CFD ANALYSIS ON SOLAR CHIMNEY FOR POWER GENERATION APPLICATION

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ABSTRACT

A solar chimney power plant working on the principle of greenhouse effect and buoyancy-driven flow to generate the electricity. Based on the reference of solar updraft prototype erected in 1982 in Manzanares, numerical analysis is carried out using steady state Navier-Stokes and energy equations in cylindrical coordinate system. Assumed the turbulent air movement inside the chimney and simulation is carried out using k-ε turbulent model, using the FLUENT-16.2 software package. Study the effects of the different parameters like chimney height and radius on the power output from the chimney. Analysis is carried out for different solar radiation intensity because that will vary throughout the day and season. As per the analysis results theoretical power output is calculated.

Keywords:Solar chimney, Renewableenergy, Numerical analysis.

I. INTRODUCTION

Energy and effective utilisation mechanization of energyare main requirements for the growth of any country to fulfil the global energy and electricityneeds. Electricity production from conventional sources are effecting the environment, and these are not economically feasible for many developing countries. So need for renewable and sustainable energy source is very much essential.Solarchimney is working based on greenhouse effect under the collector area and buoyancy-driven flow of air through the chimney. Solar irradiation incident on the collector cover and passes through the glass of the collector, which is absorbed by the ground below, and re-emitted to the air under the greenhouse. Convective effects from the ground also account for some of the air heating [1]. The high-temperature, lower density air is funnelled toward the tower. The buoyancy of the air creates a pressure difference in the column of the tower, driving the air from the base of the tower to its upper outlet. The kinetic energy of the air is captured by the turbine system, which is typically located at the base of the tower.Many inventions are carried out on this field, it was Leonardo da Vinci (1452-1519), created the earliest system, which uses hot air rising in a chimney to drive an apparatus. IsidoroCabanyes (1900-03),Prof. Engineer Bernard Dubos(1926), Günther(1931), Ridley (1956) gives their contribution to the development of solar chimney. J. Schlaich did the civil engineering structural analysis on the solar updraft technology.

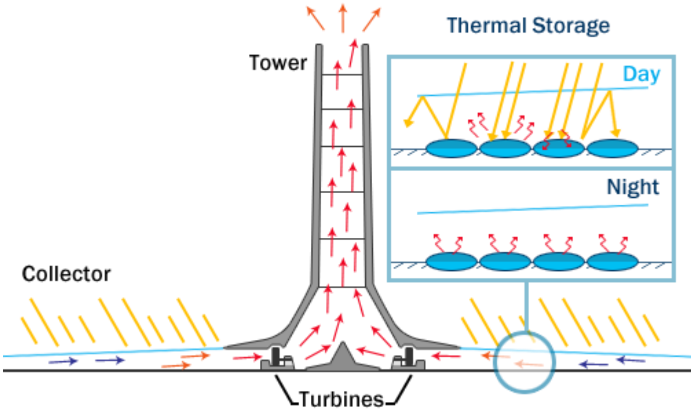


Fig.1. Working principle of solar updraft tower [1].

Constructions of entire Solar chimney power generating systems is costly and take more time therefore theoretical and CFD analysis have been carried out by many researchers using Manzanares solar chimney prototype experimental results as a reference.

II. WORKING METHODOLOGY

The solar updraft tower is a method to produce electric power from solar energy. Main component are (1) Collector – A huge greenhouse (2) Chimney placed at the center of the collector (3) Turbines - One or more placed base of the collector and connected to generators. As shown in figure (1),model working by the natural convection of air heated by the sun rays. Kinetic energy of air is extracted through a system of turbines which is connected to the generators. It can be used at night utilizing the heat stored in the soil at daytime. The main dimensions of the physical model for this study were selected as per Spanish prototype. The system geometry consists of a chimney with 200 m height and 5 m radius surrounded by a collector with 120 m radius and 1.85 m height**.**

To formulate this model the following assumptions were made [1]:

- The fluid is Newtonian and in compressible.
- The flow is stationary, three-dimensional and turbulent.
- The axisymmetric flow is assumed.
- The viscous dissipation and compressibility effects are assumed negligible.

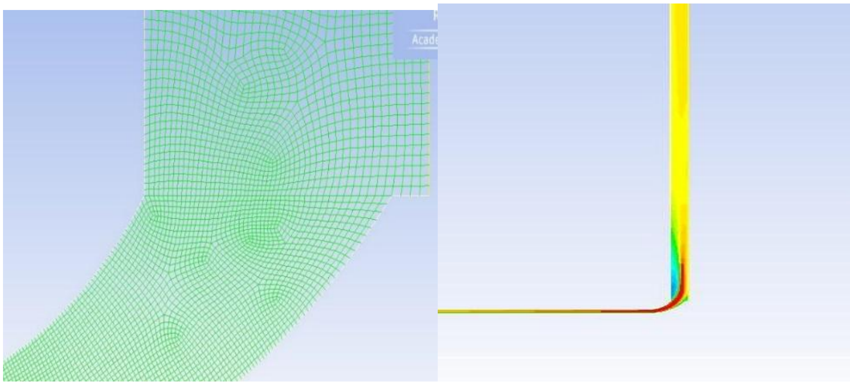
Conservation equations of mass, momentum and energy are used. Closure for the unknowns in the above equations can be obtained by the application of suitable turbulence models. The k-ε models are used as closure equations and standards values for constants are adopted.Analysis are carried out using commercial FLUENT software (Fluent Inc. 16.2).As mentioned above geometry and configurations are modelled. Three different parts were labeled as collector, transition section and chimney. Mesh of each part was generated.Most sensitive area of the computational domain is the transition zone it requires a very fine mesh we did it by adopting the tetrahedral mesh as shown in figure (2). The other two parts are meshed using hexahedral mesh. Collector inlet is specified as pressure inlet, chimney outlet is specified as pressure outlet. A standard atmospheric pressure and temperature condition and no-slip conditions are imposed.

Table 1: Main dimensions of the Manzanares prototype [2]

Tower height:	194.6 m
Tower radius:	5.08 m
Mean collector radius:	122.0 m
Mean roof height:	1.85 m

III. RESULTS AND DISCUSSION

To validate the developed model, CFD results are compared with experimental and theoretical validated data available in the literature. The CFD results werealso compared with the experimental data of the ManzanaresplantAir velocity and power output were function of the geometric parameters like collector size, chimney height and environmental condition like the solar radiation intensity. Simulated the velocity, pressure, temperature variation in the solar updraft power plant for different chimney height and chimney radius. Keeping the main dimensions of the prototype as Spanish prototype configuration and vary the specific parameter of interest andseveral simulations were conducted. Calculated the power output of the chimney using our CFD results values and as per the formulae mentioned byJörgSchlaich et.al [2].Power output "P" of the solar tower is calculated by assuming the efficiencies of collector, tower and turbine(s) and multiplied these efficiencies with the solar input Q_{solar}.

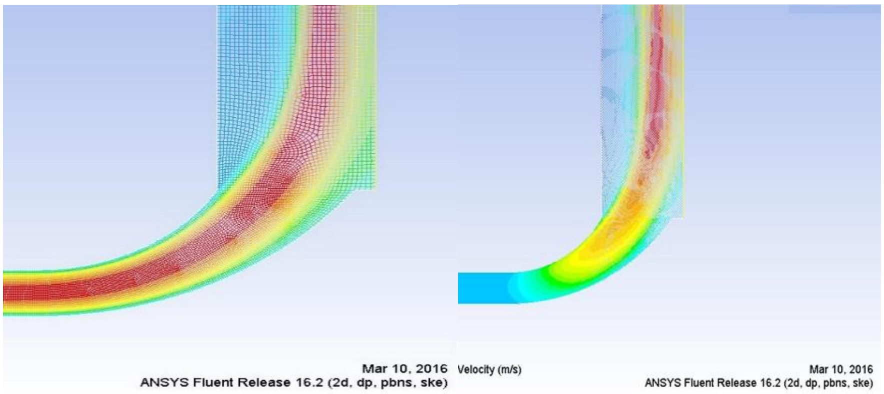


(a) (b)

Figure. 2(a): Mesh at the critical region (near the turbine location), maintain the Y plus value nearly zero(b): Variation of total pressure at different section of the chimney.

Figure (2.a) shows the mesh at the critical region, we maintain the Y plus value nearly zero to capture the exact variation near the turbine location i.e. at the base of the chimney. Figure (2.b) shows the variation of total pressure throughout the structure (half portion of the power plant -Symmetric condition applied).Pressure difference is maximum near the base of the chimney.

Figure (3) indicate the variation of the pressure and velocity near the turbine location. Figure (4) shows the effect of chimney height and chimney radius on power output. We observe the increase in power output as the chimney height increases or collector radius increases or both. As height increases we will get more density difference and hence driving/pumping buoyancy effect increases, it allows more air to flow through the chimney.



(a) (b)

Figure .3(a): Variation of pressure at the turbine location (b): Variation of air velocity across the tower.

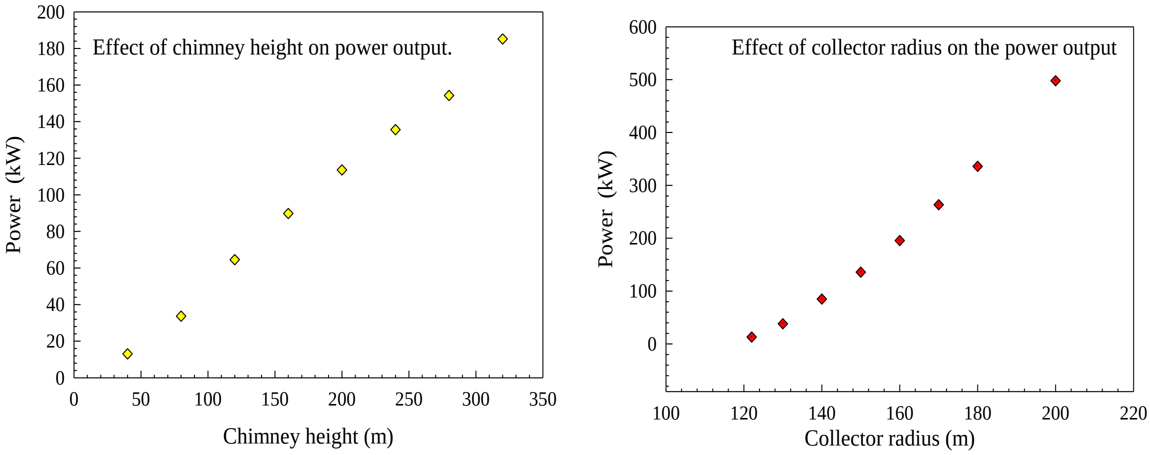


Figure. 4(a): Effect of chimney height on power output. (b): Effect of collector surface area on power output

IV. CONCLUSION

Using Three-Dimensional steady state Navier-Stokes and energy equations, fluid flow inside the solar updraft tower is simulated with the k-ε turbulent model (FLUENT 16.2 software). The CFD results are compared with the experimental data of the Manzanaresplant. An analytical study is carried out for developed model using the equations available in the literature. The effects of the chimney height and collector radius on power output have been analyzed. The solar chimney power output depends strongly on its geometric dimensions, and intensity of solar radiation. At fixed solar radiation also increase in height results in increase in exit velocity because of greater buoyance force greater air driving force is generated. The results shows that as an increase in the height of the chimney, increase in the mass flow rate inside the system. Heat transfer coefficient is low therefore this increase in these value is very much essential.

REFERENCE

[1] A. Dhahri, A. Omri and J. Orfi "Numerical Study of a Solar Chimney Power Plant", Research Journal of Applied Sciences, Engineering and Technology 8(18): 1953-1965, 2014 ISSN: 2040-7459; e-ISSN: 2040-7467.

[2] Schlaich J, Bergermann R, Schiel W, Weinrebe G "Design of Commercial Solar Updraft Tower Systems—Utilization of Solar Induced Convective Flows for Power Generation". Journal of Solar Energy Engineering 127 (1): 117–124; 2005.

[3] Groenendaal, B.J "Solar Thermal Power Technologies"; July 2002.

[4] V.Kalantar and M.zare "Numerical calculations of flow and temperature field in 3D solar chimney power plants during different months of year".

[5] Ming Tingzhen, Liu Wei, Xu Guoling, XiongYanbin, Guan Xuhu, Pan Yuan "Numerical simulation of the solar chimney power plant systems coupled with turbine";Elsevier,Renewable Energy**;** Volume 33, Issue 5, May 2008, Pages 897–905.

[6] ObоetsweMotsamai,LesediBafetanye, KobameloMashaba and OaitseKgaswane "Experimental Investigation of Solar Chimney Power Plant" ; Journal of Energy and Power Engineering 7 (2013) 1980-1984

[7] AtitKoonsrisuk , TawitChitsomboon ; Mathematical modeling of solar chimney power plants; Elsevier , Energy 51 ; 314e322 ; 2013.

[8] Richerdanthoneyhederwick "Performance Evaluation of Solar Chimney Power Plant".Phdwork,Dept of Mechanical engineering,University Stellenbosch,Dec2000.

[9] N. Ninic "Available energy of the air in solar chimneys and the possibility of its ground-level concentration" ; Elsevier ; Solar Energy 80 ; 804–811; 2006 .

[10] A.A. El-Haroun**"**Performance Evaluation of Solar Chimney Power Plants in Egypt"; International Journal of Pure and Applied Sciences and Technology; 13(2) (2012), pp. 49-59; ISSN 2229.