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Integrated Solar Heat and Wind Power Plant : Design and Performance

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Abstract

In the recent trends in application of renewable energy sources, integrated solar chimney wind power plant has been designed with different geometrical parameter for increase the accessibility of solar and wind energy due to increasing the rate of environmental pollution and lake of non- renewable energy resources. A solar chimney wind power plant (SCWPP) is a type of solar thermal system that use the thermal energy generated by solar and convert it into the electrical energy. In the recent few years there are many researcher have exposed strongest attention for exploration the performances of solar chimney wind power plant due to its economic, environmental and huge potential application. There are different geometrical parameters and operating conditions like chimney height, collector radius, throat radius, solar radiation, wind velocity, solar absorption coefficient, solar loss coefficient, chimney shapes which are play vital role for optimize the performances of solar chimney wind power plant.

In this numerical investigation a computational model of Manzanares pilot solar chimney win power plant, Spain has been created with help of commercially availableness 14.5 software. The temperature, velocity, pressure and vector distribution were plotted and evaluated for examine the influence of chimney height, collector radius, throat radius, solar radiation, solar absorption coefficient, solar loss coefficient, and collector percentage and fraction factor on the performance of solar chimney wind power plant when other parameters are constant. The obtained result is illustrated that, the power of SCWPP has enhances as increases the chimney height, collector radius, collector percentage and solar absorption coefficient but throat radius and solar loss coefficient it gives inversely effect on the power. It has been also illustrated that the throat radius gives more effect on the power of SCWPP while the effect of collector percentage on power negligible.

This study is also suggested a solar chimney wind power plant at chimney height 24.4 m with collector radius 38. 92 m and throat radius 0.7m,collector absorption coefficient 0.66 and collector loss coefficient 15it gives approximately 5.4 KW power output at Indian operating conditions means ambient temperature should be 303.15 K and solar radiation is 1000W/m2. From the study it can also revealed that for further improvement in power increase the solar absorption coefficient and reduce the solar loss coefficient in same working condition.

Keywords: Renewable energy sources, SCWPP, Wind Power plant, Solar chimney, Electrical energy.

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.

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

The operation of such a solar power plant is relatively simple. Solar radiation heats the ground beneath a clear glass collector. Underneath the collector, the heated ground heats the air, causing the air to rise. The warm air is trapped under the collector but rises through the central tower, driving the turbine and consequently generating electricity.

Solar tower power plants have some advantage over the above mentioned power generation schemes, such as the Parabolic Trough and Central Receiver solar power plants. These include the use of both beam and diffuse radiation, while energy is stored naturally in the ground during the day is released at nighttime, thus producing electricity over a twenty –four hour period. Solar tower makes use of simple technologies, are built from low cost materials and have no water requirements.

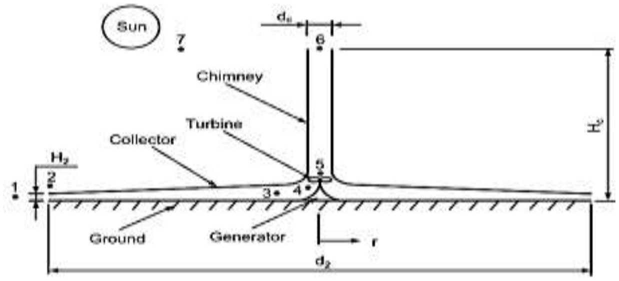


Fig 1.1Schematic illustration of a solar tower power plant

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 behavior 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- 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.

F. Denantes al.[6]developed an efficiency model at design performance for counter-rotating turbine and validated. Based on the efficiency equation, an off- design performance model for counter-rotating turbines is developed. Combined with a thermodynamic model for a solar chimney system and a solar radiation model, annual energy output of solar chimney systems is determined. Two counter-rotating turbines, one with inlet guide vanes, the other without, are compared to a single-runner system. The design and off-design performance are weighed against in three different solar chimney plant size. It is shown that the counter-rotating turbine without guide vanes have lower design efficiency and a higher off-design performance that a single-runner turbine. Based on the output torque versus power for various turbine layouts, advantageous operational conditions of counter-rotating turbines are demonstrated.

Hermann F. Fasel et al. [7] in their study investigated solar chimney power plants numerically using ANSYS Fluent and an-in house developed Computational Fluid Dynamics (CFD) code. Analytical scaling laws are verified by considering a large range of scales with tower heights between 1 m (sub-scale laboratory model) and 1000 m (largest envisioned plant). A model with approximately 6 m tower height is currently under construction at the University of Arizona. Detailed time-dependent high-resolution simulations of the flow in the collector and chimney of the model provide detailed insight into the fluid dynamics and heat transfer mechanisms. Both transversal and longitudinal convection rolls are identified in the collector, indicating the presence of a Rayleigh-Bénard-Poiseuille instability. Local separation is observed near the chimney inflow. The flow inside the chimney is fully turbulent.

D.G.Kroger et al. [8] studied that several cost models for large-scale solar chimney power plants are available in the literature. However, the results presented vary significantly, even in cases where the input parameters and the used models are supposedly very similar. The main objective of this paper is to clarify this matter by comparing previous cost models to a newly developed alternative model. Further, the impact of carbon credits on the levelised electricity cost is also investigated. A reference plant is introduced, with dimensions and financial parameters chosen specifically for making the results of this analysis comparable to those of previous publications. Cost models are presented for the main components of a solar chimney power plant, i.e. the collector, the chimney and the power conversion unit. Results show that previous models may have underestimated the initial cost and levelised electricity cost of a large-scale solar chimney power plant. It is also shown that carbon credits significantly reduce the levelised electricity cost for such a plant.

Mehran Ghalamchi et al. [9]in their study referring to the increasing rate of environmental pollution and limitation on fossil fuel resources, the use of sustainable energies seem to be inevitable and an absolute necessity for the world. Renewable energies are known as the best alternative for solving the energy shortage and CO2 emission problems. Among the renewable sources, solar energy plays a significant role in aspects of accessibility of resources and diversity of energy conversion means. Solar chimney is a power plant that uses solar radiation to produce electricity by the created wind at the entrance of chimney. A solar chimney pilot power plant with 3 m collector diameter and 2 m chimney height was designed and constructed in university of Tehran, Iran. The temperature distribution and air velocity were measured and evaluated. The temperature difference between the chimney inlet and ambient reached to 26.30C. The output data for different collector inlet heights were obtained and the report shows that reducing the inlet size has a positive effect on the solar chimney power production performance. The air inversion at the latter of the chimney was not observed and it was found that this phenomenon directly associated with the geometry. The maximum air velocity of 1.3m/s was recorded inside the chimney. While the collector entrance velocity was around zero.

Ehsan Gholamalizadeh et al.[10]In their study developed a triple-objective design method for a solar chimney power plant system that simultaneously optimizes the expenditure, total efficiency, and power output. A multi-objective genetic algorithm was used to obtain the best combination of geometric parameters of the power plant. The following design parameters were selected: collector radius, chimney height, and chimney diameter. Two different solar chimney power plant configurations were considered: the Kerman pilot power plant and Manzanares prototype power plant. A set of possible optimal solutions (Pareto optimal set) was obtained. Based on the optimal solution, the best configuration for each power plant was selected. The performance and expenditure of the optimal solution and the built power plant were compared. The results show that the increment of power output was higher than the increment of the expenditure in the optimal configuration. A parametric study was conducted to evaluate the effect of changing design parameters on different objective functions. This paper provides a very useful design and optimization methodology for solar chimney power plant systems.

Ehsan Gholamalizadeh et al.[11] in their study underlines the importance of the greenhouse effect on the buoyancy-driven flow and heat transfer characteristics through the system. For this purpose, a three-dimensional unsteady model with the RNG k-ε turbulence closure was developed, using computational fluid dynamics techniques. In this model, to solve the radiative transfer equation the discrete ordinates (DO) radiation model was implemented, using a two-band radiation model. To stimulate radiation effects from the sun's rays , the solar ray tracing algorithm was coupled to the calculation via a source term in the energy equation. Simulations were carried out for a system with the geometry parameters of the Manzanares power plant. The effects of the solar insolation and pressure drop across the turbine on the flow and heat transfer of the system were considered. Based on the numerical results, temperature profile of the ground surface, thermal collector efficiency and power output were calculated and the results were validated by comparing with the experimental data of this prototype power plant. Furthermore, enthalpy rise through the collector and energy loss from the chimney outlet between 1-band and two-band radiation model were compared. The analysis showed that simulating the greenhouse effect has an important role to accurately predict the characteristics of the flow and heat transfer in solar chimney power plant systems.

BabakGhorbani et al.[12]in their study presented an improved concept design to increase the thermal efficiency of the rankine cycle of a typical steam power plant by combining a solar chimney and a dry cooling tower. The source of the wind energy generation, include: the rejected heat from condenser to the air entering dry cooling tower, solar radiation and the airlift pumping effect on the air flow created by the stack hot flue gas which is injected into the hybrid tower as a novel change. This research primarily focuses on the Shahid Rajaee 250MW steam power plant to determine the velocity of generated flow at the turbine inlet; a numerical finite volume code was employed for a dry cooling tower having a base diameter and chimney height of 250 and 200 m respectively. Calculation have been iterated for different angle of chimney walls, slopes of collectors and the base ground to find their effects on the output power. A range of 360 kW to more than 4.4 MW power is captured by the wind turbine by changing the hybrid tower geometrical parameters. Obtained results reveal a maximum of0.538% increases for the thermal efficiency of the fossil fuel power plant.

Penghua Guo et al.[13]observed that in a solar chimney power plant, only a fraction of the available total pressure difference can be used to run the turbine to generate electric power. The optimal ratio of the turbine pressure drop to available total pressure difference in a solar chimney system is investigated using theoretical analysis and 3D numerical simulations. The values found in the literature for the optimal ratio vary between 2/3 and 0.97. In this study, however, the optimal ratio was found to vary with the intensity of solar radiation, and to be around 0.9 for the Spanish prototype. In addition, the optimal ratios obtained from the analytical approach are close to those from the numerical simulation and their differences are mainly caused by the neglect of aerodynamic losses associated with skin friction, flow separation, and secondary flow in the theoretical analysis. This study may be useful for the preliminary estimation of power plant performance and the power-regulating strategy option for solar chimney turbines.

Peng-Hua Guo et al. [14] a three-dimensional numerical approach incorporating the radiation, solar load, and turbine models proposed in this paper was first verified by the experimental data of the Spanish prototype. It then was used to investigate the effects of solar radiation, turbine pressure drop, an ambient temperature on system performance in detail. Simulation results reveal that the radiation model is essential in preventing the overestimation of energy absorbed by the solar chimney power plant (SCPP). The predictions of the maximum turbine pressure drop with the radiation model are more consistent with the experimental data than those neglecting the radiation heat transfer inside the collector. In addition, the variation of ambient temperature has little impact on air temperature rise despite its evident effect on air velocity. The power output of the SCPP within the common diurnal temperature range was also found to be insensitive to ambient temperature.

Mohammad O. Hamdan [15] his work present a mathematical thermal model for steady state airflow inside a solar chimney power plant using modified Bernoulli equation with buoyancy effect and ideal gas equation. The study

evaluates the use of constant density assumption across the solar chimney and compares it with more realistic chimney mathematical discrete model that allows density variation across the chimney. The results shows that using a constant density assumption through the solar chimney can simplify the analytical model however it over predicts the power generation. This results show that the chimney height, the collector radius, the solar irradiance, and the turbine head are essential parameters for the design of solar chimney. The maximum power generation depends on the turbine
head and the relation is not monotonic.

Atit Koonsrisuk et al.[16] in their study compared the prediction of performance of solar chimney plants by using five simple theoretical models that have been proposed in the literature. A solar chimney is a solar power plant which generates mechanical energy (usually in terms of turbine shaft work) from a rising hot air that is heated by solar energy. The parameters used in the study were various plant geometrical parameters and the insolation. Computational fluid dynamic (CFD) simulation was also conducted and its results compared with the theoretical predication. The power out and the efficiency of the solar chimney plants as functions of the studied parameters were used to compare relative merits of the five theoretical models. Models that performed better than the rest are finally recommended.

Atit Koonsrisuk et al. [17] in their study, a solar collector, chimney and turbine are modeled together theoretically, and the iteration techniques are carried out to solve the resulting mathematical model. Results are validated by measurements from an actual physical plant. Moreover, the model is employed to predict the performance characteristic of large-scale commercial solar chimney, indicating that the plant size, the factor of pressure drop at the turbine, and solar5 heat flux are important parameters for performance enhancement. In addition, the study proposes that the most suitable plant, affordable by local government standards to respond to the electricity demand of a typical village in Thailand, is the one with a collector radius and chimney height of 200 m and 400 m, respectively. Furthermore, it is shown that the optimum ratio between the turbine extraction pressure and the available driving pressure for the proposed plant is approximately 0.84. a simple method to evaluate the turbine power output for solar chimney systems is also proposed in the study using dimensional analysis.

Atit Koonsrisuk [18] in his present paper the performance of solar chimney power plants based on second law analysis is investigated for various configurations. A comparison is made between the conventional solar chimney power plant (CSCPP) and the sloped solar chimney power plant (SCSPP). The appropriate entropy generation number and second-law efficiency for solar chimney power plants are proposed in this study. Results show that there is the optimum collector size that provides the minimum entropy generation and the maximum second-law efficiency. The second-law efficiency of both systems increases with the increasing of the system height. The study reveals the influence of various effects that change pressure and temperature of the systems. It was found that SSCPP is thermodynamically better than CSCPP for some configurations. The results obtained here are expected to provide information that will assist in improving the overall efficiency of the solar chimney power plant.

Haorong Li et al.[19]in their work studied that Buildings represent nearly 40 percent of total energy use in the U.S. and about 50 percent of this energy is used for heating, ventilating, and cooling the space. Conventional heating and cooling systems are having a great impact on security of energy supply and greenhouse gas emissions. Unlike conventional approach, this paper investigates an innovative passive air conditioning system coupling earth-to-air heat exchangers (EAHEs) with solar collector enhanced solar chimneys. By simultaneously utilizing geothermal and solar energy, the system can achieve great energy savings within the building sector and reduce the peak electrical demand in the summer. Experiments were conducted in a test facility in summer to evaluate the performance of such a system. During the test period, the solar chimney drove up to 0.28 m3/s (1000m3/h) outdoor air into the space. The EAHE provided a maximum 3308 W total cooling capacity during the day time. As a 100 percent outdoor air system, the coupled system maximum cooling capacity was 2582 W that almost covered the building design cooling load. The cooling capacities reached their peak during the day time when the solar radiation intensity as strong. The results show that the coupled system can maintain the indoor thermal environmental comfort conditions at a favorable range that complies with ASHRAE standard for thermal comfort. The findings in this research provide the foundation for design and application of the coupled system.

Jing-Yin Li et al.[20] proposed acomprehensive theoretical model is for the performance evaluation of a solar chimney power plant (SCPP), and has been verified by the experimental data of the Spanish prototype. This model takes account of effect of flow and heat losses, and the temperature lapse rates inside and outside the chimney. There is as maximum power output for a certain SCPP under a given solar radiation condition due to flow and heat losses and installation of the turbines. In addition, the design flow rate of the turbine in SCPP system is found beneficial for power output when it is lower than that at the maximum power point. Furthermore, a limitation on the maximum collector radius exists for the maximum attainable power of the SCPP; whereas, no such limitation exists for chimney height in terms of contemporary construction technology.

Weibing Li et al.[21]their paper develops a model different from existing models to analyze the cost and benefit of a reinforced concrete solar chimney power plant (RCSCPP) built in northwest china. Based on the model and some assumptions for values of parameters, this work calculates total net present value (TNPV) and the minimum electricity price in each phase by dividing the whole service period into four phases. The results show that the minimum electricity prices in the first phase is higher than the current market price of electricity, but the minimum prices in the other phases are far less than the current market price. The analysis indicates that huge advantages of the RCSCPPover coal-fired power plants can be embodied in phases 2-4. In addition, the sensitivity analysis performed in this paper discovers TNPV is very sensitive to changes in the solar electricity and inflation rate ,but responds only slightly to change in carbon credits price, income tax rate and interest rate of loans. Our analysis predicts that RCSCPPs have very good application prospect. To encourage the development of RCSCPPs, the government should provide subsidy by setting higher electricity price in the first phase, then lower electricity price in the other phases.

C.B. Maia et al. [22] found that Sustainable development is closely associated with the use of renewable energy resources. In order to achieve a viable development, from an environmental point of view, the energy efficiencies of processes can be increased using renewable energy resources. There is also a correlation between exergy and sustainable development, since exergy is consumed or destroyed due to irreversibilities. The solar chimney has been highlighted in studies of using solar energy to generate electric power. In this paper, the energy and exergy analyses of the airflow inside a solar chimney are presented. Using experimental data obtained in a prototype, the first and second laws of thermodynamics were used to estimate the amounts of energy and exergy lost to the surroundings and the exergetic efficiency. The dead state was defined using two different reference temperatures. The results show that the exergy losses were lower and the efficiency was higher for the lowest ambient temperature used as the dead state temperature, when compared to the instantaneous ambient temperature.

ChiemekaOnyekaOkoye et al. [23] their present work investigates the feasibility of installing a solar chimney power plant (SCPP) under north Cyprus (NC) condition. The method utilized for the simulation of electricity production was compared and verified by the experimental recording of the prototype in Manzanares, Spain, before carrying out performance predictions for different plant sizes, collector diameter and chimney heights. The annual electricity production of a 30 MW hypothetical SCPP system is estimated to be 94.5GW h, which can cater for annual electricity needs of over 22,128residences without any CO2, NOx and SOx emissions. For an installation cost of €145million, it was estimated that the saving-to- investment ratio (SIR) would be 1.14, indicating a marginal economic feasibility. It is important to find ways of reducing the installation cost in order to strengthen the economic viability of the system. Considering that, at present, fuel oil no. 6 is being used in NC to produce electricity; the SCPP would causes avoidance of 24,840 tonnes of CO2 delivered into the atmosphere annually, if it replaced an equivalently-sized conventional power unit. To identify the most feasible cost option for the installation of the SCPP,a parametric cost analysis is carried out by varying the parameters such as; capital investment costs, carbon dioxide emission trading system price, chimney height, collector diameter and SCPP plant capacity. In all cases, the effect of these parameters on the economic feasibility indicators, such as SIR, net present value (NPV) and internal rate of return (IRR) were calculated. The results showed that SCPP investment cost, capacity of the plant and chimney height are critical in assessing the project viability.

Sandeep K. Patel et al. [24]their present work is aimed at optimizing the geometry of the major components of the SCPP using a computational fluid dynamics (CFD) software ANSYS-CFX to study and improve the flow characteristics inside the SCPP. The overall chimney height and the collector diameter of the SCPP were kept constant at 10 m and 8 m respectively. The collector inlet opening was varied from 0.05 m to 0.2 m. The collector outlet diameter was also varied from 0.6 m to 1 m. These modified collectors were tested with chimneys of different divergence angle (0°-3°) and also different chimney inlet openings of 0.6 m to 1 m. The diameter of the chimney was also varied from 0.25 m to 0.3 m. Based on the CFX computational results, the best configuration was achieved using the chimney with a divergence angle of 2° and chimney diameter of 0.25 m together with the collector opening of 0.05 m and collector outlet diameter of 1 m. The temperature inside the collector is higher for the lower opening resulting in a higher flow rate and power.

RoozbehSangi [25] in his study evaluate the performance of solar chimney power plants in some parts of Iran theoretically and to estimate the quantity of the produce electric energy the solar chimney power plantis a simple solar thermal power plant that is capable of converting solar energy into thermal energy in the solar collector. In the second stage, the generated thermal energy is converted in to kinetic energy in the chimney and ultimately into electric energy using a combination of wind turbine and a generator.. A mathematical model based on the energy balance was developed to estimate the power output of solar chimneys as well as to examine the effect of various ambient conditions and structural dimensions on the power generation. The solar chimney power plant with 350m chimney height and 1000m collector diameter is capable of producing monthly average 1-2MW electric power over a year.

Ming Tingzhen et al.[26] have carried out Numerical simulations on the solar chimney power plant system coupled with turbine. The whole system has been divided into three regions: the collector, the chimney and the turbine, and the mathematical models of heat transfer and flow have been set up for these regions. Using the Spanish prototype as a practical example, numerical simulation results for the prototype with a 3 blade turbine show that the maximum power output of the system is a little higher than 50kW. Furthermore, the effect of the turbine rotational speed on the chimney outlet parameters has been analyzed which shows the validity of the numerical method advanced by the author. Thereafter, design and simulation of a MW-grade solar chimney power plant system with a 5- blade turbine have been presented, and the numerical simulation results show that the power output and turbine efficiency are 10MW and 50%, respectively, which present a reference to the design of large-scale solar chimney power plant systems.

COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics (CFD) is a computer based simulation method for analyzing 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.

It can be advantageous to use CFD over traditional experimental based analyses, since experiments have a cost directly proportional to the number of configurations desired for testing, unlike with CFD, where large amounts of results can be produced at practically no added expense. In this way, parametric studies to optimise equipment are very inexpensive with CFD when compared to experiments.

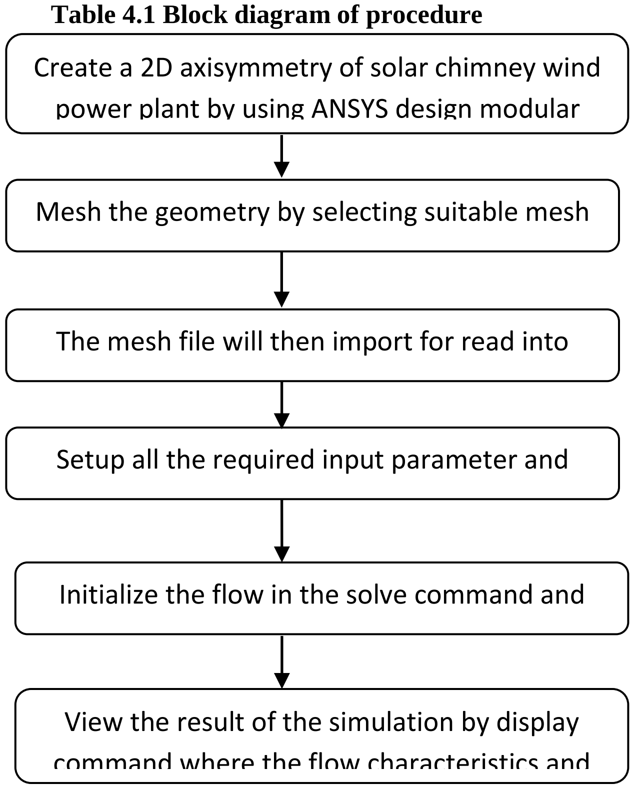
The work for this project was carried out on a HP Pavilion laptop with dual processors totaling 2 GHz RAM, running on Linux Operating System downloaded free from Caelinux. The download from Caelinux included open-source software Salomé for geometry construction and meshing, Open FOAM for the CFD calculations, preview for visualization of results, along with other useful scientific and mathematics related software. Calculations for this project were carried out for approximately 50,000 cells (CFD calculations are often made for 12 million cells – or more). On my system, the steady state solvers took between 13 hours to finish calculations, while the transient simulation took 23 days running in parallel on both processors.

One of the purposes of this project is to use all open source CFD software instead of commercial software for the simulations. This type of software is advantageous for smaller companies to use, as the cost of commercial CFD package licenses can be prohibitive.

METHODOLOGY

Basic Step Corporate for the Investigation

Table 4.1 Block diagram of procedure



CFD ANALYSIS OF SOLAR CHIMNEY WIND POWER PLANT BY USING ANSYS FLUENT:
Generation of 2D axisymmetry model of solar chimney wind power plant by using Ansys Design modeler. The solar chimney and the solar air collector were modeled for CFD Analysis. The model was created on the x-y plane on 2D axisymmetry. The overall height of the SCWPP was 194.6m and the solar air collector was 122 m in radius and chimney radius is 5.08m.

MODEL OF SCWPP AT DIFFERENT CHIMNEY HEIGHT

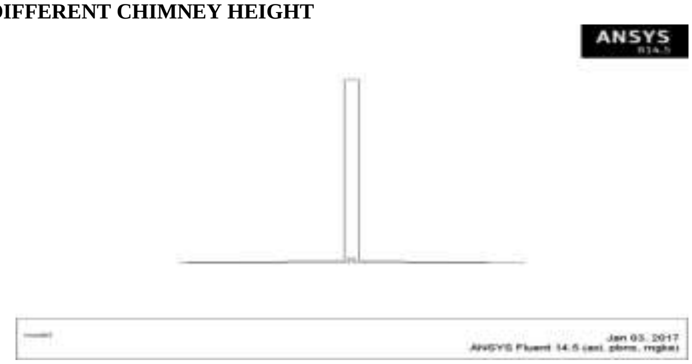


FIG.4.1(I) CHIMNEY HIGHT AT 194.6 M

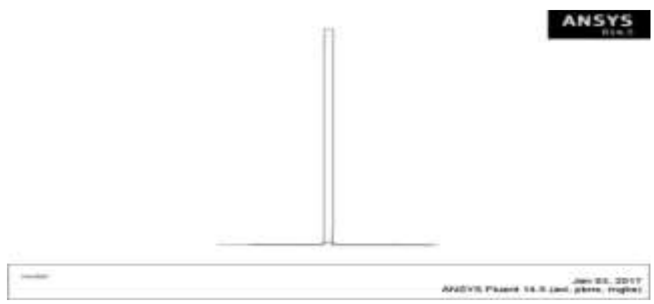


Fig.4.1 (ii) Chimney hight at 400 m

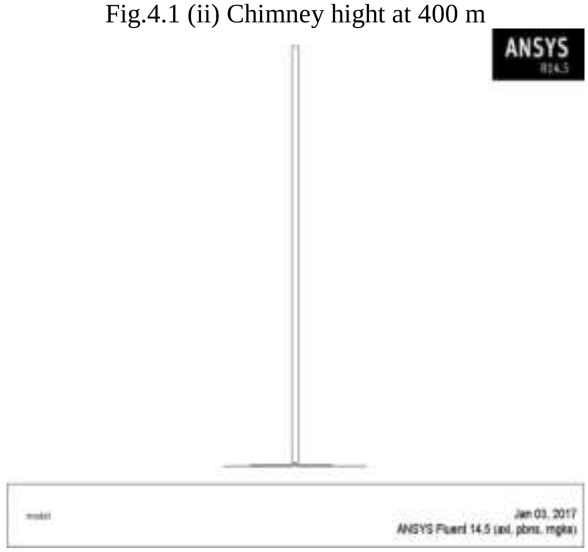


Fig.4.1(iii) Chimney hight at 600 m

Fig 4.1 (i), (ii), & (iii), shows the model of solar chimney wind power plant at different chimney height 194.6, 400, 600, (m) respectively at constant collector radius 122 m and chimney radius 5.08 m.

MODEL OF SCWPP AT DIFFERENT COLLECTOR RADIUS

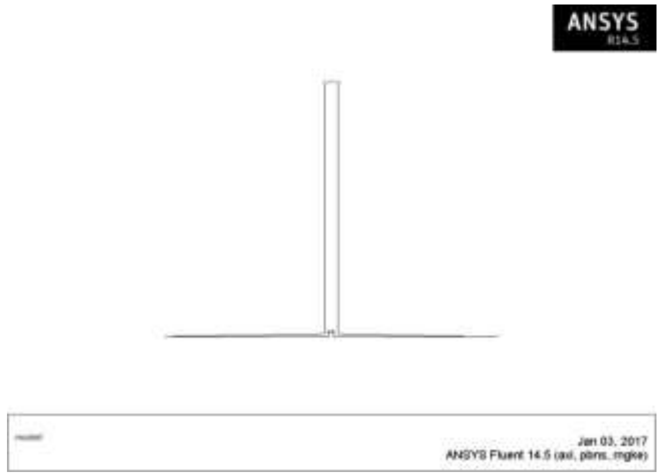


Fig 4.2 (i) Collector radiuses at 122 m

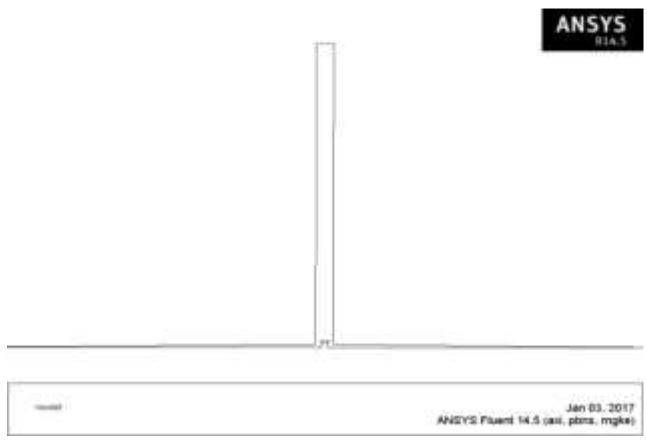


Fig 4.2(ii) Collector radius at150 m

Fig 4.2 (i), (ii), shows the model of solar chimney wind power plant at different collector radius 122,150, (m), at constant chimney height 194.6 m and chimney radius 5.08 m.

MODEL OF SCWPP AT DIFFERENT THROAT RADIUS

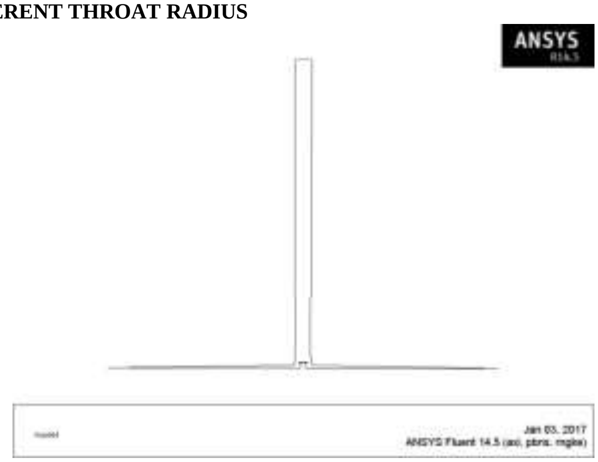


Fig 4.3 (i) Throat diameters at 4.75m

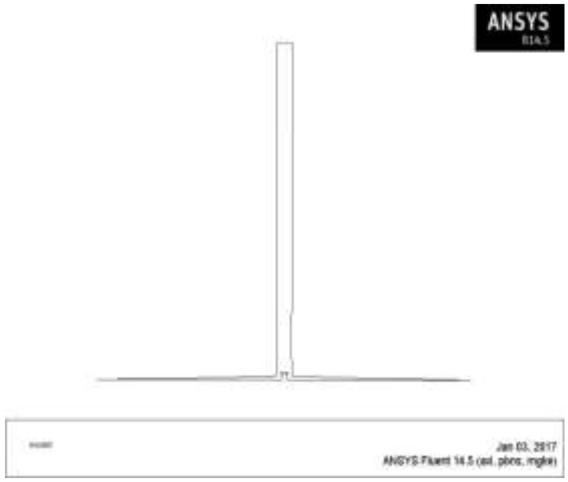


Fig 4.3 (ii) Throat diameter at 4.5 m

Fig 4.3 (i), (ii), shows the model of solar chimney wind power plant at different throat radius, 4.75, 4.5, (m) at constant chimney height 194.6 m and collector radius 122 m.

MODEL OF SCWPP AT DIFFERENT R.F.

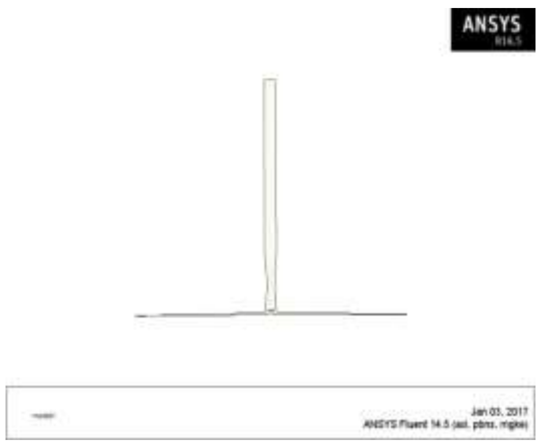


Fig 4.4 (i) at R.F= 0.18

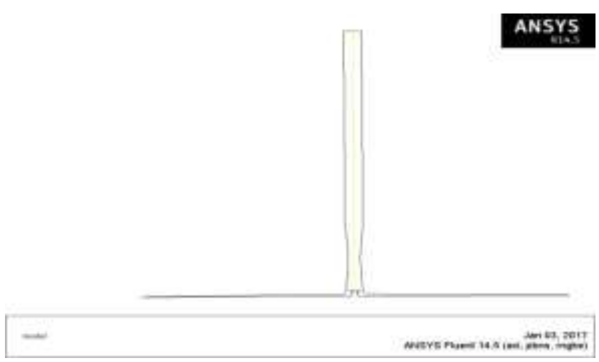


FIG 4.4 (II) AT R.F= 0.20

Fig 4.4 (i), (ii), shows the model of solar chimney wind power plant at different R.F, 0.18, 0.20,.

MESHING OF SCWPP AT DIFFERENT CHIMNEY HEIGHT

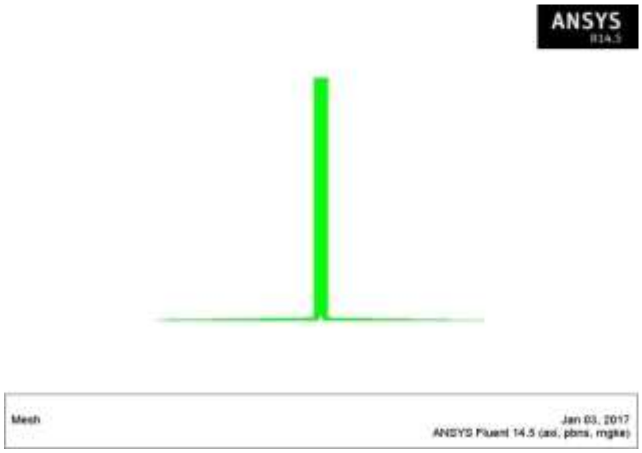


Fig.4.5. (i) (a) Chimney height at 194.6 m

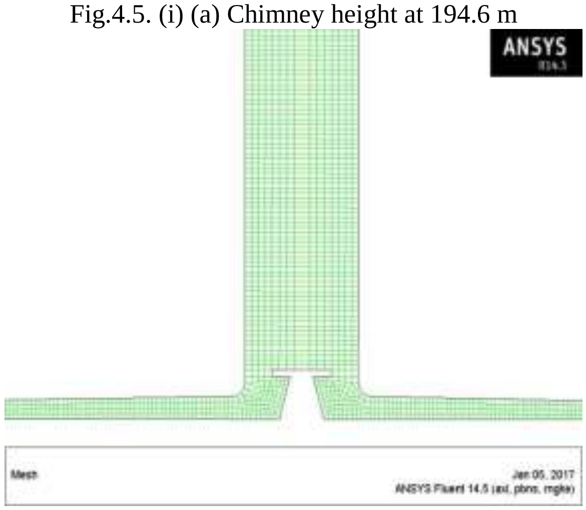


Fig.4.5. (i) (b) Magnify view of Chimney height at 194.6

Fig 4.5 (i)(a), (i)(b), shows the meshing of solar chimney wind power plant at different chimney height 194.6, 400, 600, (m). At constant collector radius 122 m and chimney radius 5.08 m.

Problem Setup in Fluent:

(i) **Problem Type:** 2D axisymmetry

(ii) **Type of Solver**: Pressure-based solver

(iii) **Physical model**: Energy

: Viscous-RNG k-e, standard wall function

Material Property: Flowing fluid is air.

: Density of air= boussinesq: 1.225 kg /m3

: Specific heat: 1006.43j/kgK

: Thermal conductivity: .0242W/mK

: Viscosity: 1.7894e-05kg/ms

:Thermal expansion coefficient: .00331/k

(iv) **Boundary condition:**

(a) Boundary condition of existing SCWPP model with different chimney height, different collector radius, different collector percentage with respect to chimney height, different throat radius is same i.e.
Operating condition: pressure: 101325pa

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: Temperature: 291.65k
Inlet: pressure inlet: gauge total pressure: 0 pa
: Turbulent intensity: 1%
: Hydraulic Dia.: .04
: Temperature: 291.65k
Outlet: Pressure outlet: Define the same outlet condition for all the fan outlet Gauge pressure = 0 Pa
: Turbulent intensity: 1%
: Hydraulic Dia.: 10.16
Axis: axis
Collector: wall: heat flux: 367.5 W/m2
Ground: wall-temp: 300.15 k

Boundary condition for Indian condition SCWPP model with optimize throat radius (3.5 m) at different solar radiation is
Operating condition: pressure: 101325pa
: Temperature: 303.15k
Inlet: pressure inlet: gauge total pressure: 0 pa
: Turbulent intensity: 1%
: Hydraulic Dia.: .04
: Temperature: 303.15
Outlet: Pressure outlet: Define the same outlet condition for all the fan outlet Gauge pressure = 0 Pa
: Turbulent intensity: 1%
: Hydraulic Dia.: 10.16
Axis: axis
Collector: wall: heat flux: 103.5, 235.5, 367.5, (W/m2) respectively
Ground: wall-temp: 311.65 k

Boundary condition of SCWPP at Indian condition with different fraction factor is:
Operating condition: pressure: 101325pa
: Temperature: 303.15k
Inlet: pressure inlet: gauge total pressure: 0 pa
: Turbulent intensity: 1%
: Hydraulic Dia.: .04
: Temperature: 303.15k
Outlet: Pressure outlet: Define the same outlet condition for all the fan outlet Gauge pressure = 0 Pa
: Turbulent intensity: 1%
: Hydraulic Dia.: 10.16
Axis: axis
Collector: wall: heat flux: 367.5 W/m2
Ground: wall-temp: 311.65 k

Boundary condition of SCWPP at Indian condition at fraction factor (.20) with different collector absorption coefficient ($\propto$) is.
Operating condition: pressure: 101325pa
: Temperature: 303.15k
Inlet: pressure inlet: gauge total pressure: 0 pa
: Turbulent intensity: 1%
: Hydraulic Dia.: .04
: Temperature: 303.15
Outlet: Pressure outlet: Define the same outlet condition for all the fan outlet Gauge pressure = 0 Pa
: Turbulent intensity: 1%
: Hydraulic Dia.: 10.16
Axis: axis
Collector: wall: heat flux: 367.5, 407.5, 457.5,(W/m2) respectively
Ground: wall-temp: 311.65 k

(b) Boundary condition of SCWPP at Indian condition at fraction factor (.20) with different collector loss coefficient ($\cup$)
Operating condition: pressure: 101325pa
: Temperature: 303.15k

Inlet: pressure inlet: gauge total pressure: 0 pa
: Turbulent intensity: 1%
: Hydraulic Dia.: .04
: Temperature: 303.15
Outlet: Pressure outlet: Define the same outlet condition for all the fan outlet Gauge pressure = 0 Pa
: Turbulent intensity: 1%
: Hydraulic Dia.: 10.16
Axis: axis
Collector: wall: heat flux: 367.5, 406.5, 445.5, 484.5(W/m2) respectively
Ground: wall-temp: 311.65 k

(v) Solution:

Solution method: Pressure velocity coupling – Scheme SIMPLE
: Pressure – Standard
: Momentum – Second order
: Turbulent Kinetic Energy (k) – First order
: Turbulent Dissipation Rate (e) First order
: Energy: Second order
Solution Initialization: Initialized the solution to get the initial solution for the problem
Run Solution: Run the solution by giving 2000 no of iteration for solution to converge and to find out the required results.

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.

5.1. 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.

5.1.1 Result of existing SCWPP model with different chimney height

Table 5.1

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

The table 5.1 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.

5.1.2 Result of existing SCWPP model with different collector radius

Table 5.2

collector radius(m)	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	Power(W)
122	794.0054	63.4439	11.68162	48044.0938
150	900.985	86.3839	13.26227	74267.31657

200	1006.212	107.8849	14.83184	103729.6123
250	1092.522	125.2797	15.97944	129774.4867
300	1101.818	138.5214	16.25754	145988.5392
350	1110.307	137.369	16.44059	146404.0852
400	1122.617	139.7278	16.47706	149248.3725

The table 5.2 shows the result obtain form the fluent solver for Solar chimney wind power plant with different collector radius(122m - 400m) at constant chimney height (194.6m), 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 5.2 it has been observed that the power is enhance as increases the collector radius. It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the Collector radius increases.

5.1.3 Result of existing SCWPP model with collector percentage with respect to chimney height

Table 5.3

Collector percentage (%)	Chimney height with %	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	Power(W)
0%	0	794.0054	63.4439	11.68162	48044.0938
10%	19.46	794.0979	63.3374	11.67878	48951.78393
20%	38.92	797.9033	64.134	11.83947	49222.95119
30%	58.38	800.2995	64.3931	11.76823	49124.43186

The table 5.3 shows the result obtains form the fluent solver for solar chimney wind power plant at different collector percentage on chimney (0% - 50%). At constant collector radius (122m), chimney height (194.6m), 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 5.3 it has been observed that the power is enhance as increases the collector percentage on chimney. It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the Collector percentage increases.

5.1.4 Result of existing SCWPP model with different throat radius

Table 5.4

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

The table 5.4 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/m2. 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.

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5.1.5 Results of Indian condition SCWPP model with optimize throat radius (3.5 m) at different solar radiation

Table 5.5

Solar radiation(W/m^2)	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	Power (W)
600	560.4742	42.48316	8.811747	24267.54771
800	706.4642	66.4816	11.09018	47795.51194
1000	807.471	86.1025	12.6649	70691.07501

The table 5.5 shows the result obtains form the fluent solver for solar chimney wind power plant at different solar radiation (600 W/m2-1400W/m2). At constant collector radius (122m), chimney height (194.6m), average roof height (1.85m), ambient temperature (303.15). In table result of mass flow rate turbine pressure drop, turbine inlet velocity and power is calculated. From the table 5.5 it has been observed that the power is enhance as increases the solar radiation. It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the solar radiation increases.

5.1.6 Result of SCWPP at Indian condition with different fraction factor

Table 5.6

R.F.	Chimney height(m)	collector radius(m)	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	power
0.18	21	35.028	9.322625	13.52778	4.413589	3870.485814
0.20	24.4	38.92	12.36664	15.77164	4.812185	4920.012771
0.25	30.5	48.65	22.44221	21.60471	5.61153	7859.171933

The table 5.6 shows the result obtains form the fluent solver for solar chimney wind power plant at different R.F. at constant throat radius (.7m), ambient temperature (303.15) and solar radiation 1000W/m2. In table result of mass flow rate turbine pressure drop, turbine inlet velocity and power is calculated. From the table 5.6 it has been observed that the power is enhance as increases R.F. It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the fraction factor increases.

5.1.7 Result of SCWPP at Indian condition at fraction factor (.20) with different collector absorption coefficient ($\propto$)

Table 5.7

collector absorption coefficient ($\propto$)	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	Power(W)
0.66	12.36664	15.77164	4.812185	4920.012771
0.70	12.78653	16.87063	4.97741	5443.544485
0.75	13.27674	18.20035	5.170282	6100.157253

The table 5.7 shows the result obtains form the fluent solver for solar chimney wind power plant at different collector absorption coefficient ($\propto$) at constant R.F(.20), throat radius (.7m), collector radius (24.4m), chimney height (38.92m) ambient temperature (303.15) and solar radiation 1000W/m2. In table result of mass flow rate turbine pressure drop, turbine inlet velocity and power is calculated. From the table 5.7 it has been observed that the power is enhance as increases R.F. It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the collector absorption coefficient ($\propto$) increases.

5.1.8 Result of SCWPP at Indian condition at fraction factor (.20) with different collector loss coefficient (U)

Table 5.8

collector loss coefficient (U) W/m^{2}K	Mass flow inlet(kg/s)	turbine-pressure drop (pa)	turbine inlet velocity (m/s)	Power(W)
15	12.36664	15.77164	4.812185	4920.012771
13	12.77802	16.84758	4.973957	5432.335867
11	13.16299	17.88765	5.1256	5943.538213
9	13.5301	18.90786	5.270134	6459.681354

The table 5.8 shows the result obtains form the fluent solver for solar chimney wind power plant at different collector loss coefficient (U) W/m2K at constant R.F (.20), throat radius (.7m), collector radius (24.4m), chimney height (38.92m) ambient temperature (303.15) 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 5.8 it has been observed that the power is enhance as decreases collector loss coefficient (U).It also has been observed that Mass flow inlet; turbine pressure drop and turbine inlet velocity also increases as the collector loss coefficient (U) decreases.

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.

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