JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# Comparative Analysis of Solar Chimney Power Plant Using Two Design Methods

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*Abstract: The high consumption of fossil fuels for power generation has resulted in increased carbon emission and faster depletion. The solar energy is available in abundance which can be tapped using solar chimney. The current research investigates roughened design of solar chimney using numerical method. The CFD analysis of roughened surface (staggered type) solar collector is conducted using ANSYS CFX and output parameters are determined. The pressure plot, velocity plot and kinetic energy plots are generated. The pressure and velocity profile obtained from analysis has shown encouraging results and roughened solar chimney design could yield better performance.*

*Key Words: Solar chimney, CFD, thermal analysis*

## 1. INTRODUCTION

The power generation using fossil fuels like coal, petroleum is causing environmental hazards. The carbon emission from thermal power plants is causing rise in environmental temperature. The viable solution to this problem is the use of solar chimney for power generation. The solar energy is available in abundance and solar power can be tapped using solar chimney. The lack of energy in various regions is causing poverty and underdevelopment. The power shortage is making industrialist reluctant to open any kind of manufacturing plants or other set up. Figure 1 below shows one of the solar power plant located in Arizona USA.

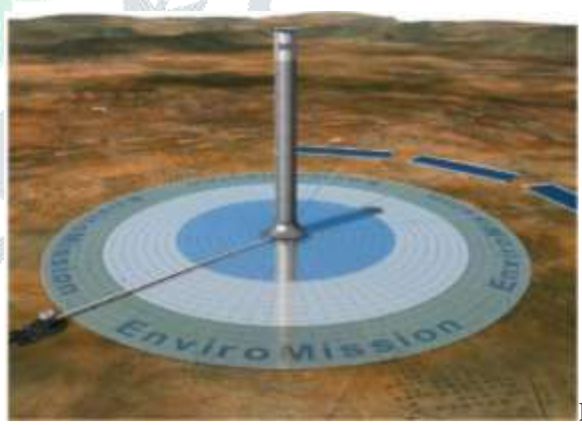

Figure 1: Solar Power Plant

The solar chimney power plant (SCPP) consists of three essential parts: a solar collector, a chimney, and a power conversion unit. Theoretical, experimental, and case studies of the SCPPs all around the world have concluded that the SCPP is with low power efficiency [1–3], huge solar collector area [4–6], and high chimney [6–9].

## 2. LITERATURE REVIEW

Hirunlabh et al. [10] has conducted experimental investigation of solar wall with six experimental points placed 1m above ground. The experimental findings have shown an increase in solar wall temperature with increase in wall height and vice versa.

Afonso and Oliveira [11] has conducted experimental investigation of solar chimney placed at Lisbon in Portugal. The experimental results have shown that volume flow rate is higher in chimneys with higher width.

Khedari et al. [12] conducted experimental investigation of solar chimney mounted on Trombe wall with solar wall. The air flow rate and volume is significantly affected by geometric dimensions of solar chimney.

## 3. OBJECTIVES

The performance of solar chimney depends upon stacking effect generated. The stacking effect depends upon solar radiation intensity incident on collector surface. The stacking effect of chimney can be improved by changing design of solar chimney from smooth to rough (staggered type design). The objective of current research is to investigate the effectiveness of rough shaped collector design in improving the performance of solar collector.

## 4. METHODOLOGY

The analysis of solar chimney is conducted using techniques of Computational Fluid Dynamics. The Naviers Stokes equation governs CFD which involves conservation of mass, conservation of energy and conservation of momentum. The energy equation used given by equation 1 below.

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\vec{v}(\rho E + p)) = \nabla \cdot \left( k_{eff} \nabla T - \sum_j h_j \vec{J}_j + (\bar{\bar{\tau}}_{eff} \cdot \vec{v}) \right) + S_h \quad (1)$$

The dimensions of chimney are taken from literature [14]. The height of chimney is 200m, diameter of chimney is 10m, diameter of collector is 500m.

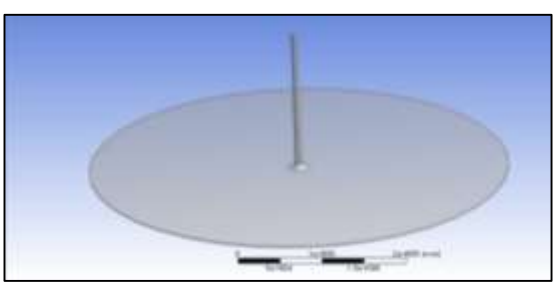

Figure 2: Imported CAD model of chimney in ANSYS design modeler

The model of chimney is converted in .iges file format which is imported in ANSYS design modeler for checking hard edges, sleeves and other errors on vertical face. The chimney design is meshed using tetrahedral elements as shown in figure 3 below.

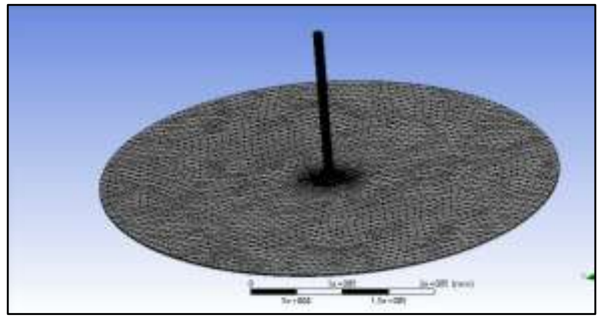

Figure 3: Meshed model of chimney

The meshed model has 5 layers, growth rate 1.2 and inflation set to normal. The number of nodes generated is 21081 and number of elements generated is 88756. The tetrahedral elements is suitable for complex geometries involving hard edges.

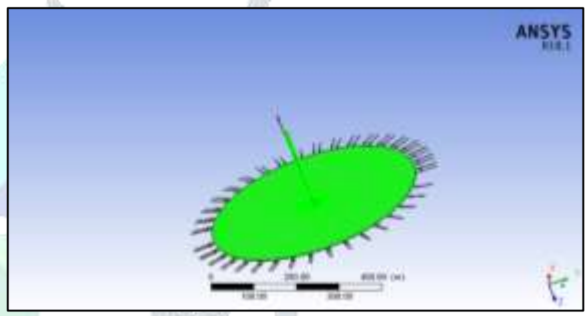


Figure 4: Fluid model definition of chimney

The domain definition is set to fluid and turbulence model set to k omega. The reference pressure is set to 1atm and fluid is set to air. The heat transfer model is set to total energy and thermal radiation model set to discrete transfer and participating media. The spectral model is set to grey. The equation for the change of radiant intensity, dI, along a path, ds can be written as

$$\frac{dI}{ds} + aI = \frac{a\sigma T^4}{\pi} \quad (2)$$

where $a$ = gas absorption coefficient

$I$ = intensity

$T$ = gas local temperature

$\sigma$ = Stefan-Boltzmann constant ($5.669 \times 10^{-8}$ W/m$^2$ -K$^{-4}$ )

The inlet boundary condition is defined on outer face of solar chimney. The outlet boundary condition is defined at the top face with relative pressure difference set to zero. The thermal flux is applied on exposed surface with magnitude of $1000 W/m^2$. The bottom surface is applied with adiabatic boundary conditions. The convergence criteria of 100 iterations and RMS residuals are set to .0001.

## 5. RESULTS AND DISCUSSION

The CFD analysis is conducted on solar chimney with roughened surface (staggered type design) is conducted using k-omega turbulence model. Pressure plot, radiation plot and other output parameters are determined.

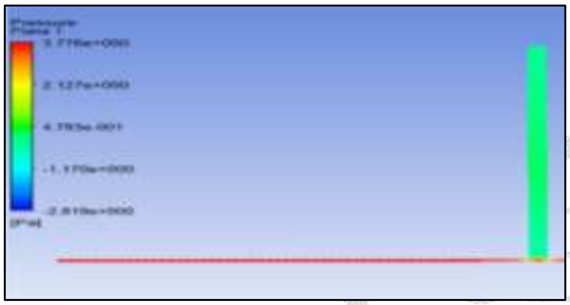

Figure 5: Roughened surface pressure plot

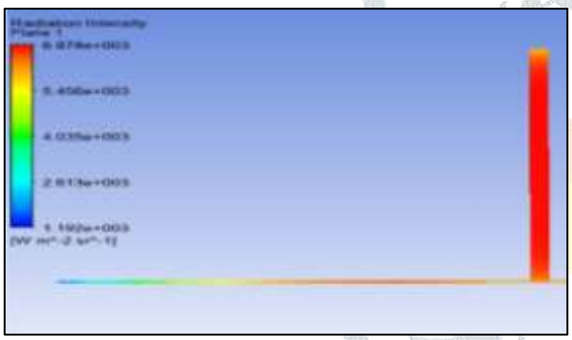

Figure 6: Roughened surface Radiation Intensity

The pressure plot and radiation intensity plot for roughened surface solar chimney is shown in figure 5 and figure 6 above. The pressure is almost uniform from air inlet section to vertical section and magnitude of pressure at this zone is 3.2Pa to 3.7Pa. The pressure profile changes at the vertical section and profile shows higher pressure at the centre of vertical section and lower pressure on corner regions. The radiation intensity plot shows lower magnitude at the air inlet as represented by light blue and dark blue colour. The radiation intensity at the region is nearly 1195 $W/m^2\ sr^{-1}$ and radiation intensity increases on moving towards the center and radiation intensity at this region is nearly 6870 $W/m^2\ sr^{-1}$.

Figure 7: Roughened surface total pressure plot

The total pressure plot obtained in figure 7 above shows higher magnitude at the centre with peak zone of magnitude 4.39Pa. This pressure profile would facilitate the turbine to generated higher power. The total pressure is almost uniform along the width of solar chimney with magnitude of nearly 3.2Pa.

Figure 8: Roughened surface Turbulence eddy dissipation plot

Turbulent eddy dissipation rate represents the rate at which energy cascades from large to small eddies within the inertial subrange. The turbulence eddy dissipation is observed to be maximum at the corners of vertical member with magnitude of nearly .0049 $m^2s^{-3}$.

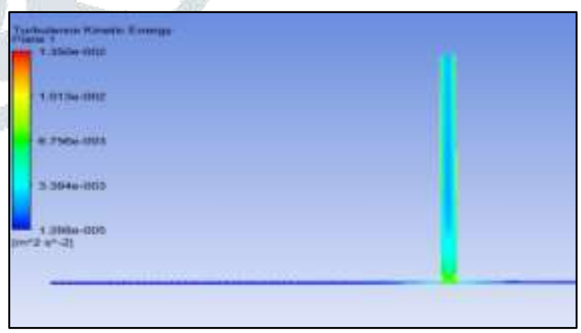

Figure 9: Roughened surface Turbulence kinetic energy plot

The kinetic energy associated with turbulence is shown in figure 9 above. The plot shows wavy structure of solar collector has significant effect on augmentation of turbulence kinetic energy. This kinetic energy increases air flow and an increased power generation is observed.

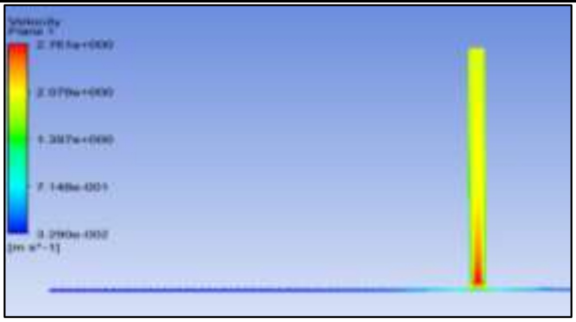

Figure 10: Roughened surface Velocity plot

The velocity plot of roughened surface solar chimney is shown in figure 10 above. The plot shows maximum air velocity at the centre of vertical member. The velocity at the centre is observed to be early 2.65m/s and reduces vertically upwards and reaches to 2.06m/s. The velocity at the horizontal zone has magnitude of .714m/s as represented by light blue colour.

## 6. CONCLUSION

The CFD simulation packages aides in conducting numerical investigation of solar chimney under varied boundary conditions which saves time. The CFD analysis of roughened surface solar collector design is conducted and provided necessary pressure and velocity data. The CFD results have shown that maximum air velocity is observed at the centre of vertical member. The velocity at the centre is observed to be early 2.65m/s and reduces vertically upwards and reaches to 2.06m/s. The use of staggered design type collectors can significantly enhance power generation.

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