$$Q_{\text{solar}} = I * A_{\text{coll}}$$

If the temperature rise in the collector is $(T_i - T_o)$ then Q_{thermal} can be easily expressed as

$$Q_{\text{thermal}} = \dot{m} * C_p * (T_i - T_o)$$

Where,

$$\text{Mass flow rate, } \dot{m} = \rho_i * A_i * v_i = \rho_i * (\pi/4) * D_i^2 * v_i$$

Using the Boussinesq approximation, the velocity of the heated air-flow can be expressed as –

$$v_i = \sqrt{[2 * g * H_i * (\Delta T / T_o)]}$$

The tower connects the lower pressure region (the hot air beneath the collector at the entrance of the tower) to the higher pressure region (the surrounding atmosphere at the top of the tower), hence creating the flow of air by this phenomenon called 'stack effect'.

A pressure difference created by this effect can be calculated as –

$$\Delta p_{\text{tot}} = g \int (\rho_o - \rho_i) dH$$

This is simplified to,

$$\Delta p_{\text{tot}} = g (\rho_o - \rho_i) H_t$$

Thus Δp_{tot} increases with tower height.

With the total pressure difference and the volume flow of the air, the power Δp_{tot} contained in the flow is now:

$$P_{\text{output}} = \Delta p_{\text{tot}} \cdot v_t \cdot A_{\text{coll}}$$

C. Design

- 1) The solar intensity (I) is taken as 1160 W/m².
- 2) The ambient temperature (T₀) is assumed as 305 K (32⁰ C).
- 3) The temperature difference is 5 K; hence the inlet air temperature, T_i is taken as 310 K (37⁰).
- 4) The specific heat of air is considered as 1005 J/kg-K.
- 5) The diagonal (D_c) of the collector is selected as 2.83 meter (2x2 meter), considering the availability of the space.
- 6) The height of the tower is selected as 2.5 meter and the diameter as 0.1016 meter (4 inches).
- 7) The collector inclined angle, β , is taken as 25⁰, as large as possible considering convenience of work.

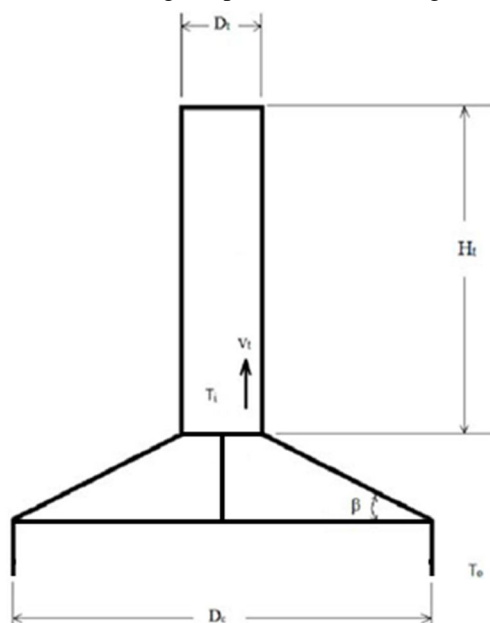


Fig. 1 Line diagram of SUT

We can find out the solar energy due to solar intensity as-

$$\begin{aligned} Q_{\text{solar}} &= I \cdot A_{\text{coll}} \\ &= 1160 \cdot (2)^2 \\ &= 4640 \text{ Watt} \end{aligned}$$

This energy is used to heat up the air inside the collector. Hence temperature of air inside the collector rises. As the temperature of collector air, the thermal energy is induced in the system and it can be calculated as-

$$\begin{aligned} Q_{\text{thermal}} &= \dot{m} \cdot C_p \cdot (T_i - T_o) \\ &= \rho_i \cdot A_t \cdot v_t \cdot C_p \cdot (T_i - T_o) \\ &= \rho_i \cdot (\pi/4) \cdot D_t^2 \cdot v_t \cdot C_p \cdot (T_i - T_o) \end{aligned}$$

Where,

The velocity of airflow can be calculated as-

$$\begin{aligned} v_t &= \sqrt{2 \cdot g \cdot H_t \cdot (\Delta T / T_o)} \\ &= \sqrt{2 \cdot 9.81 \cdot 2.5 \cdot (5/305)} \\ &= 0.8923 \text{ m/s} \end{aligned}$$

Therefore,

$$\begin{aligned} Q_{\text{thermal}} &= \rho_i * (\pi/4) * D_t^2 * v_t * C_p * (T_i - T_o) \\ &= 1.1388 * (\pi/4) * (0.1016)^2 * 0.8923 * 1005 * 5 \\ &= 41.38 \text{ Watt} \end{aligned}$$

The tower converts this thermal energy into kinetic energy and potential energy. The pressure difference induced in the tower can be calculated as:

$$\begin{aligned} \Delta p_{\text{tot}} &= g * (\rho_o - \rho_i) H_t \\ &= 9.81 * (1.1576 - 1.1388) * 2.5 \\ &= 0.4611 \text{ N/m}^2 \end{aligned}$$

With the total pressure difference and the volume flow of the air; the power P_{tower} contained in the flow can be calculated as-

$$\begin{aligned} P_{\text{tower}} &= \Delta p_{\text{tot}} * v_t * A_{\text{coll}} \\ &= \Delta p_{\text{tot}} * \sqrt{[2 * g * H_t (\Delta T / T_o)] * A_{\text{coll}}} \\ &= 0.4611 * \sqrt{[2 * 9.81 * 2.5 * (5/305)] * (2)^2} \\ &= 1.65 \text{ Watt} \end{aligned}$$

III. FABRICATION AND TESTING

A. Fabrication of Experimental model

- 1) *Step:* For the setup of a Solar Updraft Tower the first thing which we needed to do, was to find an appropriate place which was large in size, which had enough intensity of sunlight and which was open from all four sides so that fresh air can enter at any point of time.
- 2) *Step:* Next we had to buy iron for the fabrication of the frame. This iron was bought from scrap at cheap rate, so that the overall cost of the Solar Updraft Tower reduces.
- 3) *Step:* Since the iron was bought from scrap, we had to remove rust from the iron so that the paint doesn't peel off.
- 4) *Step:* The next step was to paint the iron bars with jet black colour so that it avoids corrosion and absorbs more heat which further resulted in giving enhanced results. Painting the rod black also gave an aesthetic look to the frame of the Solar Updraft Tower.
- 5) *Step:* Next we had to fasten nut and bolt with different sized iron bars so that the frame can stand on its own and give a rigid support to the tower.
- 6) *Step:* Next we had to cut the plastic for our collector. This is a special type of plastic which is used in greenhouse. We had to cut it according to the dimensions of the frame into 4 petals and tape it together tightly with the iron frame. This completed the fabrication of the collector.
- 7) *Step:* Next we had to paint the PVC pipe which we were using as a tower, with jet black colour. This helped us in increasing the temperature inside the collector as well as the tower.
- 8) *Step:* Further we had to fit the pipe in the circular ring of the iron frame with nuts and bolts so that the tower remains steady without any external support.
- 9) *Step:* At last we had to fit the anemometer at the base of the tower with steel wires. An anemometer is a device which measures the air flow velocity. This anemometer was used to measure the final readings of our project.



Fig. 2 Anemometer

B. Testing Procedure

- 1) *Step:* The ambient temperature T_0 was measured with the help of thermometer.
- 2) *Step:* The temperature of hot air at inlet of tower T_i was measured simultaneously by thermometer.
- 3) *Step:* The velocity of air-flow at the entrance of the tower v_i was measured by using the anemometer. By using property chart, the densities of air ρ_i and ρ_o were taken corresponding to the temperatures T_i and T_o .
- 4) *Step:* The steps 1 to 3 were repeated after every one hour throughout the time period the day.
- 5) *Step:* Thus data were taken for 8 experimental days and with necessary calculations the result was found.



Fig. 2 Measuring velocity of air-flow with anemometer

IV. RESULTS AND DISCUSSION

The result is described with some curves found in a typical day in the following section. The graph is plotted by taking average of the readings of 8 days corresponding to the time period.

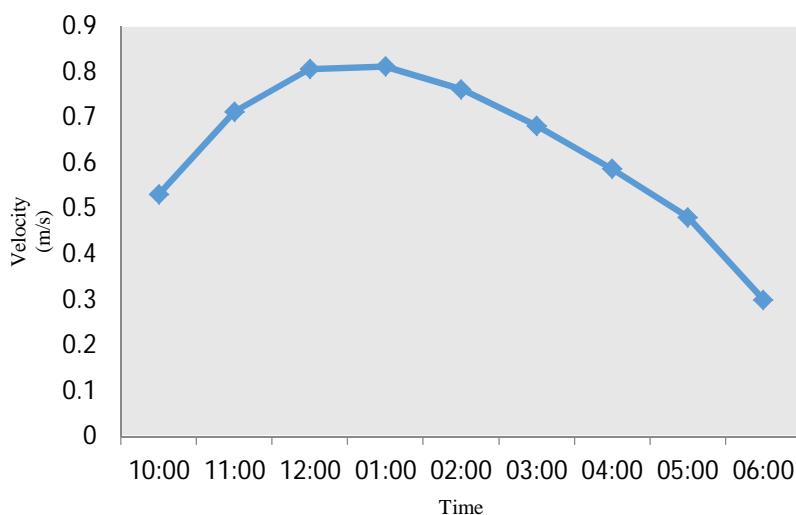


Fig. 3 Average Air velocity VS Time

Fig. 11 shows that the velocity of hot air through the tower was increasing with the time of the day. First the velocity of air is 0.531 m/s at 10:00 AM and then goes on increasing. The peak occurs at 1:00 AM having 0.812 m/s velocity of air and then the velocity dropped down progressively. Overall it can be said that the air velocity increased with time until mid-day and then fell down.

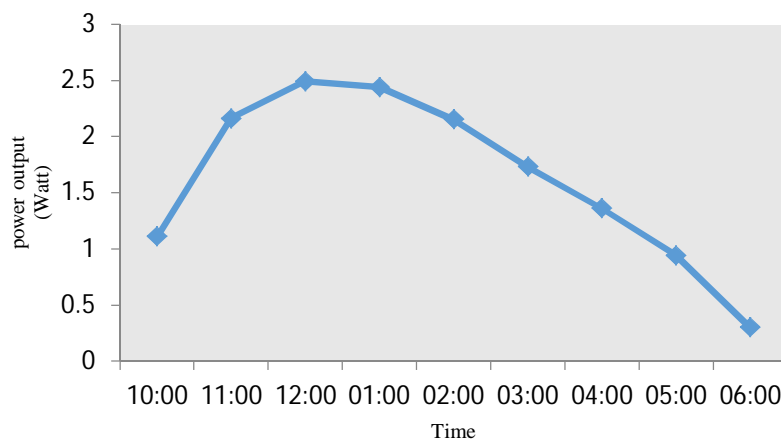


Fig. 4 Average Power output VS Time

The analysis for power output VS time is done by using simple mathematical model as discussed earlier. From the Fig. 12, it can be clearly said that the power output was increasing rapidly from 10:00 AM until 12:00 PM and then drop down. The power output is peaked to 2.49 Watts at 12:00 PM. Overall it can be said that the power output increases with time until mid-day and then starts to fell down.

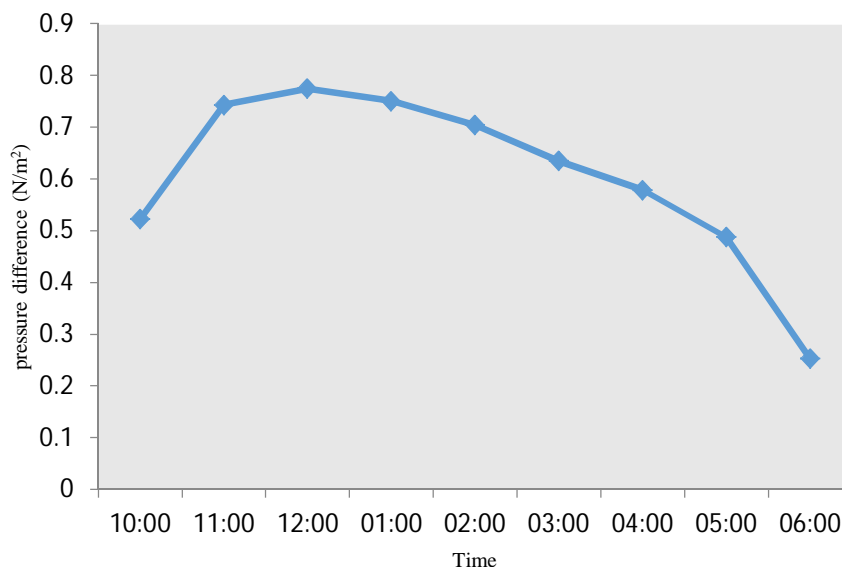


Fig. 5 Average Pressure difference VS Time

Fig. 13 shows the pressure difference increases with time until mid-day. Then the pressure difference fell down as the day pass. At the end of the day the pressure difference fell down vigorously.

The results shown above with the help of graph were approaching to the designed values with minimal deviation due to many factors. It can be clearly seen from the graph that the power output along with the other parameters like velocity of air-flow, pressure difference approaches its peak values almost between 12:00 PM to 1:00 PM (i.e. mid day) as expected because at that time, due to the position of the sun the solar irradiation is maximum.

Additional thermal storage capacity can be achieved by laying water-filled tubes side by side beneath the collector. At night when the collector starts to cool down, the water inside the tube release the heat that is stored during the day. Hence, 24 hours operating condition can be achieved.

V. CONCLUSIONS

We provide draft to the solar collector to improve dynamic pressure head at the centre of collector. For the improvement in power output, material used for solar collector has higher transmissivity and material of solar updraft Tower should have higher absorptivity so, we colored black to the surface of solar tower. The design velocity of air-flow v_t was 0.8923 m/s, but the actual value varied from 0.3 m/s to around 0.9 m/s. The design power output of the set-up was 1.65 watts while the average power outputs found practically ranged between 1.11 watts to 2.49 watts and the maximum output at any instance was about 2.49 watts. Thus the actual output powers were significantly more than the designed output. The design pressure difference was 0.4611 Pa but the actual value varied from 0.2526 Pa to around 0.7749 Pa. Thus the actual pressure difference was not always higher than the design value.

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