Design and Development of Solar Chimney

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Abstract: The solar chimney, also known as solar updraft tower, is a proposed type of renewable-energy power plant that combines a solar air collector and a central high tube (chimney) to generate a solar induced convective flow which is used to generate electrical power using turbo-generator set. Natural convective air flow obtained can be used to drive the passive ventilation system. In this paper, the functional principle of the solar chimney has been described. Design of solar chimney is done by the energy balance and force balance of various components. Mathematical modelling of solar chimney is done through thermal analysis. Solar chimney is designed to provide ventilation for the room of two occupants. To get the accurate results absorber plate is divided into number of parts and thermal analysis is performed for each elements of the absorber plate. Solar chimney is designed to provide the mass flow rate for the room of dimensions 10m*5m*3m having two occupants. To validate the mathematical modelling developed, a small scale solar chimney is developed and two sets of experiments are performed to check the experimental results obtained against the theoretical value obtained.

Keywords: Solar chimney, Passive ventilation, solar updraft tower, solar energy, passive cooling

1. Introduction

A solar chimney is basically a non-concentrating solar thermal technology. It combines three well known principles to convert solar energy into electrical energy [1]. It is a power generating facility which mainly consists of three components;
1) solar air collector
2) chimney and
3) Turbine [2]

The collector whose main function is to produce greenhouse effect is covered by a transparent glazing to trap the solar radiation. This produces greenhouse effect to increase the internal energy of the air mass inside the collector. Buoyancy drives the warmer air into the chimney, which is located at the center of the collector. This causes the collector to draw more air from the atmosphere, producing the air current flowing through the system. In this way solar chimney converts solar energy into kinetic energy of the air mass. A turbo-gen set is placed in the path of the air flow to convert kinetic energy of the flowing air into the electrical energy.

Available kinetic energy can be used to assist the room ventilation system i.e. solar chimney assisted natural ventilation system. Solar chimney used for natural ventilation system consists of two main components, 1) Solar collector 2) Chimney [3]

The whole setup, including the collector and chimney can be mounted on terrace away from the house to be ventilated, located at any floor. The collector, mounted either on the roof of the house or the terrace of the building, is covered by a transparent glazing. The main objective of the collector and chimney remains same here. Collector draws air from the house through the ducts.

Figure 1: Solar chimney

1.1 Motivation

About 40-60% of the energy consumed in a commercial building is for space cooling and ventilation [4]. This relies on the electricity which is generated by combustion of fossil fuels mainly. At present, numbers of energy sources are utilized to generate electricity such as- coal, oil, gas and nuclear energy. Continuation of the use of these fossil fuels is set to face multiple challenges namely; depletion of the fossil fuel reserves, global warming and other environmental concerns and continuing fuel price rise. For these reasons, the existing source of convective energy may not be adequate to meet the ever increasing energy demands.

The implementation of this project is of great significance in terms of energy saving opportunities. Centralized solar assisted space ventilation system could reduce the conventional energy sources dependency in considerable amount.
Solar passive cooling systems are well developed, requires south facing wall to accumulate maximum possible solar energy which is the major hurdle for making it popular in denser region. In a dense city like Mumbai it is difficult to obtain shade less south facing wall. Solar chimney on the other hand doesn’t require south facing wall and can be more conveniently used.

1.2 Working Principle

A solar updraft tower works on following two well-known principles,
1) Greenhouse effect and
2) Buoyance effect.

Direct and diffused solar radiation strikes the glass roof where specific fraction of energy gets reflected, absorbed and transmitted. The quantities of these fraction depends on the solar incident angle and the optical characteristics of the glass such as; refractive index, thickness and extinction coefficient. The transparent glazed surface of the collector provides transparency for the short wave solar radiation. The transmitted solar radiation strikes the absorber plate surface which in turn depends on the temperature difference between pressure difference available between the ambient air and hot air at the base of the chimney is used to ventilate the room. The total pressure draught available by chimney is used to overcome following friction losses,

\[ \Delta P_{\text{chimney}} = \Delta P_{\text{chimney}_{\text{loss}}} + \Delta P_{\text{collecto}_{\text{rloss}}} + \Delta P_{\text{acceleration}} + \Delta P_{\text{room}_{\text{mloss}}} \]

\[ \rho \beta \Delta T g H = f x \frac{R}{2h} \left( \frac{m}{A_{\text{pm}} H} \right)^2 + f y \frac{2H}{D} \rho \left( \frac{4m}{\rho r D^2} \right)^2 + 2 \rho \frac{2m}{\rho r D^2} + \Delta P_{\text{room}_{\text{mloss}}} \]  



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3. Results

Solar chimney was analyzed to obtain mass flow rate of the chimney from morning 7.00 am to 5.00 pm.

| Sr. No. | Time            | \( T_4 \) (°C) | \( M \) (kg/s) | \( M_{req} \) (kg/s) |
|---------|------------------|----------------|---------------|----------------------|
| 1       | 7.00 to 8.00 am   | 48.84          | 0.015         | 0.017                |
| 2       | 8.00 to 9.00 am   | 60.39          | 0.021         | 0.018                |
| 3       | 9.00 to 10.00 am  | 66.89          | 0.026         | 0.022                |
| 4       | 10.00 to 11.00 am | 73.03          | 0.027         | 0.024                |
| 5       | 11.00 to 12.00 pm | 76.14          | 0.029         | 0.026                |
| 6       | 12.00 to 1.00 pm  | 79.79          | 0.027         | 0.026                |
| 7       | 1.00 to 2.00 pm   | 78.59          | 0.026         | 0.022                |
| 8       | 2.00 to 3.00 pm   | 75.41          | 0.025         | 0.018                |
| 9       | 3.00 to 4.00 pm   | 69.14          | 0.022         | 0.014                |
| 10      | 4.00 to 5.00 pm   | 57.66          | 0.015         | 0.011                |

In the graph below mass flow rate is plotted against time and it is found that maximum mass flow rate 0.029 kg/s is obtained at 11.00 to 12.00 pm.

Figure 2: Mass flow rate vs. Time

Figure below shows variation of mean plate temperature over time.

Figure 3: Mean plate temperature vs. Time

Mean plate temperature increases from morning and reaches maximum value 107°C at 12.00 pm.

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**Table 1: Chimney Dimensions**

| Component                    | Dimension |
|------------------------------|-----------|
| Height of chimney (H)        | 5 m       |
| Diameter of collector (D)    | 4 m       |
| Diameter of chimney (d)      | 1 m       |
| Space between collector plate and absorber plate (H) | 1 m |
Temperature of air at the base of the chimney increases from morning 7.00 am and reaches to maximum value of 71.66°C at 1.00 pm. After this it reduces to and at 5.00 pm air base temperature reduces to 52.79°C at 5.00 pm.

**Figure 4**: Air temperature at the base of the chimney vs. Time

**Figure 5**: Actual mass flow rate vs. Theoretical mass flow rate

Figure above shows the required mass flow rate for the given hour and actual mass flow rate obtained from solar chimney.

### 4. Validation

#### 4.1 Design of small scale solar chimney

Depending on manufacturing feasibility and cost for manufacturing of solar chimney, following dimensions were chosen and small scaled solar chimney was analyzed for its performance.

Dimensions of small scaled solar chimney:

- H = 1.5 m
- D = 1.2 m
- h = 0.03 m
- d = 0.1 m

#### 4.2 Manufacturing of Solar Chimney

Following materials were used to fabricate the components of solar chimney,

| Sr.No. | Component | Material            | Dimension                  |
|--------|-----------|---------------------|----------------------------|
| 1      | Absorber  | Mild steel          | Diameter = 1.2m Thickness = 5mm |
| 2      | Collector | Transparent acrylic sheet | Outer Diameter = 1.2m Inner diameter = 0.1m Thickness = 4mm |
| 3      | Chimney   | PVC pipe            | Diameter = 0.1m Height = 1.5m |

#### 4.3 Testing of solar chimney

Two sets of readings were taken while testing a solar chimney. Following instruments were used:

1) Thermo-electric Pyranometer with RN 2104 indicator – Dynalab,
2) RTD sensor PT-100 – Anadig system,
3) Thermometer
4) Hot wire anemometer – Kusam meco.
obtained readings (E).

To validate the mathematical model developed above, calculated theoretical results and experimental observations obtained for small scaled solar chimney are to be compared. In the table given above values of mean plate temperature (T\text{pm})), Cover plate temperature (Tc), temperature of air at base of chimney (T4) and velocity of air inside chimney (V\text{chimney}) obtained from mathematical modelling i.e. theoretical value (T) is compared against experimentally obtained readings (E).

Result Table 1. shows the velocity of air inside chimney obtained by measuring the time required to raise the smoke from the bottom of the chimney to the top of chimney, during which time was noted. By knowing the time required by the smoke to rise from the bottom to the top of chimney, diameter and length of chimney, velocity and hence mass flow rate of the air inside chimney can be calculated.

Table 4: Result Table 1

| Sr. No. | Time  | T4 (°C) | V\text{air} (m/s) | S (W/m\text{2}) | T\text{pm} (°C) | Tc (°C) | T4 (°C) | V\text{chimney} (m/s) |
|---------|-------|---------|------------------|----------------|----------------|---------|---------|----------------------|
| 1       | 12.00 | 39.6    | 0.6              | 725            | 87.72         | 78.2    | 58.2    | 61.5                 |
| 2       | 1.00  | 42.5    | 0.3              | 646            | 85.19         | 75.2    | 59      | 62.4                 |
| 3       | 2.00  | 44      | 0.5              | 549            | 79.19         | 65.9    | 56.3    | 50.5                 |
| 4       | 3.00  | 41      | 0.3              | 378            | 66.44         | 59.3    | 49.4    | 49.6                 |
| 5       | 4.00  | 39      | 0.2              | 260            | 56.89         | 54.7    | 44.3    | 47.3                 |
| 6       | 5.00  | 38      | 0.4              | 217            | 52.8          | 51.4    | 41.8    | 44.6                 |

Result Table 2 shows the results obtained from hot wire anemometer.

Table 5: Result Table 2

| Sr. No. | Time  | T4 (°C) | V\text{air} (m/s) | S (W/m\text{2}) | T\text{pm} (°C) | Tc (°C) | T4 (°C) | V\text{chimney} (m/s) |
|---------|-------|---------|------------------|----------------|----------------|---------|---------|----------------------|
| 1       | 2.45 pm | 39.5    | 0.4              | 400            | 66.85         | 65.8    | 46.1    | 49.8                 |
| 2       | 3.00 pm | 36.3    | 0.5              | 340            | 60.52         | 62.1    | 42.9    | 45.5                 |
| 3       | 3.15 pm | 34      | 1.0              | 306            | 56.09         | 58.2    | 40.2    | 42.5                 |
| 4       | 3.30 pm | 36      | 0.3              | 259            | 54.75         | 55.8    | 41.5    | 42.2                 |
| 5       | 3.45 pm | 28.6    | 1.2              | 215            | 45.93         | 52.3    | 32.8    | 40.2                 |

5. Conclusions

It is clean technology that uses solar energy as a heat source which produces neither greenhouse effect gases nor hazardous wastes. Efficient use of solar radiation, the solar collector utilizes both the direct and diffuse solar radiation. The plant therefore is able to generate power under cloudy conditions, although reduced.

Solar chimney can also be used to create the draft for passive heating and cooling of building. Pressure draught developed by solar chimney depends on solar radiation.

Air mass flow rate is obtained from the solar chimney, hence can be used to provide natural ventilation for the house. Result obtained from mathematical model and experimentation is close and hence mathematical model for solar chimney is successfully developed.

It being observed that value of velocity of air inside chimney obtained from hot wire anemometer is in close range with theoretical value obtained from mathematical modelling as compared to experimental value of velocity of air inside chimney obtained from smoke method.

References

[1] A. Koonsrisuk, S. Lorente and A. Bejan, Constructual solar chimney configuration, International Journal of Heat and Mass transfer.
[2] Jörg Schlaich and Wolfgang Schiel, Solar chimneys, Encyclopedia of Physical Science and Technology, Third Edition 2000.
[3] Amel Dhahri and Ahmed Omri, A Review of solar Chimney Power Generation Technology, International Journal of Engineering and Advanced Technology, ISSN: 2249 – 8958, Volume-2, Issue-3, February 2013.
[4] R. K. Rajput, Power system engineering, Firewall media, 2006, pp. 198
[5] S. P. Sukhatme and J. K. Nayak, Solar energy principles of thermal collector and storage, Third edition, Mc Graw Hill.

Figure 8: Nodes of measurement

One more set of reading was taken on 26th November, 2015 with hot wire anemometer. In the hot wire anemometer based on cooling effect produced by air passes through the hot wire, and velocity of air is measured. Result table 2 shows the results obtained from hot wire anemometer.
[6] D. Yogi Goswami, Frank Kreith and Jan F. Kreider, Principles of Solar Energy, Second edition, Taylor and Francis.
[7] Duffie and Beckman, Principles of Solar energy, 1991

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