SOLAR POWER PLANT PERFORMANCE ANALYSIS BY CHANGING CHIMNEY DESIGN PARAMETERS USING CFD

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***Abstract*: To analyzed the performance of solar chimney power plant in terms of power generation, different process parameters were optimized here in this work. Effect of height of chimney on the performance of solar plant were analyzed, for analyzing height of chimney 180, 185, 190, 195, 200, 205 and 210 m different height were considered in which 190 m height chimney shows the maximum power output. The effect of divergence of chimney where also analyzed, different chimney divergence angle that is 0, 1, 2 and 3 degrees in which 1-degree divergence shows the maximum power output. Here in this work, it also analyzed the effect of different height of air inlet space in between ground and solar roof. For analyzing different height, it considered 1.5, 2, 2.5, 3, 3.2 and 3.5 m height. In which 3.2 shows the most effect output power generation.**

1. Introduction

Energy demand is dependent on five different factors which include wealth status of a nation, the statistics of weather and climate conditions throughout the year, human populations, the efficient consumption of energy resources, and the energy conversion technologies. The growing energy demand of the globe has mainly been mitigated by the habit of non-renewable energy resources such as fossil fuels (oil, gas and coal) and nuclear energy. The use of these non-renewable energy resources contributes to environmental degradations such as acid rain, greenhouse gas emission, global warming and the depletion of natural resources. The global energy demand has been greatly influenced by the global human population growth which was rated at 1.23 % per year for the years between 2000 and 2015 (World-Bank 2017). This growing energy demand can be attributed to the increased economic growth and advanced lifestyles of luxury among individuals as well as technological advancements. Fossil fuels (oil, natural gas and coal) are usually combusted for energy and power generation in plants. Renewable energy has long been the interest quest in the field of electricity power generation. Considering the various renewable sources of energy, solar energy is considered the Earth's predominant source of energy but time and location dependent. The radiant heat as well as light approaching from the Sun can be converted directly or indirectly into different forms of energy. However, it is known that the solar power is being disadvantaged by the low efficiencies of the energy conversion systems. One of the drawbacks of solar power systems is the initial investment cost which restrains the masses from investing into the energy system. The economic disadvantage is associated with the increased costs of the installation of solar energy technologies while producing only a relatively small amount of energy related to other conventional energy system, thus characterized of low efficiency.

The performance of solar chimney power plant depends on different process parameters, which are chimney height, roof surface of solar collector, inclination angle of solar collector, height of solar collector from the ground surface. Many researchers have done different work to increase the performance of solar chimney power plant. During operation of plant, solar radiations coming from the sun fall on the transparent solar collector roof and heated the soil and air below the roof. Due to heating the air particles start moving in upward direction, due to convergent section geometry the velocity of air increases and reaches maximum when it enters in to the chimney. Due to this high-speed air velocity, turbine placed inside the chimney start rotating and generates the power. For future improvement in the efficiency of solar chimney here in this work effect of different solar collector roof inclination angle and solar chimney height was studied. For determining the effect of different height of chimney, here in this work six different height of chimney was considered. And to analyse the effect of different slope of solar roof inclination angle it considered five different inclination angles.

2. Geometric dimension of solar chimney power plant

Here in this work, for performing the CFD analysis of the system first we have to develop the solid model of the solar chimney power plant. The sold model of the complete setup is based on the geometric parameters given in the base paper. The geometric parameters of the solar chimney power plant are shown in the table mention here.

Table: 4.1 Geometry of the solar chimney power plant

Height of chimney (H)	195 m
Radius of collector	122 m
Radius of chimney	5 m
Collector inlet to ground distance	2 m
Distance of chimney base from ground	6 m

Base on the above mention geometric conditions, it develops the 3D solid model of the complete setup which is considered during the numerical analysis. The solid model of solar chimney is shown in the below fig.

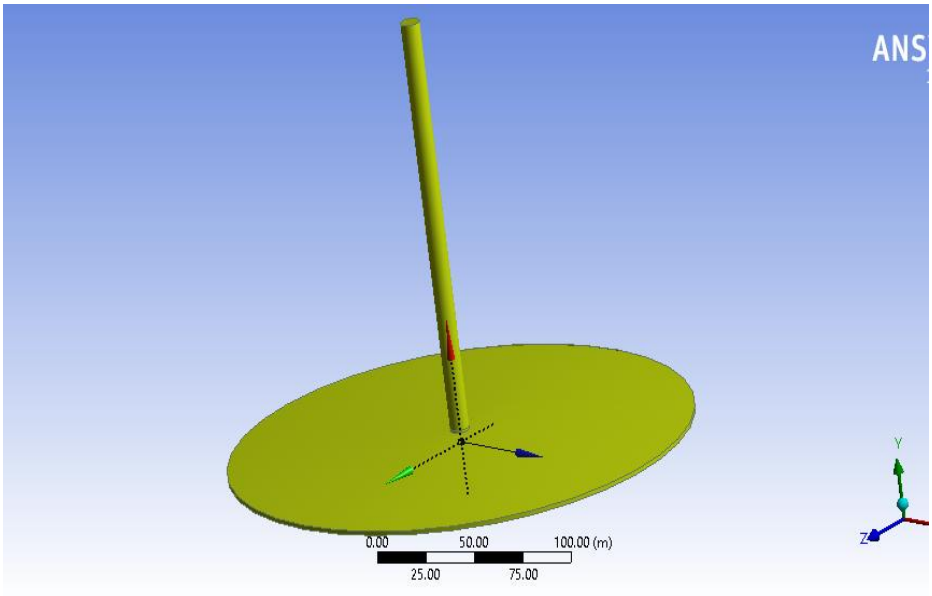

Fig. 4.1 Solid model of the solar chimney power plant

4.2 Meshing

It is necessary to discretize the solid model into numbers of nodes and elements. In order to get optimum number of nodes and elements, here in this work it considered different numbers of nodes and elements and calculated the performance parameters. For the refinement of mesh different tools was used during meshing. First, we have to generate the mesh of the complete setup because to perform the computational analysis first we have to discretize the complete system in to number of elements and nodes. For performing the node independence test here in this work, it preforms the mesh with different number of nodes and elements and calculates the velocity of air. Through analysis it is found that mesh with 287458 numbers of elements and 48754 numbers of nodes shows the optimum value of velocity of air.

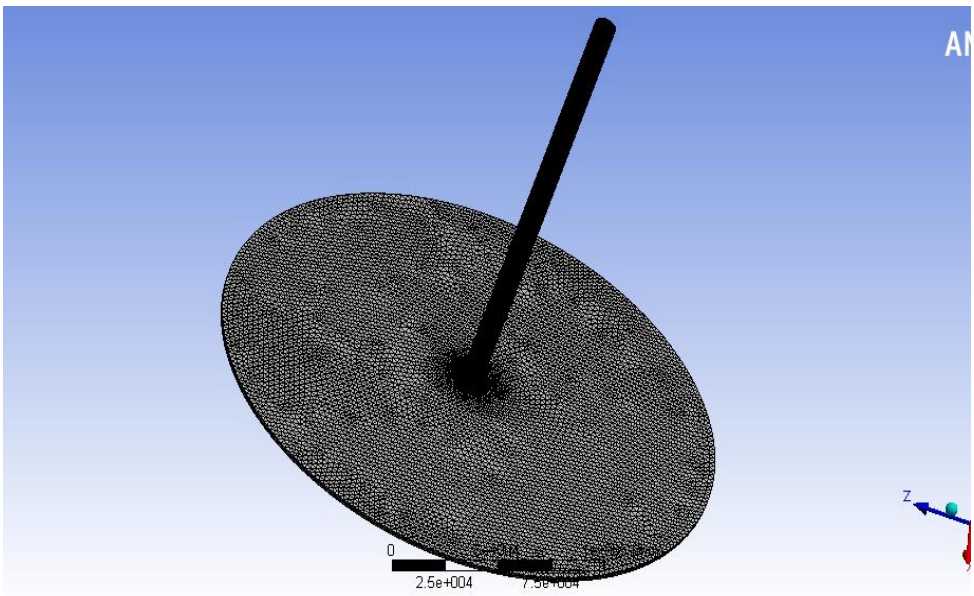

Fig. Mesh of the complete setup geometry considered during the numerical analysis

Boundary conditions

Here in this analysis air is used as a working fluid, the velocity of air at the inlet of the section is 0.3 m/s whereas the pressure at the inlet is near about 1.01325 bar. Boundary condition at the inlet is shown in the below figure. The temperature at solar panel is near about 303 K, whereas the external emissivity of solar panel is 1. In order to perform the numerical analysis, selection of appropriate model is very necessary. For selecting the appropriate model, different models were applied during the analysis and calculate the performance parameters of solar chimney. Through CFD analysis appropriate selection of model is determined. Here in this work K-epsilon model is used for the analysis of solar chimney power plant.

Validation of the CFD model

To specify the correct numerical CFD analysis of solar chimney, first it has to validate the CFD model of solar chimney. For validating the CFD model of the solar chimney power plant here in this work. First we have considered the same geometric dimension as considered in the base paper and apply the same boundary condition as applied in the base paper and calculated the value of maximum velocity and temperature inside the chimney.

For calculating the power output of turbine following mathematical relation were used.

$$P = \frac{1}{2}\rho A V^3 \quad \text{.....} \quad (1)$$

Where P is the power output, ρ is the density of air and A is the cross sectional of chimney and V is the velocity of air at a turbine zone.

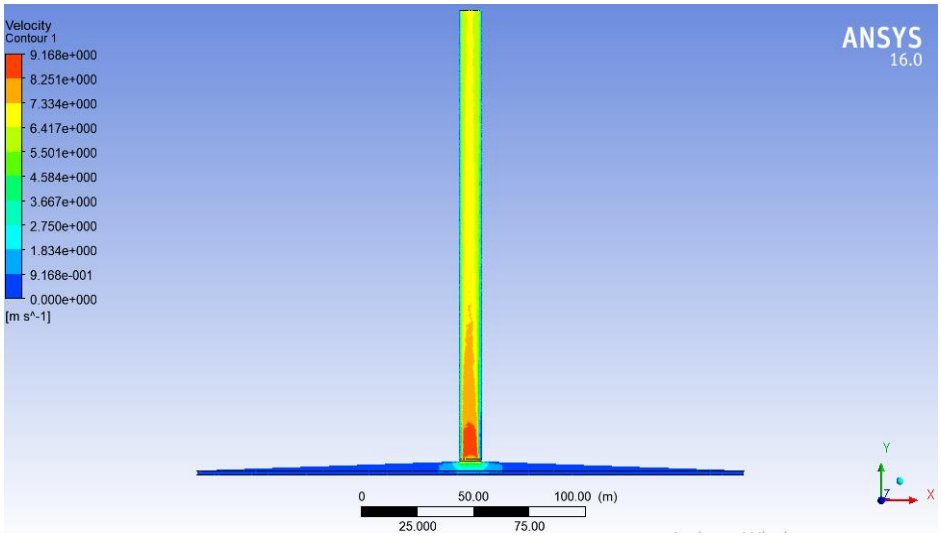

Fig.4.14 Velocity contours of solar chimney power plant

Through numerical analysis it is found that, after applying the different process parameters given in base paper, maximum velocity and temperature inside the solar chimney power plant were determined. Through CFD analysis, the maximum velocity of air obtained inside the chimney is 9.16 m/s whereas temperature is near about 316.6 K. The comparison of CFD and base paper value is shown in the below fig.

Table: 4.2 Comparison of different performance parameters

S.No	Parameters	Base paper	CFD analysis	Error %
1	Maximum velocity	9.16 m/s	9.138 m/s	0.24 %
2	Maximum temperature	318.44	316.6	1 %

Through analysis it is found that value of temperature and velocity inside the solar chimney power plant obtained through CFD simulation is near about same as obtained in the base paper. From the above comparison it is found that CFD analysis of solar chimney power plant is correct. After validating the CFD model of solar chimney plant, effect of different process parameters was determining. To increase the performance of solar chimney, effect of change in inclination angle of solar roof and height of chimney was optimized. The value of velocity of air inside the chimney and power output for different height of chimney is mention in the below table. While calculating the effect of different height of chimney, the solar collector slope was remaining constant that is of 3 degree. Whereas other boundary conditions were remaining constant as considered during numerical analysis of solar chimney having different solar collector slope.

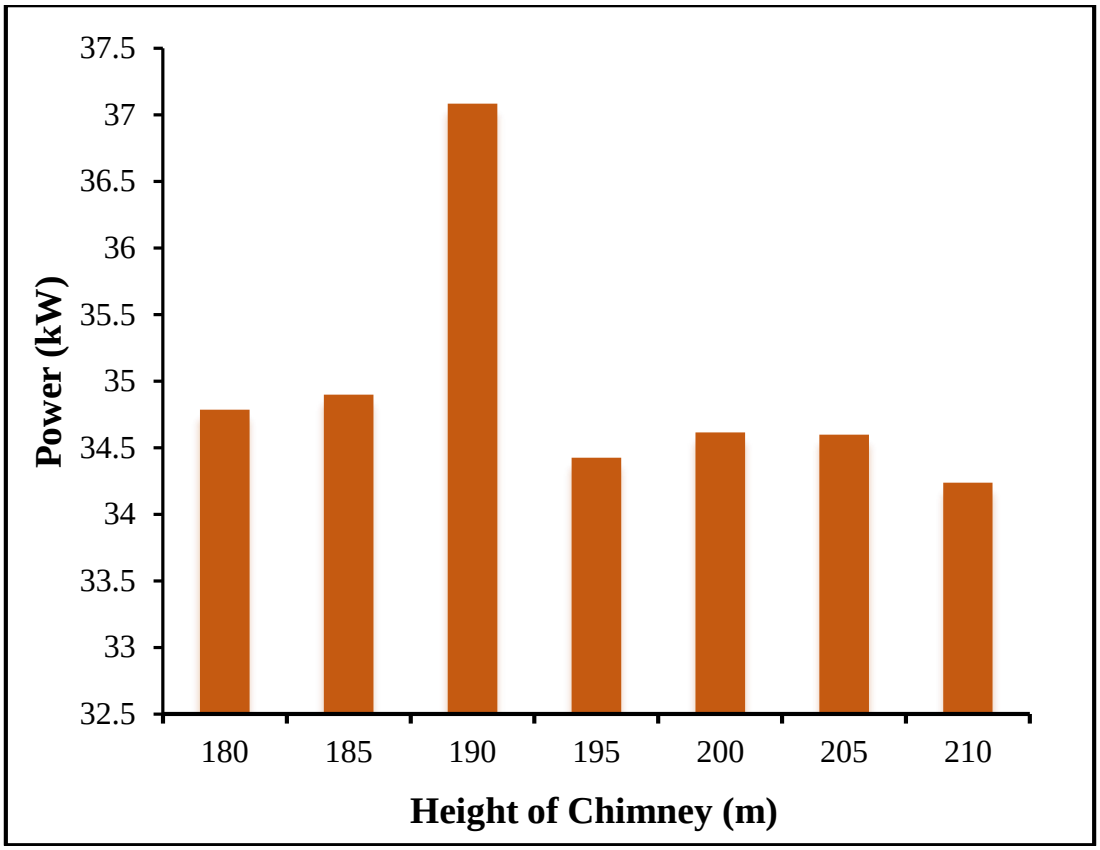

Fig.4.27 Comparison of power output of solar chimney power plant for different height of chimney

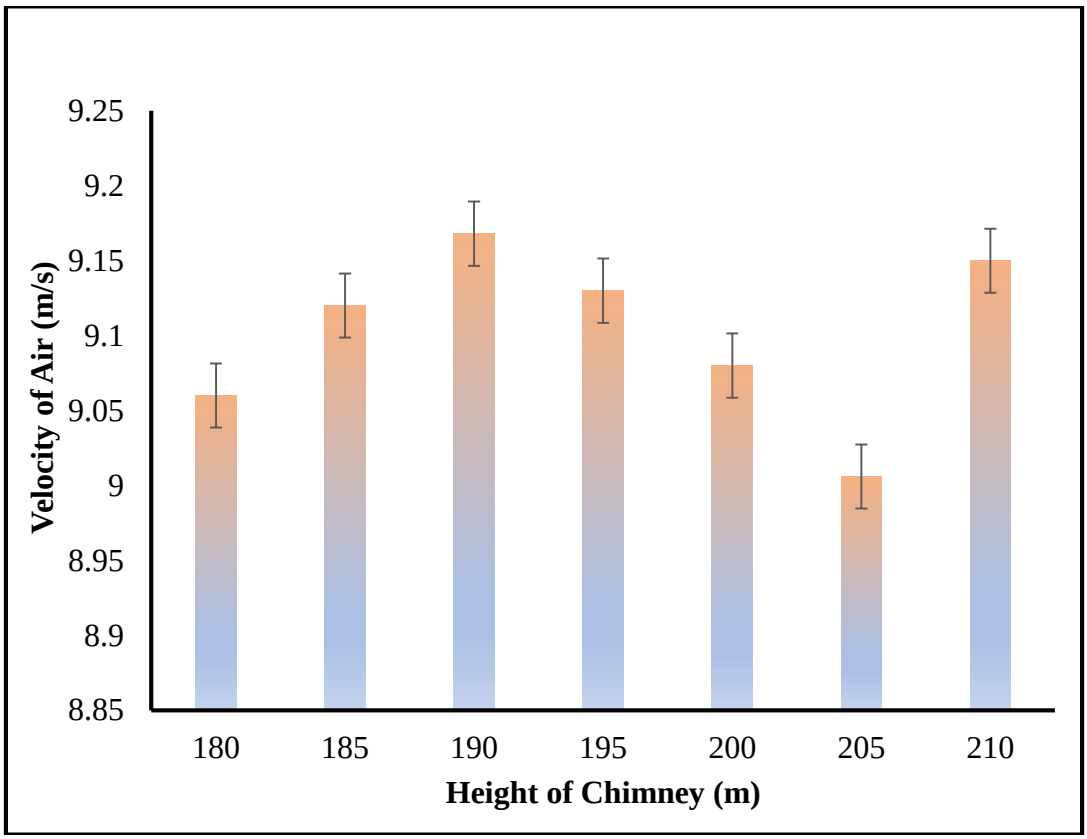

Fig.4.28 comparison of maximum velocity of air for different height of chimney

Form above graph it is found that the power output is maximum for 190 m height of chimney, which means that the velocity of air is higher in case of chimney having 190 m height as compared to other chimney height. The power of turbine in solar plant is directly depends on the velocity of air flowing inside the chimney, because of this 190 m height is the best one.

Conclusion

The efficiency of the solar chimney power plant was measured in terms of power generated by the turbine installed inside the chimney, which is mainly depends on the velocity of air flowing inside the chimney. Through analysis it is found that the solar chimney plant with 190 m height of chimney shows the maximum power output which is 5 m small as compared to previous reported data. So, with the reduce in chimney height performance of solar plant increases, whereas it also reduces the installation cost of plant.

REFERENCES

[1] Wilson Phua Yuen Zheng [2018], "Performance Enhancement of Inclined Solar Chimney Power Plant Using Underneath Air-Vents and Thermal Storage Medium", Master of Philosophy (Mechanical Engineering) of Curtin University. Open Journal of Fluid Dynamics, 2016, 6, 337-342.

[2] Qingjun Liu, Fei Cao, Yanhua Liu, Tianyu Zhu, and Deyou Liu [2018], "Design and Simulation of a Solar Chimney PV/T Power Plant in Northwest China", International Journal of Photo energy Volume 2018, Article ID 1478695, 12 pages, doi.org/10.1155/2018/1478695.

[3] Sivaram P.M., Sivasankaran Harish, Premalatha M., Arunagiri A [2018], "Performance analysis of solar chimney using mathematical and experimental approaches", International Journal of Energy Research · March 2018 DOI: 10.1002/er.4007.

[4] Ahmed Ayadi, Abdallah Bouabidi, Zied Driss, Mohamed Salah Abid [2017], "Experimental and numerical analysis of the collector roof height effect on the solar chimney performance", Renewable Energy (2017), doi: 10.1016/j.renene.2017.08.099.

[5] Aakash Hassan, Majid Ali, Adeel Waqas [2017], "Numerical investigation on performance of solar chimney power plant by varying collector slope and chimney diverging angle", Energy (2017), doi: 10.1016/j.energy.2017.10.047.

[6] T. Mekhail, A. Rekaby, M. Fathy, M. Bassily, and R. Harte [2017], "Experimental and Theoretical Performance of Mini Solar Chimney Power Plant", Journal of Clean Energy Technologies, Vol. 5, No. 4, July 2017.

[7] Zheng Zou, Hengxiang Gong, Xieshi Lie, Xiaoxiao Li, Yong Yang [2017]," Numerical Investigation of the Crosswind Effects on the Performance of a Hybrid Cooling-Tower-Solar-Chimney System", Applied Thermal Engineering (2017), doi.appl thermaleng.2017.07.198.

[8] Chiemeka Onyeka Okoye, Onur Taylan [2017], "Performance analysis of a solar chimney power plant for rural areas in Nigeria", Renewable Energy (2017), doi: 10.1016/j.renene. 2016.12.004.

[9] R.S. Vieira, A.P. Petry, L.A.O. Rocha, L.A. Isoldi, E.D. dos Santos [2017], "Numerical evaluation of a solar chimney geometry for different ground temperatures by means of constructal design", Renewable Energy 109 (2017) 222e234.

[10] Fei Cao, Tian Yang, Qingjun Liu, Tianyu Zhu, Huashan Li, Liang Zhao [2017], "Design and simulation of a solar double-chimney power plant", Renewable Energy (2017), doi: 10.1016/j.renene.2017.05.100.