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Numerical Simulation of Solar Updraft Tower

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Abstract: *The Solar updraft tower also known as solar chimney is zero emission of green house gases & green energy technology. It is one of the renewable energy technologies. This project is utilization of solar induced convective flow generated by updraft tube. Solar chimneys are very suitable for use in remote communities wherever there is high solar energy as a power source for both residential and industrial use, based on reliability, cost, and operational factors. They can provide a suitable energy source in many remote areas of India.*

Solar updraft tower consisting of a circular air collector (green house), a central updraft tower for generating solar induced convective flow and a turbine unit driven by warm air. But it has limitation for continuous 24 hour power generation because solar radiation is not available for 24 hour. To overcome this problem, closed black pipe network of high heat capacity fluid that is water is used beneath the solar collector. During day time water absorb the some part of radiation heat comes from sun and releases the heat at night time which decreases the fluctuation of power produced.

The purpose of this study is to conduct a more detailed numerical analysis of a solar updraft tower. A mathematical model based on the Navier Stokes, continuity and energy equations was developed to describe the solar chimney power plant mechanism. The numerical simulation was performed on ANSYS FLUENT 15 CFD software that can simulate two dimensional axis symmetry model of solar updraft tower with standard k-epsilon turbulence model and Boussiesq approximation was also taken for considering buoyancy driven flow also known as natural convection. This simulation was also taken heat flux from bottom of collector during night time as heat flux transfer from thermal storage system.

1. Introduction

Development requires mechanization and energy. Energy consumption increases proportionally to the gross national product or prosperity while simultaneously the population growth will decrease exponentially. Many developing countries possess hardly any energy sources and their population doubles every 15 to 30 years. The results are commonly known: Civil wars and fundamentalism. If these developing countries are provided with only a humane and viable minimum of energy the global energy consumption will drastically increase. Who could supply such an enormous amount of energy without an ecological breakdown (because poor countries cannot afford environmental protection) and without safety hazards (because they are not acquainted with the safety requirements for nuclear power plants) and without a rapid depletion of natural resources at the expense of future generations? The sun Many of these countries are lavishly provided with solar radiation in their desert areas.

Sensible technology for the wide use of renewable energy must be simple and reliable, accessible to the technologically less developed countries that are sunny and often have limited raw materials resources. It should not need cooling water and it should be based on environmentally sound production from renewable or recyclable materials.

The solar tower meets these conditions. Economic appraisals based on experience and knowledge gathered so far have shown that large scale solar towers >100 MW are capable of generating electricity at costs comparable to those of conventional power plants. This is reason enough to further develop this form of solar energy utilization, up to large, economically viable units. In a future energy economy, solar towers could thus help assure the economic and environmentally benign provision of electricity in sunny regions. For Australia, a 200 MW solar tower project is currently being developed.

Insolation levels are high ,there are large suitably flat areas of land available, demand for electricity increases, and the government’s Mandatory Renewable Energy Target, requires the sourcing of 9500 gigawatt hours of extra renewable electricity per year by 2010 through to 2020. In the paper an overview is given over solar updraft tower theory, practical experience with a prototype, and economies of large scale solar updraft tower power plants.

2. Literature Review

The prototype solar chimney power plant at Manzanares in Spain (Haaf et al. (1983)) showed that the solar chimney is a practical technology capable of generating electrical power from the sun. Solar chimney power plant systems are being considered as feasible options to produce energy in countries where unexploited desert areas are abundant, like South America, Africa, Asia and Oceania. Haaf et al. (1983) and Haaf (1984) presented fundamental studies for the Spanish prototype in which the energy balance, design criteria and cost analyses were discussed, and reported preliminary test results [3].

Krisst (1983) and Kulunk (1985) demonstrated different types of small-scale solar chimney devices with power outputs not exceeding 10 W. Its collector had a diameter of 6m and the chimney was 10m tall. In 1997, a solar updraft tower thermal power generating demonstration model was built and modified twice on the campus of the University of Florida, and both theoretical and experimental investigation on their performances was carried out. A micro-scale model with a chimney of 3.5 cm in radius and 2m in height on a patch of area of 9 m2 was built by Kulunk in lzmit, Turkey, which produces an electric power of 0.14W [4]. Pasumarthi and Sherif (1998a, b) and Padki and Sherif (1999) developed a mathematical model to study the effects of various environment and geometry conditions on the heat and flow characteristics and power output of a solar chimney [5].

Lodhi (1999) presented a comprehensive analysis of the chimney effect, power production, efficiency, and estimated the cost of the solar chimney power plant set up in developing nations [6]. Gannon and von Backstro¨m (2000) presented a thermodynamic cycle analysis of the solar chimney power plant for the calculation of limiting performance, efficiency, and the relationship between the main variables including chimney friction, system, turbine and exit kinetic energy losses [7]. Pastohr et al. (2004) presented a numerical simulation result in which the energy storage layer was regarded as solid [8]. Liu et al. (2005) carried out a numerical simulation for the MW-graded solar chimney power plant, presenting the influences of pressure drop across the turbine on thedraft and the power output of the system [9]. Schlaich et al.(2005) presented a simplified theory, some practical experience results and a detailed economic analysis of solar chimneys for the design of commercial solar chimney power plant systems like the one being planned for Australia [10].

Pretorius (2006) reviewed most of the outstanding issues. Different calculation approaches with a variety of considerations have been applied to calculate chimney power plant performance [11].]. Schlaich et al.(2005) presented a simplified theory, some practical experience results and a detailed economic analysis of solar chimneys for the design of commercial solar chimney power plant systems like the one being planned for Australia [10]. Pretorius (2006) reviewed most of the outstanding issues. Different calculation approaches with a variety of considerations have been applied to calculate chimney power plant performance [11]. The available work potential that atmospheric air acquires while passing through the collector has been determined and analyzed by Ninic (2006). In this study, the dependence of the work potential on the air flowing into the air collector from the heat gained inside the collector, air humidity and atmospheric pressure as a function of elevation are determined.

3. Components of Solar Updraft Tower

3.1. Collector:

Hot air for the solar tower is produced by the greenhouse effect in a simple air collector consisting of a glass or plastic glazing stretched horizontally several meters above the ground. The height of the glazing increases adjacent to the tower base, so that the air is diverted to vertical movement with minimum friction loss. This glazing admits the solar radiation component and retains long-wave reradiation from the heated ground. Thus the ground under the roof heats up and transfers its heat to the air flowing radially above it from the outside to the tower.

3.2. Updraft tower:

The tower itself is the plant’s actual thermal engine. It is a pressure tube with low friction loss like a hydro power station pressure tube or pen stock because of its favorable surface-volume ratio. The updraft velocity of the air is approximately proportional to the air temperature rise in the collector and to the tower height. In a multi-megawatt solar tower the collector raises the air temperature by about 30 to 35 K. This produces an updraft velocity in the tower of only about 15 m/s at nominal electric output, as most of the available pressure potential is used by the turbine and therefore does not accelerate the air. It is thus possible to enter into an operating solar tower plant for maintenance without danger from high air velocities.

3.3. Turbine:

Using turbines, mechanical output in the form of rotational energy can be derived from the air current in the tower. Turbines in a solar tower do not work with staged velocity like free-running wind energy converters, but as shrouded pressure staged wind turbo generators, in which, similarly to a hydroelectric power station, static pressure is converted to rotational energy using cased turbines. The specific power output power per area swept by the rotor of shrouded pressure-staged turbines in the solar tower is roughly one order of magnitude higher than that of a velocity staged wind turbine. Air speed before and after the turbine is about the same. The output achieved is proportional to the product of volume flow per time unit and the pressure differential over the turbine. With a view to maximum energy yield, the aim of the turbine control system is to maximize this product under all operating conditions.

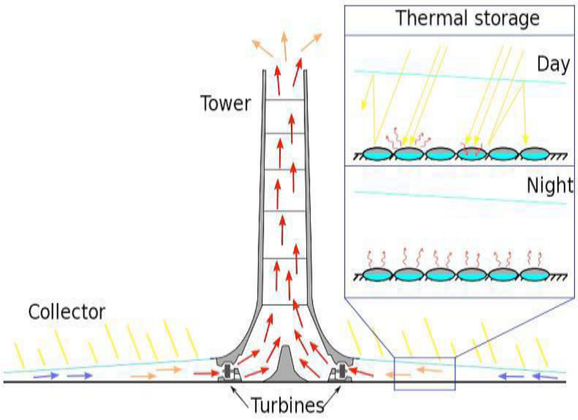

Figure 1. Component of Solar Updraft Tower

4. Methodology

It is utilization of solar induced convective flow for power generation. Air is heated by solar radiation under a low circular transparent or translucent roof open at the periphery the roof and the natural ground below it form a solar air collector. In the middle of the roof is a vertical tower with large air inlets at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in hotter air from the collector, and cold air comes in from the outer perimeter.

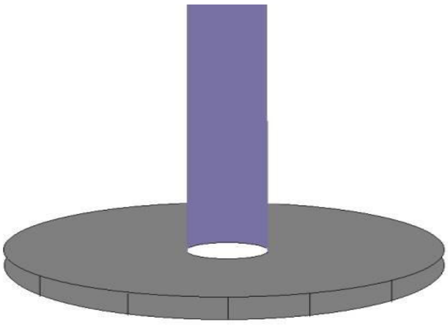

Figure 2. Collector and Updraft Tower

Power output P of the solar tower can be calculated as the solar input Q_{solar} multiplied by the respective efficiencies of collector, tower and turbine. Solar energy input to the collector is the product of global horizontal radiation G_h and collector area A_c.

The tower converts heat floe produced by collector into kinetic energy (Convection Current) and potential energy (pressure drop at the turbine). Thus the density difference of air caused by temperature rise in the collector works as the driving force.

$$P = \dot{Q}_{Solar} * \eta_{Collector} * \eta_{Tower} * \eta_{Turbine} = \dot{Q}_{Solar} * \eta_{Plant}$$

$$\dot{Q}_{Solar} = G_h * A_{Collector}$$

Where G_h is the global horizontal radiation (W/m^2) and $A_{collector}$ is the area of collector in m^2.The tower chimney converts the heat-flow produced by the collector into kinetic energy (convection current) and potential energy (pressure drop) at the turbine. Thus the density difference of the air caused by the temperature rise in the collector works as a driving force.

$$\Delta p_{total} = g \cdot \int_0^H (\rho_a - \rho_{tower}) dH$$

Thus total pressure difference increases with tower height. The pressure difference can be subdivided into a static and a dynamic component, neglecting friction losses;

$$\Delta p_{total} = \Delta p_s + \Delta p_d$$

The static pressure difference drops at the turbine, the dynamic component describes the kinetic energy of the airflow. With the total pressure difference and the volume flow of the air at the power P contained in the flow is now;

$$P_{Total} = \Delta p_{total} * V_{tower,max} * A_{collector}$$

Actual subdivision of the pressure difference into a static and a dynamic component depends on the energy taken up by the turbine. Without turbine, a maximum flow speed is achieved and the whole pressure difference is used to accelerate the air and is thus converted into kinetic energy;

$$P_{total} = \frac{1}{2} m \cdot V_{tower,max}^2$$

Using the Boussinesq approximation, the speed reached free convection currents can be expressed as

$$V_{tower,max} = \sqrt{2.g.H_{tower}.\frac{\Delta T}{T_o}}$$

Where T is the temperature rise between ambient and collector outlet. This simplified representation explains one of the basic characteristics of the solar tower, which is that the tower efficiency is fundamentally dependent only on its height.

5. Modeling and Simulation

Fluent offers complete mesh flexibility, including the capability to solve flow problems using unstructured meshes that can be created about complex geometries with relative ease. All functions required to compute a solution and display the results are available in FLUENT through an interactive, menu-driven interface.

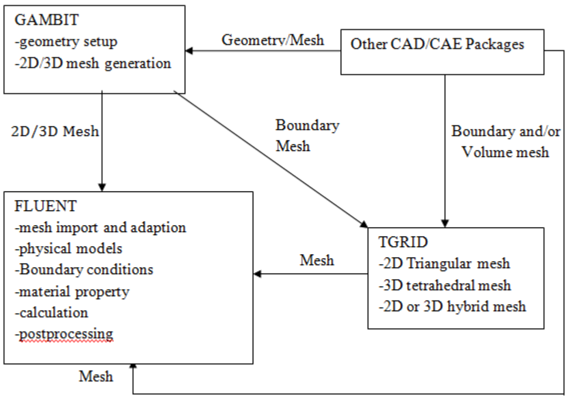

Figure 3. Basic Program Structure

All simulation was performed using ANSYS FLUENT that can simulate a two-dimensional axisymmetric model of a solar chimney power plant with the standard k-epsilon turbulence model of system. For geometry collector diameter is 3 m and gap between glazing plate and bottom is 0.06m. Axis is passes through the mid of the tower and radius of curvature of turbine wall is 0.2 m and outer radius of curvature is 0.15m. Height of tower is 2 m from the bottom.

6. Result and Discussion

For the 1st simulation we take the solar radiation density incident upon the upper plate of collector that is glazing plate. We use solar map history of India to get the approximate value of solar radiation density. We take the solar radiation density 800 W/m2. Ambient temperature was 300 K .

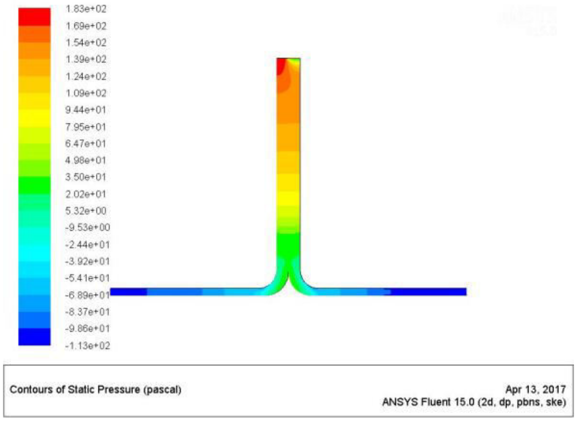

Figure 4. Pressure

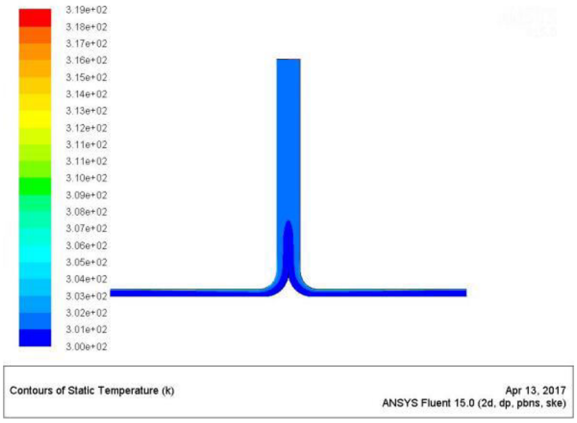

Figure 5. Temperature

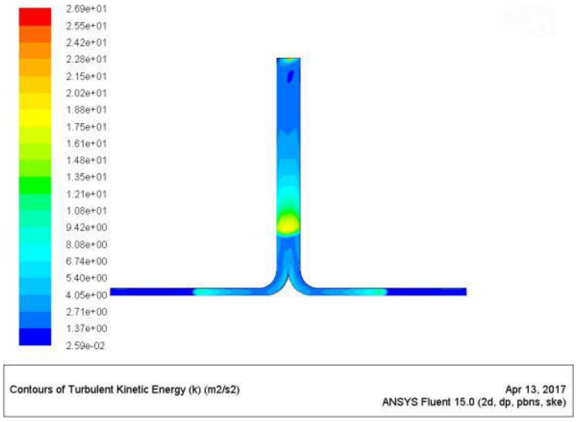

Figure 6. Turbulence

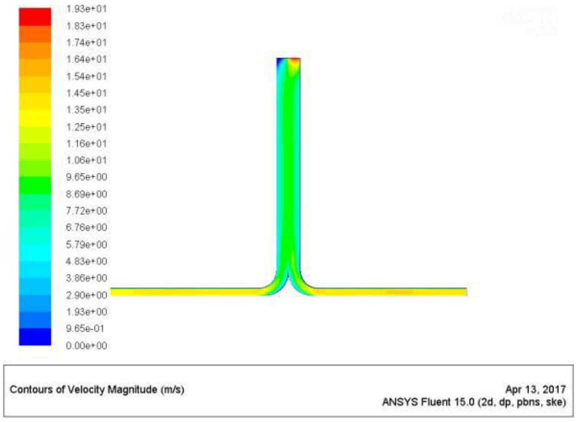

Figure 7. Velocity

For the 2nd simulation we take the heat flux from thermal storage system from the bottom of the collector. This heat is given by water at night time when solar radiation is not available. We take this heat flux 600 W/m2. Ambient temperature was 300K.

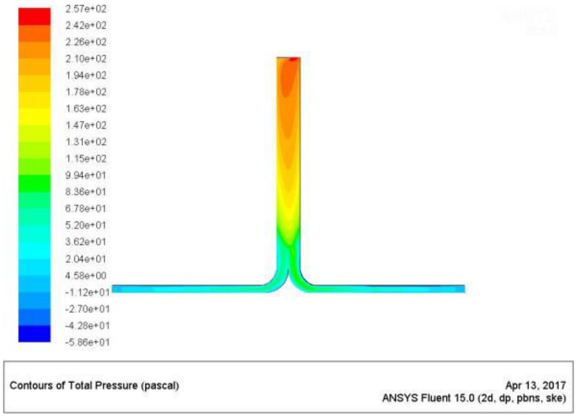

Figure 8. Total Pressure

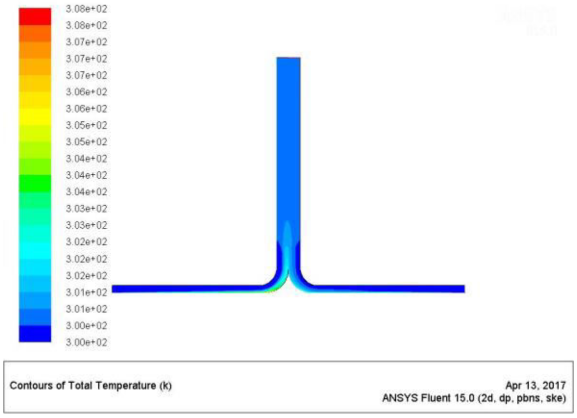

Figure 9. Total Temperature

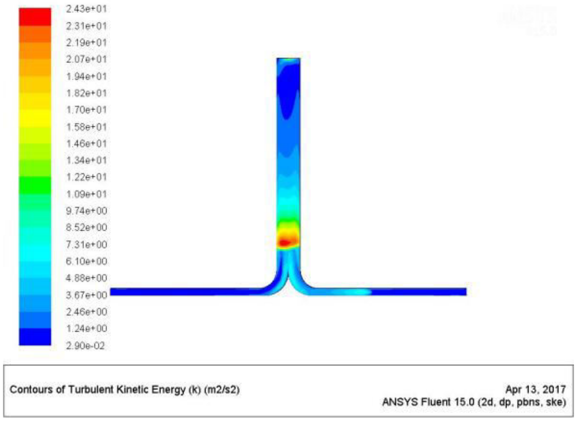

Figure 10. Turbulence

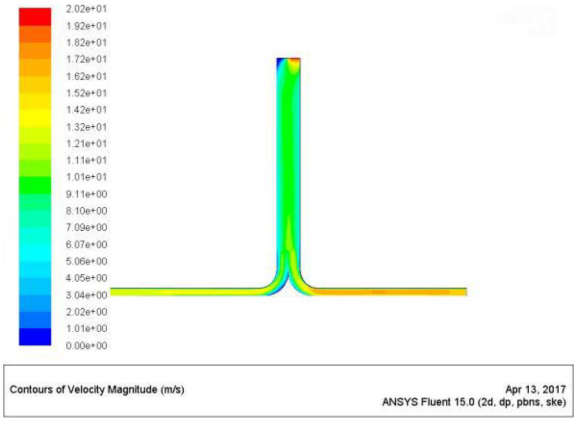

Figure 11. Velocity

7. Conclusion

For the steady state small scale simulation we can conclude that the static chimney inlet temperature is greater than exit temperatures and increases along the chimney height. The static pressure increase with the increase of the chimney diameter and the minimum values lie in the bottom of the chimney, which an indication for lower pressure difference between the ambient and chimney inlet so velocity decrease.

8. Acknowledgement

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