Effect of Different Chimney and Collector Contour on Output in a Solar Updraft Tower

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Abstract: *This Research includes the effect of different chimney shapes and collector canopy angles on output parameter involving velocity and temperature. This research uses software known as Energy 2d, mainly used to numerically analyze the problems related to Fluid mechanics, Fluid dynamics, Thermodynamics and Heat transfer. Also, the reason behind choosing such shapes and draft is also discussed here. Integrated charts of all found results is displayed here which will lead us to a conclusion. Keeping these design changes in mind, one can design their own updraft tower as per their velocity and temperature difference requirements.*

Key Words: Solar, Updraft, Tower, Chimney design, Collector design, Energy2d, Thermal power plant.

1. INTRODUCTION

A Solar updraft tower is a device which generates power on the virtue of density and pressure difference of air. Using collector area, it absorbs heat from the sun radiation. Due to this heat absorption process, air inside the collector area tends to heated with convection. As it gets heated, Temperature of air increases and density decreases based on design of collector area and materials used for it.

One of the main reasons for non-commercial-experimental level of SUT is very low energy conversion efficiency, compared to other solar power technologies, and large construction requirements [1]. Even of such low efficiency of around 1% to 2% [2], due to its low maintenance and cheap construction materials it is favorable for the developing countries. So to increase the efficiency of powerplant this research has been done.

1.1 BRIEF INTRODUCTION OF ENERGY2D

We have used Energy2d here to analyze effect of different shapes and contours on the output velocity and to see up to which extent, temperature difference is created. This software uses integrated physics to simulate the programs which is based on heat transfer coupled with dynamics of particle [3]. This software provides very user-friendly interface so that one can easily research and learn.

2. ATMOSPHERIC CONDITIONS & MATERIAL PROPERTIES

In general properties of this software the Sunny and convective feature is turned on. Following are the ambient air condition, considering which these models has been analyzed.

- Ambient temperature = 273 kelvin
- Conductivity of = 1 W/m-C
- Specific heat of = 1012 J/kg-C
- Density = 1.2 kg/m^3
- Kinematic viscosity = 0.01 m^2/s
- Thermal expansion coefficient=2.5 x 10^{-4} m/s^2-C
- Buoyancy = All cell average & Gravity kept uniform
- Ray number = 48; Ray speed = 7.998 cm/s
- Emission interval = 4
- Solar Density = 20000 W/m^3
- Drag co-efficient = 0.01 kg/s
- Hardness = 1 (unitless number to use in software)
- Thermophoretic Co-efficient = 0 $(kg\text{-}m/s)^2$
- Thermal boundary = 0 all value
- Mass boundary = all through

Table -1: Material Properties

Property	Chimney	Collector	Absorber
Thermal conductivity	0.001	0	0.1
Specific Heat	1300	1000	1000
Density	25	25	10
Absorptivity	0	0	1
Transmissivity	0	1	0
Reflectivity	1	0	0
Emissivity	0	0	0
Is a Source?	No	No	No

All units are discussed in above atmospheric conditions

The materials generally used in solar updraft tower are as follows: -

1) Chimney: Low thermal conductivity materials like Furnace Bricks or Cement Bricks.
2) Collector: Low thermal conductivity & Maximum possible transmissibility having materials like Glass, High density Polyethene, Transparent Plastics etc.

3) Absorber: High thermal conductivity & absorptivity materials like sand, gravels, Black water pipes etc.

3. GENERAL SHAPE DIMENSIONS

Following list describes the Primary dimension used for design:

- Chimney height: 3m
- Chimney Internal Diameter: 2m
- Chimney thickness: 0.2m
- Collector Diameter: 7m
- Collector Draft (canopy, if any): 11 degrees
- Absorber diameter: 7m
- Deflector Height: depends on collector design

Sensor positions:

- Main Anemometer: At 2m height from Ground in center
- Thermometer:
  T2 i.e., T_{exit} Center at 1.5m above ground
  T1 i.e., T_{Inlet} Right at 0.1m above ground

4. SHAPE DESCRIPTION WITH INDIVIDUAL VELOCITY(L) AND TEMPERATURE(R) OUTPUT

Following are the images describing different types of shapes and contours used to study the effects:

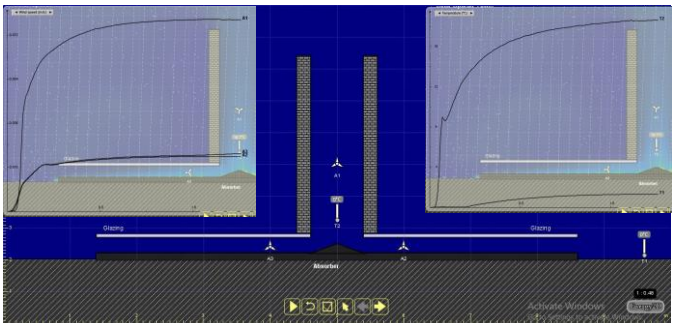

Fig -1: Straight Tower with 0-degree canopy angle

In Model-1, Tower section is taken straight, as mostly used commercially with no canopy angle. This design is most commonly used experiments and commercially made updraft towers. Peak speed found here is 0.078423 m/s. Max temperature difference is found to be 17.35865 K.

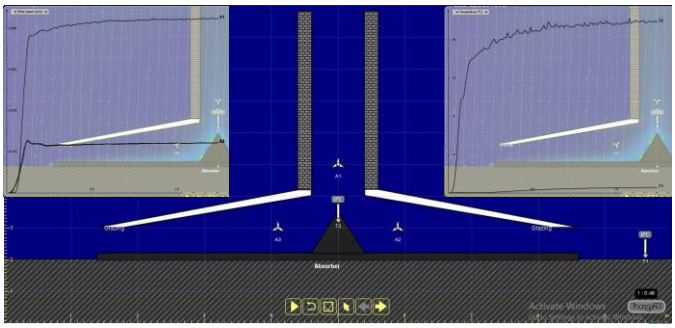

Fig -2: Straight Tower with 11-degree canopy angle

In Model-2, Tower section is kept straight with 11-degree canopy angle just to see the effect of only canopy angle on output parameters. Here there is no specified value for canopy angle. It is just provided to avoid air inlet & exit from collector instead of going into chimney. Peak speed found here is 0.059618 m/s. Max temperature difference is found to be 17.69507 K.

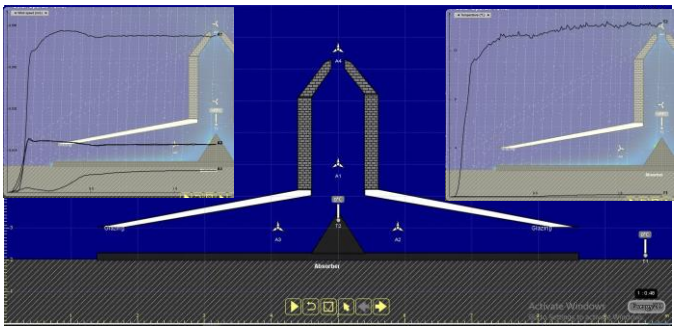

Fig -3: End nozzle Tower with 11-degree canopy angle

In Model-3, Tower section is kept straight, but on the head, nozzle is fitted to see how convection interfere with law of continuity. Also canopy of 11 degrees is provided. As the property of nozzle, we know that it is used to convert pressure energy to kinetic energy [4]. Peak speed found here is 0.054542 m/s. Max temperature difference is found to be 14.23431 K.

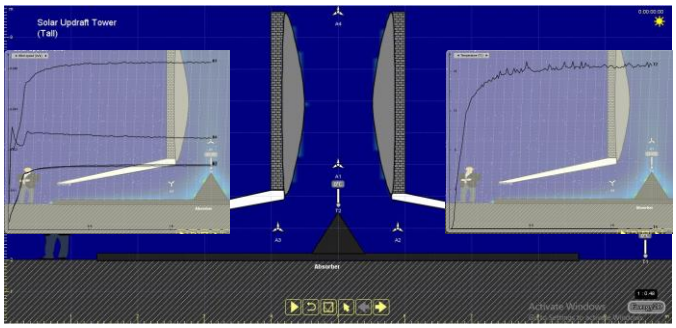

Fig -4: Hyperboloid Tower with 11-degree canopy angle

In Model-4, Tower section is kept hyperboloid with 11 degree of canopy angle. The specific reason of using hyperboloid cross-section is to that it's application in Aerospace engineering. Even-though it is applied when the flow is supersonic, it gives better results in sub-sonic flow than some other shapes [5]. Peak speed found here is 0.048132 m/s. Max temperature difference is found to be 16.9728 K.

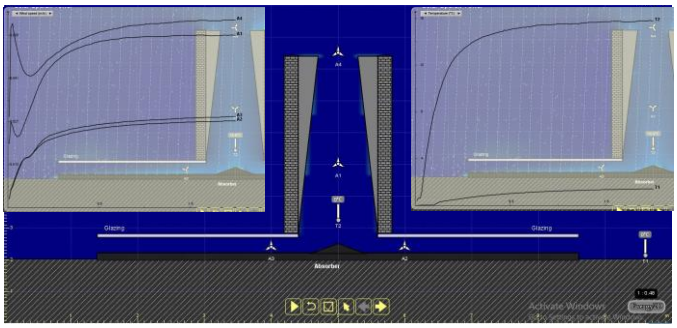

Fig -5: Gradual decreasing cross section area Tower with 0-degree canopy angle

In Model-5, As previously described in Model-3, Nozzle shaped chimney is made for same reason. But here, Nozzle length is along the tower height with gradual decrease in area with draft of 0.25m at 3m. Peak speed found here is 0.060056 m/s. Max temperature difference is found to be 14.44524 K.

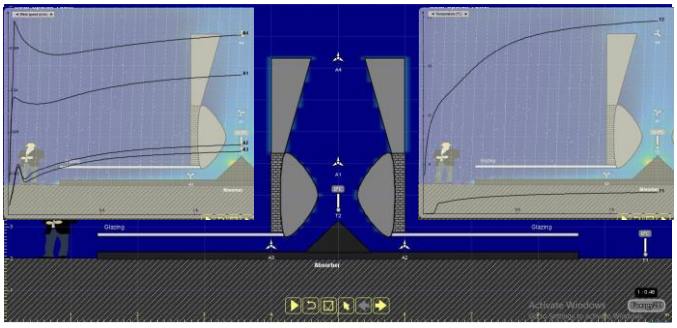

Fig -6: Tower having integrated design of hyperboloid and nozzle with 0-degree canopy angle

In Model-6, Tower is integrated shape of hyperboloid and nozzle. Peak speed found here is 0.063262 m/s. Max temperature difference is found to be 20.94472 K.

All these models has been analyzed with runtime of 2 minutes and considering that incident rays are falling at 90-degree angle.

5. INTEGRATED RESULTS OF ABOVE GIVEN MODELS

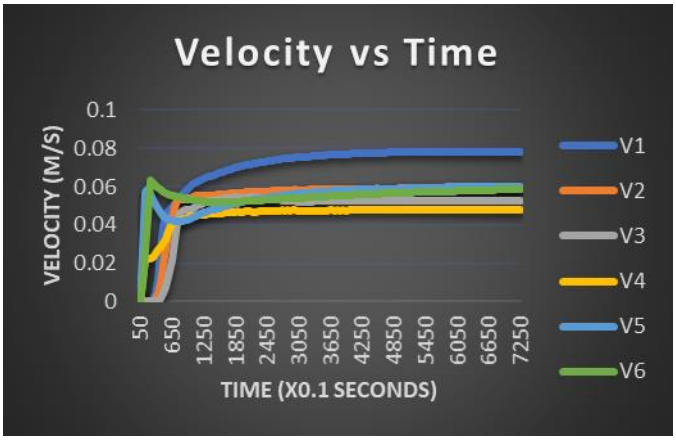

Chart -1: Velocity vs Time chart

Out of all models, Peak velocity is found to be 0.078423 m/s as in Model-1

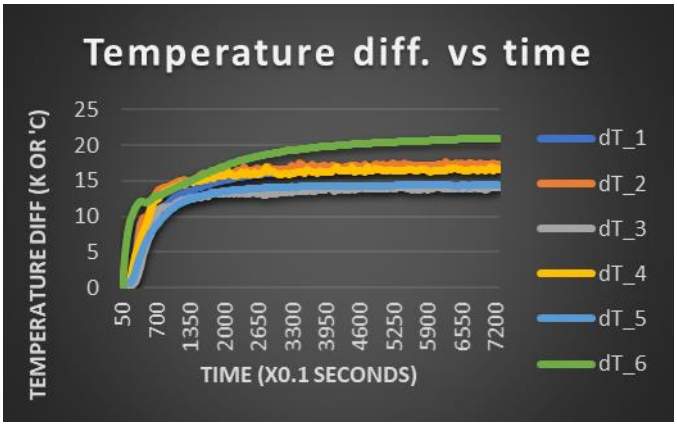

Chart -2: Temperature difference vs Time chart

Out of all models Maximum temperature is found to be 20.94472 K as in Model-6.

6. CONCLUSIONS

From the results we got from running solution, we can say that:

1) Model-1 i.e. The straight tower with no collector draft has maximum peak velocity of 0.078423 m/s.
2) Model -6 i.e. The Tower with integrated nozzle and hyperboloid design has maximum temperature difference of 20.94472 kelvin.

So to get maximum velocity we can use 1st model & to get maximum temperature difference we have to use integrated nozzle-hyperboloid design.

Moreover it is a important to note that differences are there with maximum deviation of 38.6251 % for velocity and 32.0138 % for temperature difference, Which cannot be neglected.

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