PARAMETRIC EVALUATION OF DIFFERENT PROCESS PARAMETERS OF SOLAR CHIMNEY THROUGH NUMERICAL METHOD

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***Abstract*: Solar chimney power plant is used to convert the renewable energy in to non-renewable energy source. In solar chimney power plant, air enters below the solar roof and flow through chimney, turbine was placed inside the chimney which generates electricity. To analyze the performance of solar chimney power plant in terms of power generation, different process parameters were optimized in this work. Effect of different slope angle of solar collector was analyzed with the help of Ansys Fluent. For different solar collector slope angle value of maximum velocity and power output for each case was calculated. Through CFD analysis it is found that solar power plant having 3-degree inclination of solar collector roof shows maximum velocity and power output as compared to other slope of inclination.**

***Keywords:* Solar chimney, height of chimney, optimization, CFD analysis, Power generation**

1. Introduction

Solar chimney power plant (SCPP) is a low temperature solar thermal system that combines three technologies (greenhouse technology, chimney technology and wind turbine technology) in a serial alteration of solar energy to electrical energy. The SCPP energy conversion processes include the conversion of solar energy into thermal energy at the collector absorber, conversion of the thermal energy at the absorber to kinetic energy in the buoyant air, conversion of the kinetic energy in the air into mechanical work using the turbine and conversion of the mechanical work into electrical power through the rotation of a connected shaft from the turbine to the generator. The solar stack system essentially works as a hydroelectric power plant, but uses hot air instead of water. The principle is relatively simple. A round ascending glass roof with several thousand meters in diameter serves as a sensor. A chimney in the middle absorbs warmed up air and the air rise at a speed of about fifteen meters per second. The suction of the air that occurs causes the wind turbines that are located in the chimney. Turbines are used with a generator and gearbox to generate electricity.

he 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 analyze 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.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.

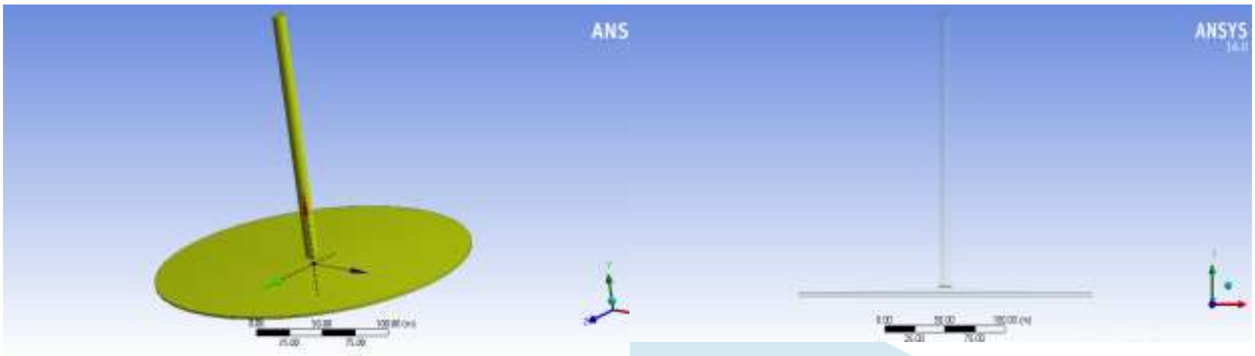

Fig.1 Solid model of the solar chimney power plant

The wire frame model of solar chimney power plant is also shown in the below figure. Through wire frame model it is seen that, solar roof surface is at some inclination angle to chimney which helps in enhancing the velocity of air.

3. 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, it generates 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. The meshing of solar chimney 3D model considered during the numerical analysis is shown in the below fig.

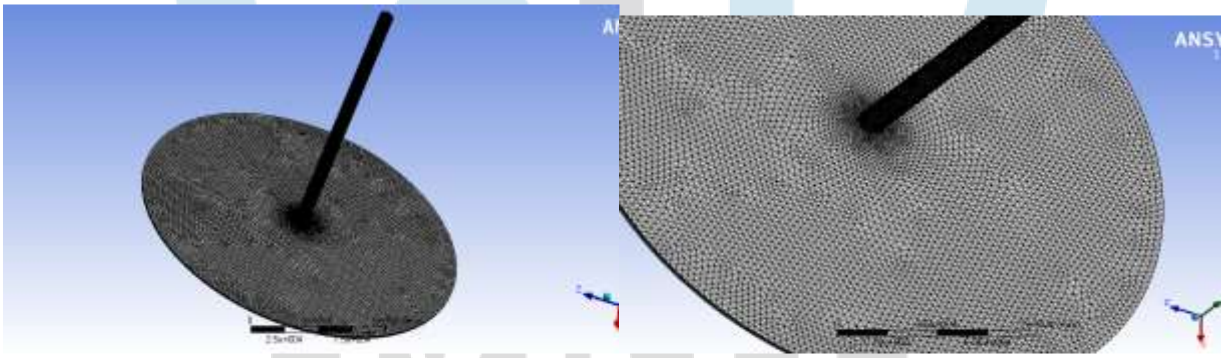

Fig.2 mesh of the complete setup geometry considered during the numerical analysis

4. Selection of model and Boundary conditions

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. For analyzing the ration effect of solar rays, here discrete ordinates system is used. 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.

5. 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, it 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.

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

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.

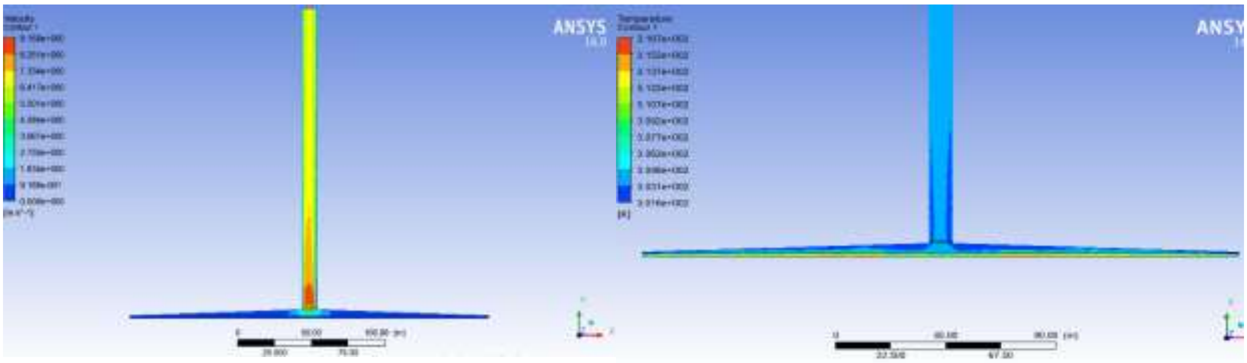

Fig.3 Velocity and temperature contours of solar chimney power plant

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.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 determined. To increase the performance of solar chimney, effect of change in inclination angle of solar roof and height of chimney was optimized.

6. Effect of slope angle of solar collector roof

For evaluating the effect of different slope angle of solar collector, here in this case solar chimney system having different slope angle was considered. Five different slope angles were considered during numerical analysis and power output of turbine was measured for each case. For the initial case of analysis 1.958-degree slope angle was considered as considered in the base paper. Boundary conditions applied during the numerical analysis of chimney having different roof inclination angle was remain same as considered in validation case.

6.1 For 3-degree slope angle

In this case the solar collector slope angle is 3 degree, whereas the height of chimney is 195 m. the velocity contours for this case is shown in the below fig.

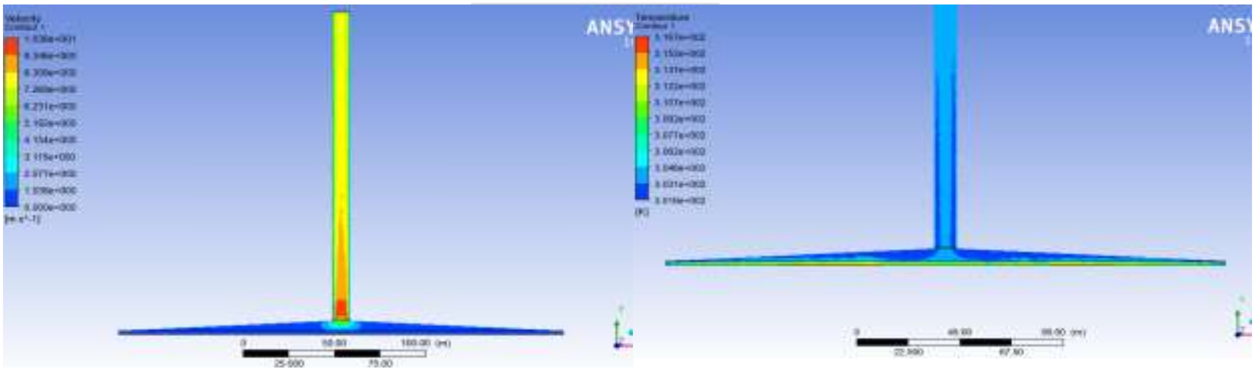

Fig.4 velocity and Temperature contour of solar chimney having 3-degree slope angle

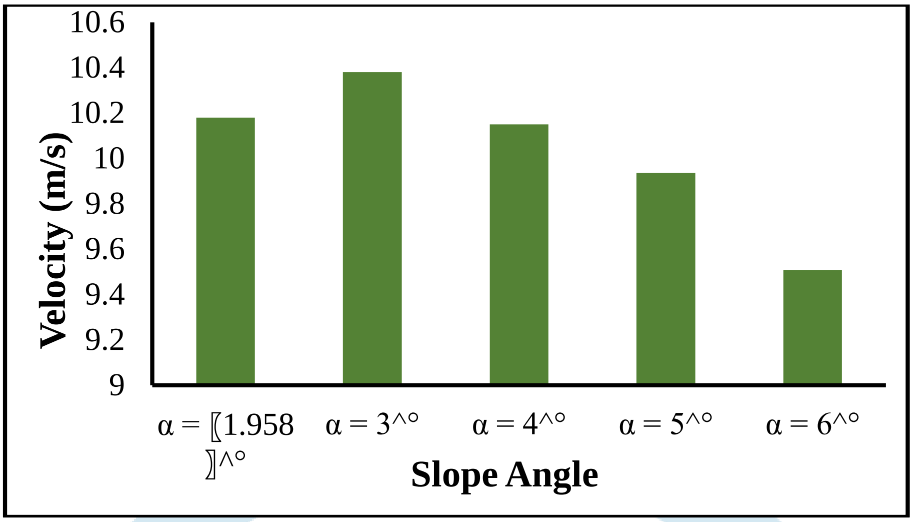

Fig.5 comparison of maximum velocity for different slope angle of solar collector

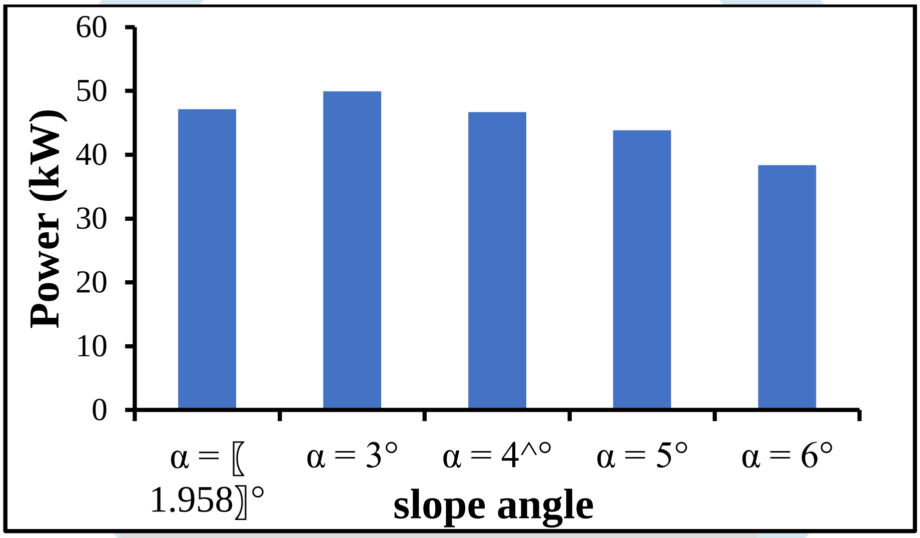

Fig.6 comparison of Power output for different slope angle of solar collector

From the above comparison, it is found that for 3-degree inclination angle of roof, the value of velocity is maximum as compared to other inclination angle. It is also seen from the fig. that from 1.95 to 4-degree inclination angle, the variation of maximum velocity of air inside the chimney is marginal. Whereas for 5- and 6-degree inclination angle, it is significantly lower than upto 4 degree inclination angle of roof. Based on the value of maximum velocity of air for different inclination angle of roof surface, power was calculated. The comparison of power for different inclination angle of roof surface is mention in the below section. Through CFD analysis of solar chimney, effect of different slope angle on the performance of solar power plant was analyze. Through analysis it is found that solar chimney having 3 degree of inclination of collector roof have higher velocity of air as compared to other slope angle and gives maximum power output. From the comparison of power output for different inclination, it is clear that power output of solar chimney has direct dependence on maximum velocity of air. same variation trend was shown in power comparison graph as shown in velocity comparison. Through analysis it is concluded that solar chimney having 3 degree of inclination angle shows the optimum geometry for enhancing the performance of solar chimney.

7. **Effect of solar chimney height**

For analyzing the effect of different height of solar chimney, on performance of solar chimney power plant here in this work it considered seven different height of solar chimney that is 180, 183, 185, 190, 195, 200 and 205 meters. For each different height of solar chimney, it calculates the value maximum velocity of air inside the chimney and with the help of equation mention in the above section it calculates the value of power obtained from the turbine. For different height of chimney, velocity contours were shown here.

Table.3 Value of velocity and power output for different height of the chimney

S.No	Height of chimney (m)	Velocity of air (m/s)	Power (kW)
1	180	10.03	45.07
2	183	10.04	45.21
2	185	10.18	47.12
3	190	9.397	37.06
4	195	9.138	34.08
5	200	9.184	34.60
6	205	9.181	34.57

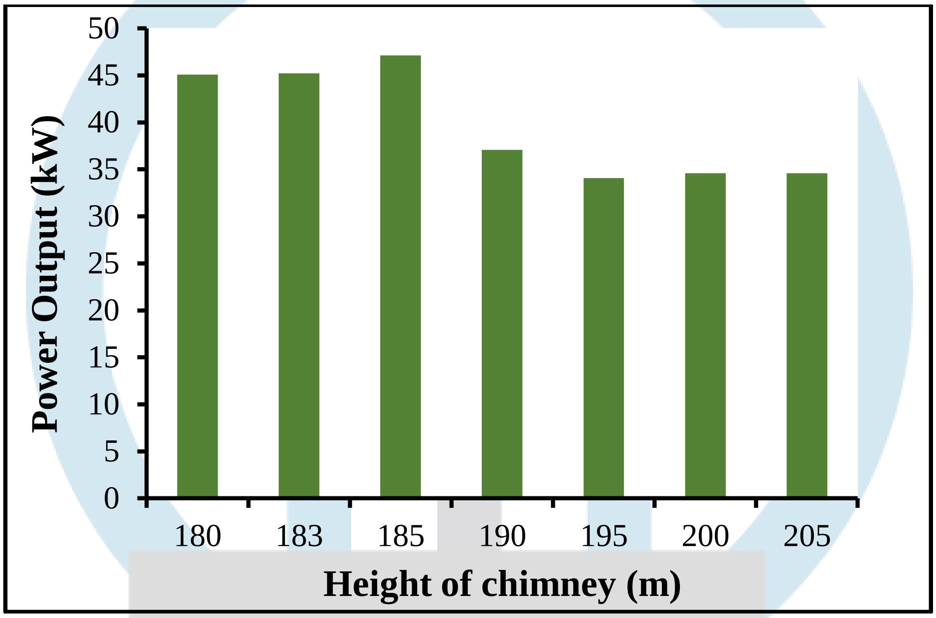

Fig.7 Comparison of power output of solar chimney power plant for different height of chimney

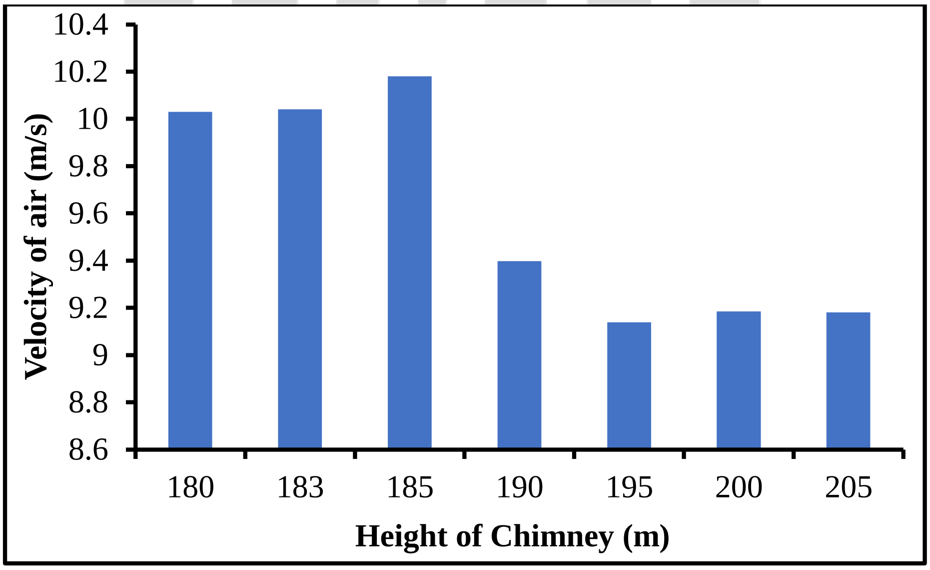

Fig.8 comparison of maximum velocity of air for different height of chimney

Form above graph it is found that the power output is maximum for 185 m height of chimney, which means that the velocity of air is higher in case of chimney having 185 m height as compared to another chimney height. The power of turbine in solar plant is directly depends on the velocity of air flowing inside the chimney, because of this 185 m height of chimney is the best one.

8. 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. Solar power plant having 3-degree slope angle of solar collector roof shows the maximum value of velocity of air as compared to another slope of angle. Because of maximum velocity of air, power output for 3-degree slope angle is maximum for this case. Which conclude that plant having 3 degree of slope shows the best performance as compared to other. Through analysis it is found that the solar chimney plant with 185 m height of chimney shows the maximum power output which is 10 m small as compared to previous reported data. So, with reduce in chimney height performance of solar plant increases, whereas the installation cost of plant gets reduce.

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