

Numerical Analysis of Solar Updraft Tower with Solar Load applied to Discrete Ordinate Model

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ABSTRACT: The working of The Solar Updraft Tower or commonly referred to as Solar Chimney is based on utilizing Solar Energy Induced Convective Heat Flow to generate Power. The basic components of this mechanism involve a Solar Air Collector and a Central Updraft Tube. The analysis is carried out using steady state Navier-Stokes equation and energy equation in cylindrical coordinate system. The air inside the system is considered turbulent and solved using k- ϵ model in Ansys Fluent 15.0. The chimney height is kept constant while varying the tower radius at the top of the tower. Its effects on air velocity and pressure are observed at the location of turbine.

KEYWORDS: Solar Updraft Tower, Renewable Energy System, Power Generation, Computational Fluid Dynamics

I. INTRODUCTION

For widespread usage Renewable Energy Technology should be simple, reliable and effective in underdeveloped and developing countries, where raw material is not abundant. It should not utilize large amount of water for cooling or produce environmentally hazardous waste as by-products. It should derive energy from renewable and virtually inexhaustible resource present found readily in that location. It should not have drastic consequences on the ecological balance of the area. The Solar Updraft Tower meets all these requirements and utilizes solar radiation generate power. But unlike conventional solar panels, it doesn't require expensive compounds like Gallium Arsenide or Germanium etc. Large plant are capable of producing power greater than 100MW [2].

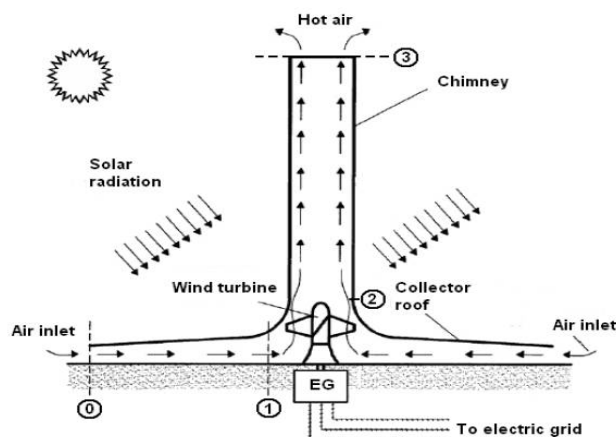


Fig 1: Schematic diagram of Solar Updraft Tower

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The three basic components of the solar updraft tower include Solar Air Collector, Tower and wind Turbines which work simultaneously to generate electricity [1]. The working principle of this mechanism as depicted in Figure 1 shows that, a transparent or translucent glass roof roughly 2 meters from the ground, heats the air inside by incident solar radiation. This is referred to as the Solar Air Collector since it is open at the periphery to draw in more air. Through the centrally located tower, the heated air rises and suction at the base draws in more from the collector. The rising air impinges onto turbine blades located at the entrance of the tower and converted from mechanical to electrical energy by conventional generators.

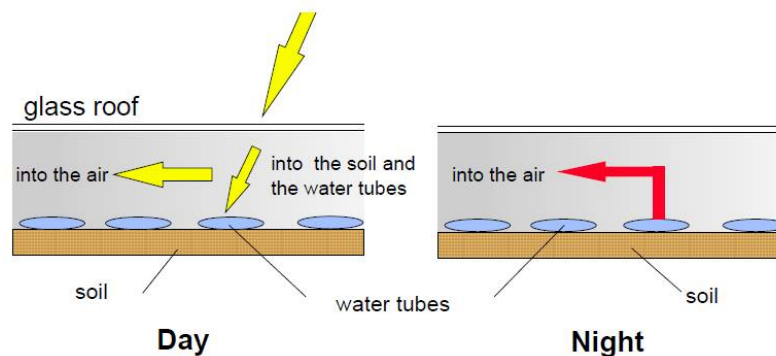


Fig 2: Mechanism to provide heat at night

To facilitate continuous operation even at night, a medium to supply heat is required to create air flow. For this purpose water-tubes or bags are placed in the Collector which absorb solar radiation and heat up during the day. The water doesn't need to be replaced so it does not affect the ecology [7].

II. MATERIAL AND METHODS

The idea of the Solar Updraft Tower is based on the Manzanares Prototype [7] built in Spain to generate energy, utilizing the abundant solar radiation present in the region. The dimensions of the plant have been referenced and based on a study by R. V. Filkoski [4]. The model is made axisymmetric around a 100m tall chimney and spans 100m in each direction. The roof of the collector gradually increases from 2m to 8m to facilitate rising warm air to flow to the chimney. The mathematical model analysed was to optimize the geometry with a CFD tool (Ansys Fluent 15.0), for given thermo-fluid boundary condition. The 3 dimensional flow in the volume of the model was considered under a k-ε turbulent realizable model.

III. WORKING METHODOLOGY

The dimensions and design of the model being analyzed is based on Manzanares Prototype built in Spain. Due to the axisymmetric nature of the chimney, the boundary conditions on the periphery of the collector are kept same for ease of computation and better accuracy of solution. Second Order Upwind SIMPLEC scheme is chosen to calculate the solution from equations of mass, momentum and energy. The radiation on the glass surface is varies as per the time of the day and the weather conditions, Direct Solar Irradiation as 1423 W/m^2 and Diffuse Solar Irradiation as 200 W/m^2 .

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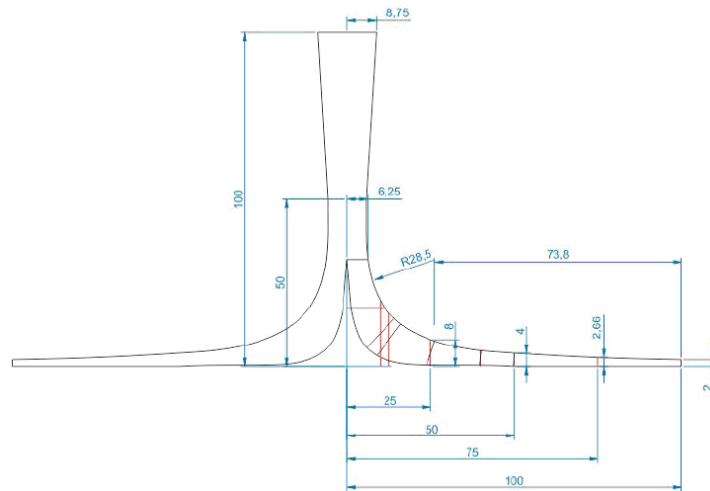


Fig 3: Dimensions of the plant

To formulate this model the following assumptions were made [5]:

1. The fluid is Newtonian and incompressible.
2. The flow is static, 3-dimensional and turbulent.
3. The axisymmetric flow is assumed.
4. The energy dissipation due to viscosity and compressibility of fluid are neglected.

A structured mesh was generated with Size Function applied on both Proximity and Curvature for mesh refinement, in conjunction with additional size controls and inflation meshing. The number of generated nodes were 107779 and Elements were 475150. Upon further refinement of the mesh only a change within 0.5% of the final solution was observed.

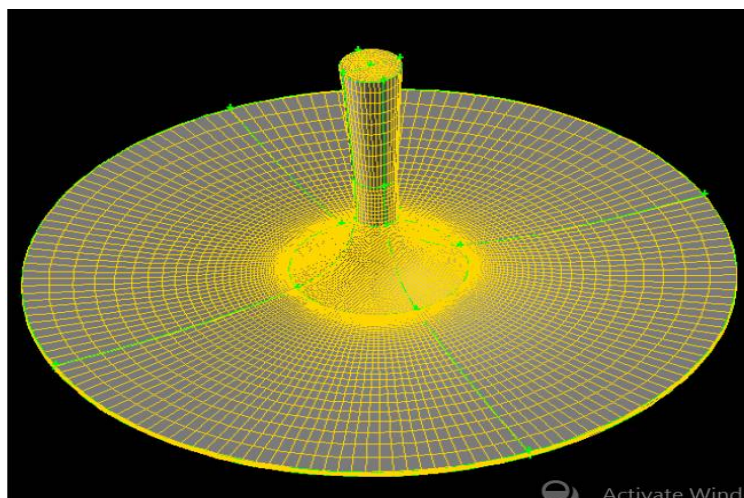


Fig 4: Meshed model

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IV. RESULTS AND DISCUSSION

The k- ϵ model used with Enhanced Wall Treatment due to minimal Flow separation and wall-bounded effects. The Radiation model used to account for Solar Load is the Discrete Ordinate model [6]. Using the Solar Calculator the intensity of radiation from the sun at any given time, date, and location can be calculated. At +5 hours from GMT, the Direct Solar Irradiation and Diffuse Solar Irradiation has been accurately predicted. Through Discrete Ordinate Irradiation method used, the irradiation flux is applied to the semi-transparent glass roof of the Solar Collector.

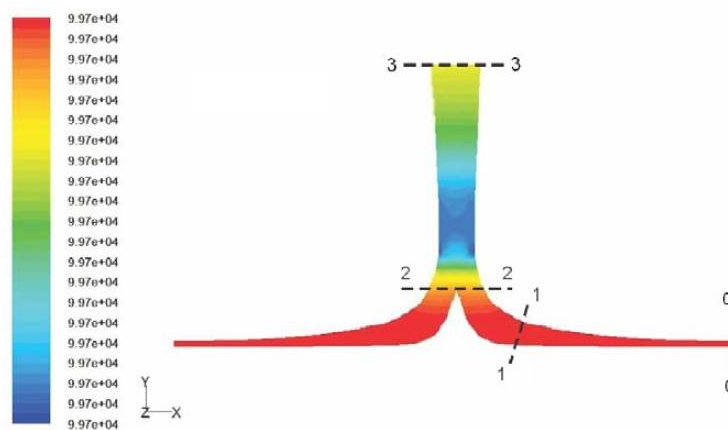


Fig 5: Static Pressure Contours

Figure 5 represents the variation of static pressure throughout the collector and chimney. High pressure regions can be observed at the collector region i.e. between section 0 and 1 and also in the turbine region i.e. between section 1 and 2. It is followed by a low pressure region caused by the suction of the updraft in the throat section of the central tube.

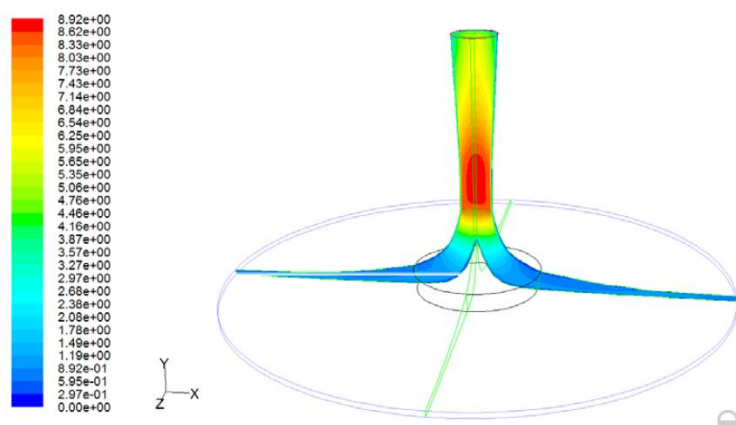


Fig 6: Velocity Contours

The velocity contours in Figure 6 on the cross section show high velocity of air in the central tube region caused due to the low pressure and suction of the updraft. The pressure staged turbine receives low velocity, high pressure air from all directions channeled from the periphery to the chimney.

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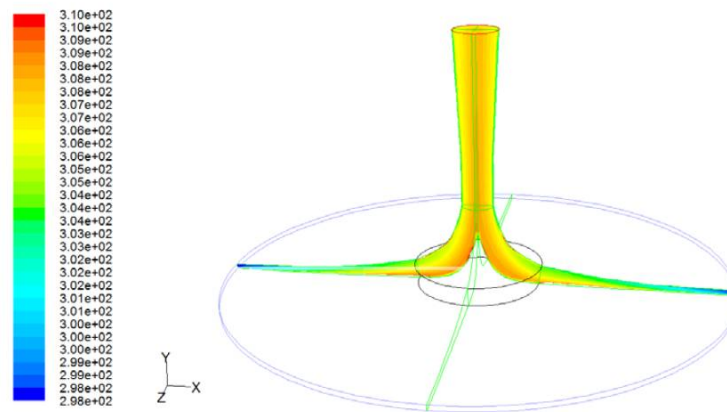


Fig 7: Static Temperature Contours

The heating effects of this Solar Load cause temperature to reach 310K near the turbine location as seen in Static Temperature Contours in Figure 6. The ΔT air temperature rise observed is about 12 degrees. The resultant air flow due to the Convective Heat Flow creates flow velocity of up to 8.98 m/s as depicted by Velocity Contours in Figure 7. The Updraft Air Velocity is proportionate to the Temperature rise in the device.

V. CONCLUSION

1. Plant efficiency increases with the size of the plant. A larger plant would exhibit significantly higher output.
2. It can be inferred that, although the initial investment increases, the cost of power production per Megawatt would decrease as the size of plant increases.
3. Due to significantly lower cost of electricity production for larger plants, its cost and output becomes comparable to conventional power production facilities.
4. Optimization of plant geometry is crucial to design an economically viable and technologically productive plant.
5. The following geometry of the plant has successfully been analyzed and tested for commercial use and production of energy.

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