CFD ANALYSIS OF SOLAR CHIMNEY WIND POWER PLANT BY ANSYS FLUENT

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Abstract: ***Computational fluid dynamics was used to simulate solar chimney power plants and investigate modeling techniques and expected energy output from the system. The solar chimney consists of three primary parts: a collector made of a transparent material such as glass, a tower made of concrete located at the center of the collector, and a turbine that is typically placed at the bottom of the tower. The collector absorbs solar radiation and heats the air below, whereby air flows inward towards the tower. As air exits at the top of the tower, more air is drawn below the collector repeating the process. The turbine converts pressure within the flow into power. The study investigated three validation cases to numerically model the system properly. Modeling the turbine as a pressure drop allows for the turbine power output to be calculated while not physically modeling the turbine. The numerical model was used to investigate air properties, such as velocity, temperature, and pressure. The results supported the claim that increasing the energy into the system increased both the velocities and temperatures. Also, increasing the turbine pressure drop decreases the velocities and increases the temperatures within the system. In addition to the numerical model, analytical models representing the vertical velocity without the turbine and the maximum power output from a specific chimney were used to investigate the effects on the flow when varying the geometry. Increasing the height of the tower increased the vertical velocity and power output, and increasing the diameter increased the power output. Dimensionless variables were used in a regression analysis to develop a predictive equation for power output. The predictive equation was tested with new simulations and was shown to be in very good agreement.***

I. INTRODUCTION

With the decrease of fossil fuel resources and increasing worldwide pollution problems, there is a growing need for an environmentally friendly renewable energy source. It is vital that the utilization of this energy source be economically viable, especially for its possible use in third world countries. Engineers and scientists are increasingly looking to solar energy as a potential answer to this problem.

Man has already tried to harness energy from the sun in various different ways. These include parabolic trough solar power plant, Central Receiver power plants, Dish-Stirling systems, Solar pond power plants and Photovoltaic power plant.

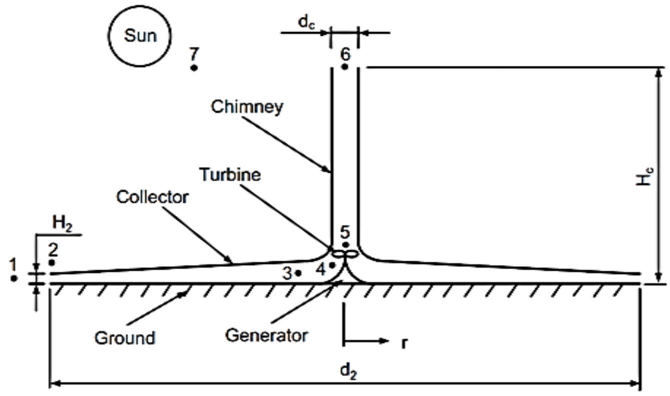


Fig 1.1Schematic illustration of a solar tower power plant

Since the 1970's, the development of solar tower power plant have been investigated and have since become a good prospect for large scale energy generation. The solar tower power plant consists of a translucent collector (located a few meters above ground level) with a central tower which houses a turbo-generator at its base, as shown schematically in fig. 1.1

Solar Chimney Component

As we see that the solar chimney consist of a solar collector, chimney and turbine and rest of the component i.e. generator, transmission is as same in other power plants. The main components in solar chimney power plant are as follows.

- The solar collector
- The chimney
- The wind turbine

The Solar Collector

By means of an absorber, a collector which can be used for space heating. Solar collector transforms about 80% of radiation energy into heat. Hot air from the chimney is produced by greenhouse effect in a simple air collector consisting only of a glass of plastic film covering stretched horizontally 2 to 6 m above the ground. Height increases only adjacent to the chimney base, so that the air can be diverted to vertical movement without friction loss. This covering admits short wave solar radiation component and retains long-wave radiation from the heated ground. Thus, ground under the roof heats up and transfer its heat to the air flowing radially above it from the outside to the chimney, like flow heater. The air temperature rise could be 350C in a well-designed collector. The total radius requires for 5MW, 30MW, 100MW is 500,1000and 1800m respectively.

The Solar Chimney

The chimney itself is the plant's actual thermal engine .it is a pressure tube with low friction and loss (like a hydroelectric tube) because of its optimum surface-volume ratio. The up – thrust of the air heated in collector is approximately proportional to air temp. rise T in collector and volume (i.e. height and diameter of the chimney). In large solar chimney the collector raises the temperature of air by T=350C. This produces an up –draught velocity in chimney of about V=15m/s. the efficiency of the chimney (i.e. conversion of heat into kinetic energy) is practically independent of T in collector and determined by outside temperature To(lower the better) and height of chimney (higher the better).

The Solar Turbine

Mechanical output in the form of rotational energy can now he derived from the vertical air-current in the chimney by turbines. Turbines in solar chimney do not work with stepped velocity like a free-running wind energy convert, but as a cased pressure-stepped wind turbo-generator, in which, similar to a hydroelectric power station, static pressure in converted in to pipe. The energy yield of a cased pressure-stepped turbine of this kind is about eight times greater than of the same diameter. 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 fall in pressure at the turbine. With a view to maximum energy yield the aim of the turbine regulation concept is to maximize this product under all operating conditions.

II. LITERATURE REVIEW

Solar energy has important role in aspects of accessibility of resources and diversity of energy conversion. Renewable energy are none as the best option for solving the energy shortage and CO2 emissions trouble due to increase the rate of environmental pollution and control on fossil fuel resources , the use of sustainable energies seem to be inevitable and absolute need for the world. Solar chimney wind power plant is best option for utilize the renewable energy resources so it is important factor to analysis the behaviour of the SCWPP in different running parameter. There are many investigator have done the experiments for optimize the performances of solar chimney wind power plant.

Some of the important paper related to analysis of solar chimney wind power plant have been reviewed and discuss here.

A.Asnaghi et al.[1] in their report a solar chimney power plant (SCPP) is proposed to be built as the first national SCPP in central regions of Iran. Studies of DLR MED-CSP project show that Iran can be a part of the Mediterranean solar power generation chain in 2050 to provide electrical power demand of Europe. High direct solar radiation and available desert lands in Iran are factors to encourage the full development of solar power plants like solar chimney power plant for the thermal and electrical production of energy for various uses. The interested region is the central region of Iran where solar radiation and global insolation are much better than other areas. However to evaluate SCPP performance and power generation throughout Iran, 12 different areas across the country are considered. The obtained results clear that solar chimney power plants can produce from 10 to 28 MWh/month of electrical power. This power production is sufficient for the needs of the isolated areas and can even used to feed the grid.

Fei Cao et al.[2] studied the solar chimney power plant (SCPP that it is a promising technology for the large-scale utilization of solar energy. Due to the significant difference of weather conditions, the performance of SCPPs varies from one place to another, and thus specific design work is required for different regions. In addition, little effort has been carried out to evaluate the SCPPs both simply and precisely. In view of this, a program based on TRNSYS is built to stimulate the performance of SCPPs in this paper. With the program, the major meteorological parameter that influences the SCPP performance is identified. Also, the configuration size design and techno-economic analysis of commercial SCPPs are carried out for location than to the ambient temperature. The SCPP with higher generation capacity holds better cost-benefit characteristics. It is believed that the TRNSYS program can be used as a convenient tool for SCPP investigation.

Wei Chen et al. [3] in their paper, the chimney is assembled with porous absorber for the indirect-mode solar dryer. Local thermal non-equilibrium (LTNE) exists in the porous absorber, so the double energy equations and Brinkman-Forchheimer extended Darcy model are employed to analyze the heat transfer and flow in the solar porous absorber, and the k-ε turbulent model coupled with the above equations are also used to investigate the influences of the porous absorber inclination and the height of drying system on the heat transfer in the solar dryer. The specific heat capacities (ρc) and thermal conductivity ks have remarkable effects on the average temperature of solar porous absorber in the drying system. The mean temperature of the higher (ρc) Aluminous solar absorber is lower and the top temperature of porous absorber delays due to lower thermal conductivity ks. The inclined angle of porous absorber influences the airflow and temperature field in the solar dryer greatly. With the height of solar dryer changing from 1.41 m to 1.81m, the higher airflow velocity and the lower temperature at chimney exit can be achieved. The simulations agree with the published experimental data. All these results should be taken into account for the promotion & application of the solar chimney dryer with porous absorber.

Y.J. Dai et al. [4] analyzed a solar chimney power plant, which is expected to provide electric power for remote villages in northwestern China, in this paper. Three counties in Ning Xia HUi autonomous region, namely, Yinchuan, Pingluo, and Helan, where solar radiation is better than other regions of China, were selected as pilot locations to construct solar power plant. The solar power plant chimney, in which the height and diameter of the chimney are 200 m and 10 m, respectively, and the diameter of the solar collector cover is 500 m, is able to produce 110~190kW electric power on a monthly average all year. Some parameters, such as chimney height, diameter of the solar collector, ambient temperature, solar irradiance and the efficiency of wind turbine, etc. which influence the performance of power generation, are also analyzed.

Saeed Dehghani et al.[5]In their communication, a multi-objective optimization method is implemented using evolutionary algorithm techniques in order to determine optimum configuration of solar chimney power plant. Power output of the system is maximizing while capital cost of the component in minimized. Design parameters of the considered plant include collector diameter (Dcoll), chimney height (Hch) and chimney diameter (Dch). The results of optimal design are obtained as a set of multiple optimum solution, called 'the Pareto frontier'. For some sample point of Pareto, optimal geometric is presented. In addition, effect of changing design variables on both objective function is performed. This multi- objective optimization approach is very helpful and effective for selecting optimal geometric parameters of solar chimney power plants. The result shows that, power output of the plant increases linearly when solar irradiation increases and increase in ambient temperature causes slight decrease in power output of the plant.

III. COMPUTATIONAL FLUID DYNAMICS

Computational fluid dynamics (CFD) is a computer-based simulation method for analysing fluid flow, heat transfer, and related phenomena such as chemical reactions. This project uses CFD for analysis of flow and heat transfer. Some examples of application areas are: aerodynamic lift and drag (i.e. airplanes or windmill wings), power plant combustion, chemical processes, heating/ventilation, and even biomedical engineering (simulating blood flow through arteries and veins). CFD analyses carried out in the various industries are used in R&D and manufacture of aircraft, combustion engines, as well as many other industrial products.

This section briefly describes the general concepts and theory related to using CFD to analyses fluid flow and heat transfer, as relevant to this project. It begins with a review of the tools needed for carrying out the CFD analyses and the processes required, followed by a summary of the governing equations and turbulence models and finally a discussion of the discretisation schemes and solution algorithms is presented.

Conservation Equations

The conservation laws of physics form the basis for fluid flow governing equations (previously listed as Equations 1 3 in Section 2.1: Governing Equations and Numerical Schemes). The laws are

Law of Conservation of Mass: Fluid mass is always conserved. (Equation 1)

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0$$

Newton's 2nd Law: The sum of the forces on a fluid particle is equal to the rate of change of momentum. (Equation 2)

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\rho p}{\rho x_j}$$

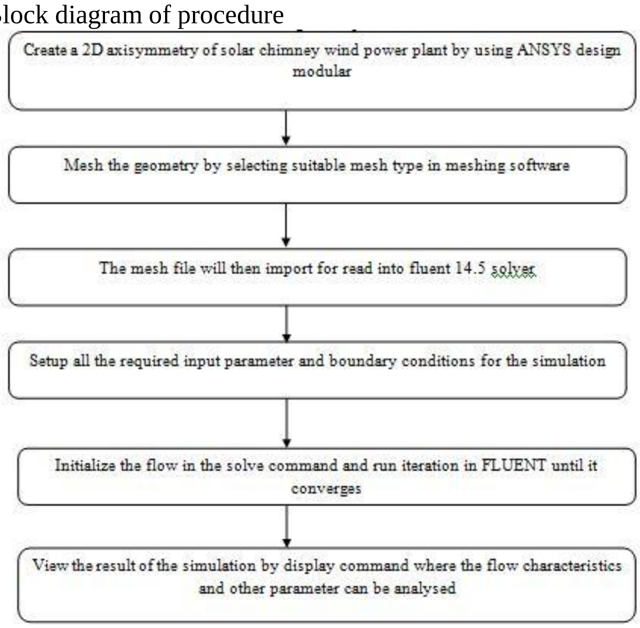
First Law of Thermodynamics: The rate of head added to a system plus the rate of work done on a fluid particle equals the total rate of change in energy. (Equation 3)

$$\frac{\partial}{\partial x_i}(\rho u_i\, T) = \frac{\partial}{\partial x_i}\{\frac{k}{C_p}\frac{\partial u_j}{\partial x_i}\}$$

The fluid behaviour can be characterised in terms of the fluid properties velocity vector **u** (with components u, v, and w in the x, y, and z directions), pressure p, density ρ, viscosity μ, heat conductivity k, and temperature T. The changes in these fluid properties can occur over space and time. Using CFD, these changes are calculated for small elements of the fluid, following the conservation laws of physics listed above. The changes are due to fluid flowing across the boundaries of the fluid element and can also be due to sources within the element producing changes in fluid properties. This is called the Euler method (tracking changes in a stationary mass while particles travel through it) in contrast with the Lagrangian method (which follows the movement of a single particle as it flows through a series of elements).

IV. METHODOLOGY

Block diagram of procedure



Relation involves in study- Following relationship has been used for analysis.

For calculating the property of air

Properties of air in temperature range between 300 K and 350 K.

Density: $\rho = 1.1614 - 0.00353(t - 300)$ (1)

Thermal conductivity: $\lambda = 0.0263 + 0.000074(t - 300)$ (2)

Dynamic viscosity: $\mu = [1.846 + 0.00472(t - 300)] \times 10^{-5}$ (3)

Specific heat: $c_p = [1.007 + 0.00004(t - 300)] \times 10^3$ (4)

For calculating the integrated SCWPP

$$q'' = \alpha I - U(T_2 - T_1) \quad (5)$$

$$p = \eta_{t \times \Delta P_t \times Q_v} \quad (6)$$

$$\eta = \frac{p}{\pi r_c^2 I_{ra}} \quad (7)$$

Geometrical parameter

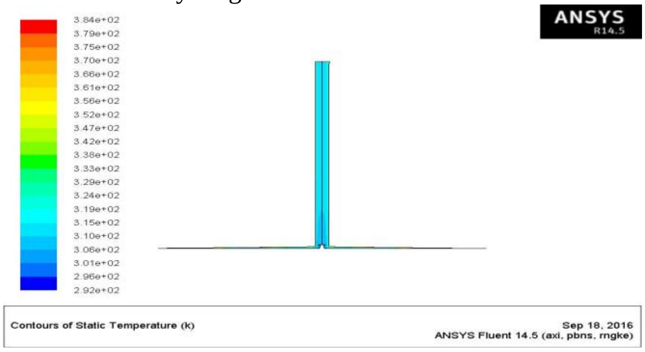
1	Mean roof radius, r_r	122m
2	Average roof height, h_r	1.85m

3	Tower height,	194.6m
4	Tower radius, r_c	5.08m

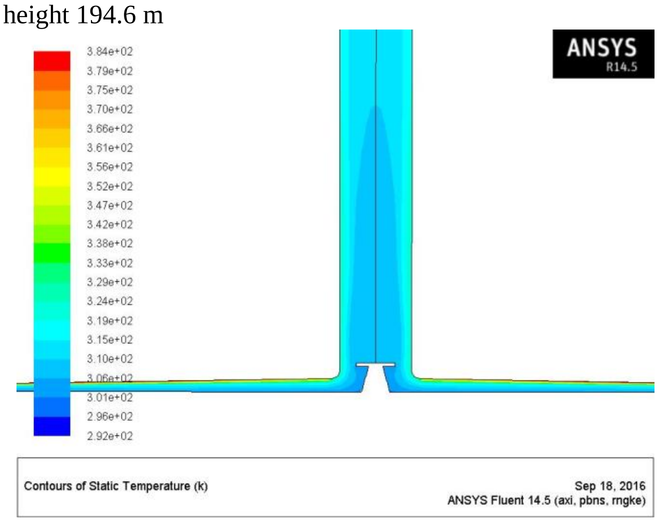
V. RESULT & DISCUSSION

For analysis the performance of SCWPP the result can be viewed and interpretation in various format of images like temperature distribution, pressure distribution, velocity distribution, vector profile, and various graphs and tables.

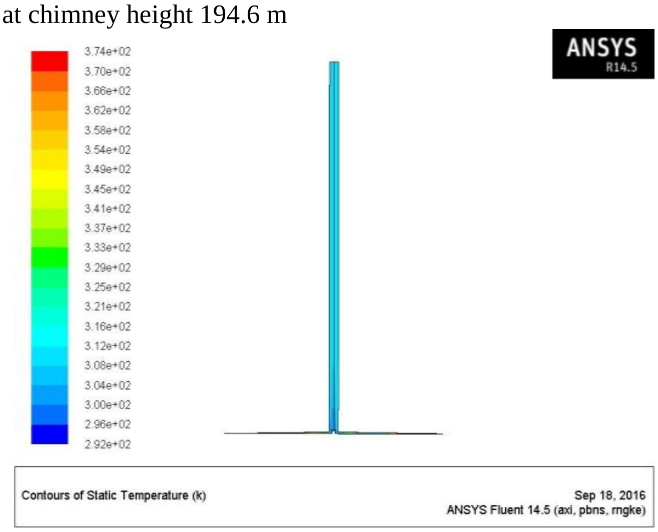
Temperature distribution of existing SCWPP model with different chimney height



(a) Temperature contour of existing SCWPP at chimney height 194.6 m



(b) Magnify view of temperature contour of existing SCWPP at chimney height 194.6 m



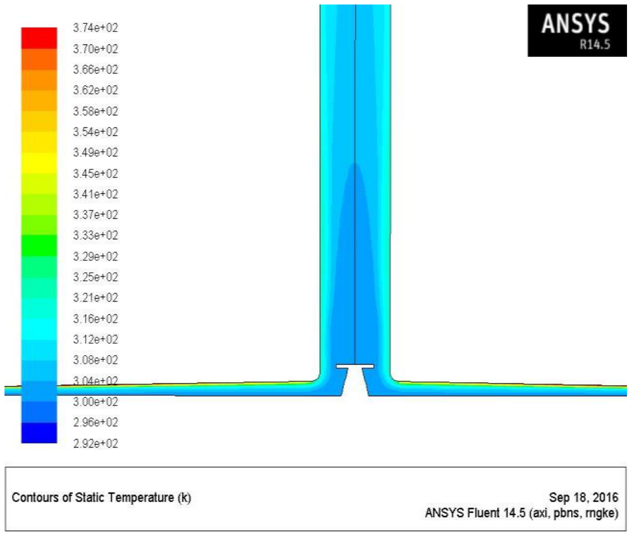


Fig shows the temperature contour of solar chimney wind power plant at different chimney height 194.6, 400, 600, 800, 1000 (m) respectively at constant collector radius 122 m and chimney radius 5.08 m and solar radiation 1000W/m^2. From these figures it can be observed that, temperature decreases at chimney outlet from 313.2375K to 305.061K and temperature decreases at collector outlet from 313.31K to 304.931K.

Computed Value of Different Parameter of Solar Chimney Wind Power Plant

The Value of Pressure drop, mass flow rate, turbine inlet velocity, chimney height, collector radius, collector percentage, throat radius ,solar radiation, fraction factor, collector absorption coefficient, collector loss coefficient, power are computed using function in post- processor. Then these values are put in tabular form and also plotted by using Microsoft excel software.

Result of existing SCWPP model with different chimney height

Chimney Height(m)	Mass Flow Inlet(kg/s)	Turbine-Pressure Drop (pa)	Turbine Inlet Velocity (m/s)	Power (W)
194.66	794.0054	63.4439	11.68162	48044.0938
400	1038.593	115.7378	15.24137	114352.6645
600	1205.413	148.3987	17.58019	169122.2394
800	1351.519	203.057	19.86091	261435.2646
1000	1458.723	217.9338	21.28376	300690.7056

The table shows the result obtain form the fluent solver for Solar chimney wind power plant with different chimney height (194.66m – 1000m) at constant collector radius (122m), average roof height (1.85m), ambient temperature (291.65),and solar radiation 1000(W/m2). In table result of mass flow rate turbine pressure drop, turbine inlet velocity and power is calculated. From the table 5.1 it has been observed that the power is enhance as increases the chimney height. It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the Chimney Height increases.

Result of existing SCWPP model with different throat radius

Throat radius(m)	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	Power(W)
4.75	801.0184	66.527	11.88531	51257.27488
4.5	802.1503	68.7762	11.94117	53239.27313
4	800.2512	80.553	12.33239	64398.54117
3.5	807.8694	86.1843	12.67119	70793.37564
3	796.5724	99.2821	12.90245	83040.54659
2.5	773.4088	104.6956	12.8914	87493.45647

The table shows the result obtains form the fluent solver for solar chimney wind power plant at different throat radius (2.5m - 4.75m). At constant chimney height (194.6m), collector radius (122m), average roof height (1.85m), ambient temperature (291.65), and solar radiation 1000W/m^2. In table result of mass flow rate turbine pressure drop, turbine inlet velocity and power is calculated. From the table 5.4 it has been observed that the power is enhance as decreases the throat radius. It also has been observed that turbine pressure drop and turbine inlet velocity also increases as the throat radius decreases.

Validation of Result of Presented Model with Reference [20] for Chimney Height and Collector Radius.

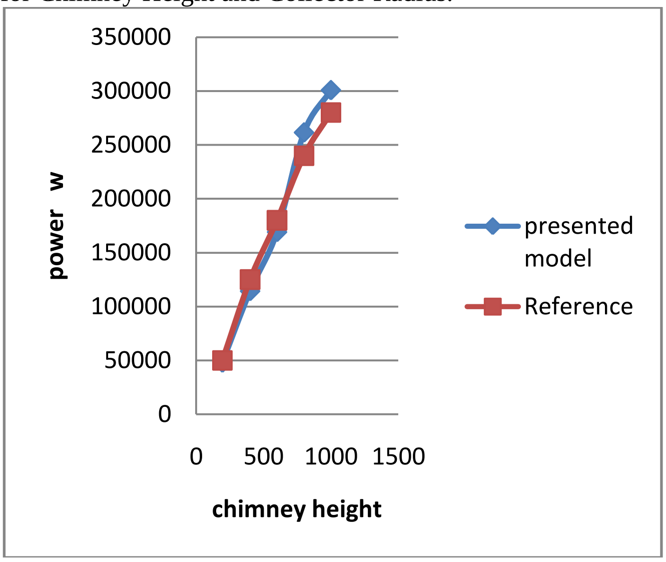


Fig shows the comparison between result of presented numerical model and the data of [20] for chimney height and collector radius versus power respectively. From these two figures it can be observed that the value of presented model and data of [20] is very near to close. The negligible difference between both the parameter (chimney height and collector radius) due to the mesh and solving control method. There for the present numerical model is reliable and can be used to study the effect of different geometrical parameter and running conditions of solar chimney wind power plant.

Graphical representation existing SCWPP model with different chimney height

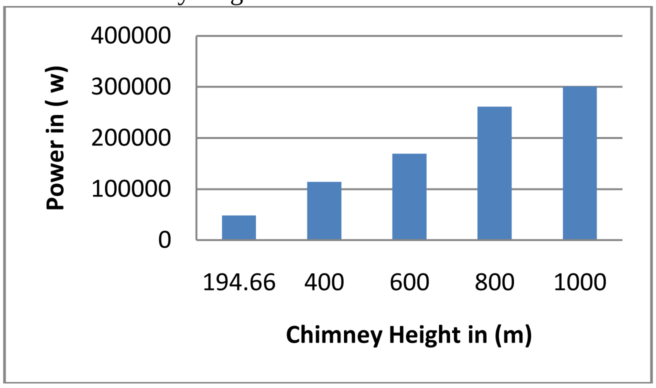


Fig. shows the variation of chimney height with power in existing solar chimney wind power plant at same running condition from the entire figure it has been observed that At constant collector radius, average roof height, and same boundary condition of ambient temperature and solar radiation, power of SCWPP is enhance as increases the chimney height in existing model of Manzanares pilot plant.

Graphical representation existing SCWPP model with collector percentage with respect to chimney height

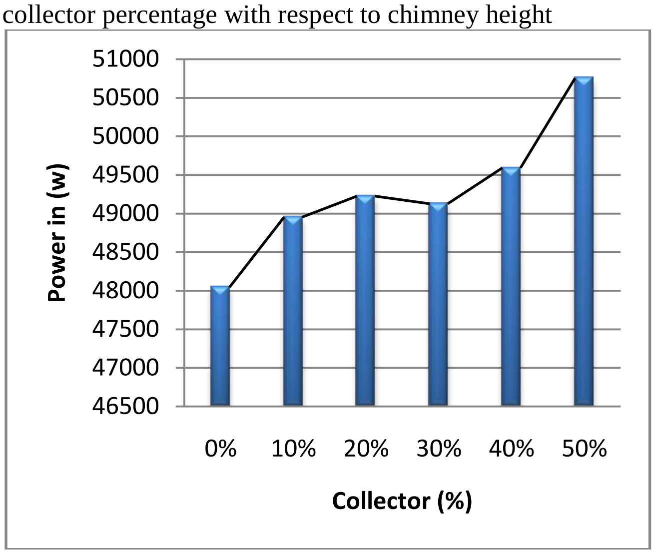


Fig shows the variation of collector percentage with power in existing solar chimney wind power plant at same running condition from the entire figure it has been observed that At same boundary condition of ambient temperature, solar radiation and constant collector radius, chimney height, average roof height, the power of SCWPP is slightly enhance as the percentage of collector covering is increases in existing model of manzanares pilot plant.

VI. CONCLUSION

Following points worth noting from the present exploration on computational analysis form performances characteristics of different geometrical parameter and running condition of solar chimney wind power plant.

- At constant collector radius, average roof height, and same boundary condition of ambient temperature and solar radiation, power of SCWPP is enhance as increases the chimney height in existing model of manzanares pilot plant.

- At constant chimney height, average roof height and same boundary condition of ambient temperature and solar radiation. power of SCWPP is enhance as increase the collector radius in existing model of manzanares pilot plant.
- At same boundary condition of ambient temperature, solar radiation and constant collector radius, chimney height, average roof height, the power of SCWPP is slightly enhance as the percentage of collector covering is increases in existing model of manzanares pilot plant.
- At constant chimney height, collector radius, average roof height, and same boundary condition of ambient temperature, and solar radiation the power of SCWPP is enhance as reducing the throat radius, but it gives the best performance at throat radius is 3.5 m due to after this there is chance of chocking in existing model of manzanares pilot plant.
- In Indian condition at optimize throat radius (3.5m) and constant collector radius, chimney height, average roof height the power of SCWPP is enhances as the solar radiation is increases in existing model of manzanares pilot plant.
- In Indian condition at constant throat radius and same boundary condition of ambient temperature and solar radiation, the power of SCWPP is enhance as fraction factor is increases. And also observed that at the R.F. = 0.2 it gives power approximately 5 KW.
- In India condition at constant R.F, throat radius , collector radius, chimney height and same boundary condition of ambient temperature and solar radiation, the power of SCWPP is enhances as the collector absorption coefficient ($\propto$) is increases.
- In India condition at constant R.F, throat radius , collector radius, chimney height and same boundary condition of ambient temperature and solar radiation, the power of SCWPP is enhances as the collector loss coefficient (U) is decreasing.

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