

A REVIEW ON DIFFERENT PROCESS PARAMETERS OF SOLAR CHIMNEY POWER PLANT

¹Arun Kumar Pravakar, ²Vardan Singh Nayak

Vidhyapeeth institute of science & technology
Bhopal (m.p.), India

Abstract: In recent years, there has been an increasing interest in utilizing the solar energy for electricity generation and various reviews have stated that the advantages of the solar technologies outweigh their disadvantages. Solar chimney now a day also a promising field of using solar energy to generate electricity. So, it is necessary to review the different process parameters and working mechanism of solar chimney power plant. Here in this paper, existing research work of solar chimney plant was reviewed.

Keywords: Solar chimney, power, performance parameters, efficiency, review

1. Introduction

Renewable energy has long been the interest quest in the field of electricity power generation. Considering the various renewable sources of energy, solar energy is considered the Earth's predominant source of energy but time and location dependent. The radiant heat as well as light approaching from the Sun can be converted directly or indirectly into different forms of energy. However, it is known that the solar power is being disadvantaged by the low efficiencies of the energy conversion systems. One of the drawbacks of solar power systems is the initial investment cost which restrains the masses from investing into the energy system. The economic disadvantage is associated with the increased costs of the installation of solar energy technologies while producing only a relatively small amount of energy related to other conventional energy system, thus characterized of low efficiency. As a result, the solar power still remains considerably a high cost energy option when compared to conventional energy sources such as the fossil fuels, nuclear and hydropower.

In recent years, there has been an increasing interest in utilizing the solar energy for electricity generation and various reviews have stated that the advantages of the solar technologies outweigh their disadvantages. For examples, some of the benefits of solar energy embrace free and abundant supply, and its environmentally friendly nature. Solar energy also is inexhaustible in supply which has recorded 1.8×10^{14} kW/hr interception on the earth surface out of the total 3.8×10^{23} kW/hr emitted by the Sun. The unlimited source of solar energy makes it a promising option to provide continuous supply of electricity to meet the global energy demand. Asian countries receive a reasonably high volume of solar radiation throughout the year. Even though the Asian countries receive higher solar radiation from the Sun with longer sunshine duration as compared to other temperate countries, solar energy is yet to be effectively harnessed in this region.

Solar energy can be converted directly and indirectly to electrical power using different energy conversion systems. Example of well-known technology for the direct conversion of solar energy into electrical energy is the use of the photovoltaic cells. The solar thermal energy conversion systems are used for indirect generation of electricity from the solar energy. The solar thermal systems could be categorized as either low temperatures or high temperatures solar thermal systems. High temperatures solar thermal systems include parabolic trough solar collectors, solar power tower (heliostat), parabolic reflector, linear Fresnel concentrators, solar oven, dish concentrator etc. Low temperatures solar thermal systems are mainly flat-plate solar collectors which the Solar Chimney Power Plant finds its origin. Solar energy is said to be the cleanest form of energy that can be employed to generate electricity, without causing harm to the environment. The construction of solar energy-based power generating plants could prove to be beneficial in the long term, as initial investments on the solar power plants would serve to provide sustainable energy future for both urban and technologically less developed areas. Extensive researches have been supported out to improve the cost effectiveness of solar technologies for electricity production to allow the possibilities for the development of commercial solar power generation plants in the near future. On top of that, as the radiation intensity varies with locations, countries that receive a reasonable quantity of solar radiation would not have issues with the reliability of energy supply.

2. Working principal of a solar chimney

The updraft is one of the technologies based on the principle of buoyancy, whereby the air is heated by solar radiation (heat energy) at low cost through the greenhouse effect. The solar chimney is a passive (non-mechanical) solar ventilation system that can be installed on roofs or walls. The heat transfer takes place on the principle of convection cooling because of the circumstance that the hot air rises; these fireplaces reduce unwanted heat during the day by moving (warm) indoor air through the (cold) outside air. Solar chimneys mainly consist of a black and hollow thermal mass with an opening at the top, which serves as an outlet for hot air. The air in the room arises out of the chimney. The process can also be reversed for space heating.

The sun heats up the ground and the air beneath the collector roof. The heated air follows the slope towards the rooftop. This air flows at high speed in the chimney and drives the wind turbines. The higher the chimney, the lower the pressure at its top, increasing the flow rate and thus power output.

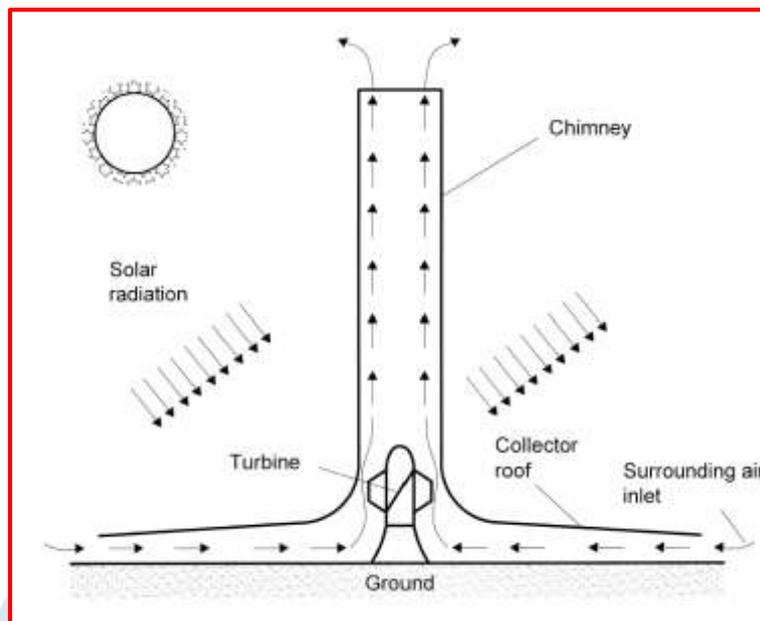


Fig 1.2 Ref [18] A solar chimney power plant

3. Characteristics of the solar chimney power plant

The solar chimney power plants have certain features or characteristics that make it attractive for power generation. They include the following:

- Clean technology using renewable solar energy as a heat source which produces neither greenhouse effect gasses nor hazardous wastes.
- Efficient use of solar radiation, the solar collector utilizes both the direct and diffuse solar radiation. The plant therefore is capable to create power under cloudy conditions although reduced.
- Ground floor under the collector serves as a heat storage, avoids sudden fluctuations and allows the power supply after sunset.
- The Plant has a low maintenance cost as compared to other conventional power technologies. This is considered a key advantage especially in areas with enough sunshine.
- The SCPP power plant does not requisite any cooling water to operate. This makes them advantageous in areas where water supply is a challenge.

4. Solar chimney power plant challenges

The SCPP also have certain features or disadvantages that make them less suitable for some sites.

- We need large areas of flat land. This land should be accessible at a low cost, which in turn means that there should be no contending use, like e.g. intensive agriculture for the land.
- Zones with frequent sand storms should also be avoided, as either collector performance losses or collector operation and maintenance costs would be substantial there.
- The total efficiency of the SCPP is the invention of the efficiencies of the three technologies of the plant. The solar collector has efficiency of about 20% and characterized of high thermal losses of over 30%. The turbine has been rated the most effective and efficient component of the SCPP due to the location of the turbine which lead to over 60% energy conversion efficiency. The chimney has the least efficiency which is because of the dependence of the performance on the height of the chimney where 1000 m tall chimney has efficiency of about 3%.
- Most literatures have suggested that increasing the SCPP size will increase the plant's efficiency, however increasing the collector size also increases the thermal losses while increasing the chimney height increases the investment cost and engineering challenge of the chimney construction.

5. Existing researcher work

1. Yuen Zheng et.al [2018] This research work had focused on improving the efficiency of the collector of inclined SCPP through the use of underneath air-vents. The study employed numerical method using a Computational Fluid Dynamics software, Star-CCM+. In the system modelling and simulation, radiation modelling principles were adopted under condition of steady state. The study revealed that with the use of underneath air-vents, there was 4.25% and 4.64% reduction in convection and radiation heat transfer respectively from the collector cover to the ambient at 1000 W/m². It was also observed that the air mass flow rate was increased by 210% and consequently the power output of the plant improved by 60%.

2. Liu et.al [2018] In this work, a PV / T power plant with solar chimney (SCPVTTP) was proposed. Mathematical models were established for the solar collector PV / T, the chimney and the energy conversion unit, respectively. Then the interpretations of the SCPVTTP designed were simulated. It was found that the photovoltaic cells maintain the highest temperature in the solar collector. The increase in temperature of the photovoltaic module had significant influences on its power generation. Without cooling, the photovoltaic power capacity had an average decrease of 28.71%.

3. Sivaram et.al [2018] In this work, a mathematical model based on the one-dimensional energy and mass balance was developed by the solar chimney. The airflow characteristics such as exit velocity and temperature are evaluated based on the inclination angle of the sensor, solar radiation, ambient temperature and wind speed. The model is validated by comparing the obtained performance parameters with the experimental results as well as with the experimental data of various geometric ranges and environmental conditions of the literature. For the sun chimney with an inclination angle of the absorber of 30° there is an average difference of 8% for the exhaust air velocity and 1.35% for the exhaust air temperature. a sensor surface of 0.41 m² and a chimney height of 0.24 m.

4. Ayadi et.al [2017] The objective of this work was to study and optimize the characteristics of a chimney power plant (SCPP) using numerical and experimental methods. The numerical simulations were simulated using the Ansys Fluent commercial CFD code. The effect of the collector ceiling height on the performance of the solar chimney is realized. The local characteristics of the airflow within the SCPP system have been presented and analysed, such as; the characteristics of temperature, speed, pressure and turbulence. The results confirmed that the height of the collector roof is very influential in the optimization of the SCPP.

5. Hassan et.al [2017] In this study, effects of collector's slope and diverging chimney on performance of SCPP were numerically investigated. This study comprised the validation of CFD simulations performed on Manzanares prototype with reported experimental results. The validated CFD approach that incorporates RNG k- ϵ , solar charge, DO radiation model was used to study the effects of different collector slopes and divergent chimney angles on airflow and heat transfer in the SCPP, with the goal of improving your performance. Numerical results showed that by increasing collector's slope there was a gradual increase in air velocity.

6. Mekhail et.al [2017] In this study a very small model of the chimney height of 6 m was installed, the collector diameter of 6 m and the chimney diameter of 0.15 m. The mathematical model, based on the thermodynamic analysis of the flow within the SCPP, was used to predict its performance. The city of Aswan is one of the hottest and sunniest cities in the world. These climatic conditions make the city an ideal place to generate electricity for the Solar Chimney power plant (S.C.P.P). The experimental performances and the theorems calculated by the mathematical model were in good agreement.

7. Zou et.al [2017] In this work, a three-dimensional space acoustic model was established to investigate crosswind and ambient pressure influences on the thermal performance of the solar chimney with hybrid cooling tower. The results of the numerical analysis showed that the autonomous production capacity of the system HCTSC decreased with increasing wind speed, and s reached a minimum at a side wind speed of 8 m / s. If the side wind speed was low (<4 m / s), took the heat dissipation capacity of the HCTSC system with increasing wind speed. In strong winds (more than 4 m / s), however, the evacuated HCTSC system gets more heated because of the increased forced convection generated by the cross wind.

8. Okoye et.al [2017] The purpose of this paper was to raise awareness that Stacked Solar Power Plants (SCPPs) are a viable and sustainable alternative in rural communities with limited or no access to the grid. The study considered site-specific hourly meteorological data to assess the feasibility of SCPP in seven selected areas of Nigeria. A theoretical model has been developed for the power output, the electricity cost paid (LCOE) and the avoided CO₂ emissions forecasts. In addition, the effects of seasonality on solar radiation, ambient temperature and energy were investigated.

9. Vieira et.al [2017] This research project aimed to examine the influence of geometrical parameters on the available power of stacked solar power plants (SCPPs) by design. The influence of different soil temperatures (mimicking the effect of different solar influences on the collector device) on the optimal shapes is also appraised. The geometry is subject to three limitations: sensor zones, turbines and chimneys. In addition, three degrees of freedom are taken into account: R / H (ratio between the bend radius and its entry height), R₁ / H₂ (ratio between the radius and the height of the chimney) and H₁ / H (ratio between collector base height and sensor entry height) constant (H₁ / H 10.0). The time averaged conservation of mass, momentum and energy equations (RANS) was solved numerically with the finite volume method (FVM). For turbulence modelling, the standard model k- ϵ was used.

10. Cao et.al [2017] in this study, a new solar double chimney power plant (SDCPP) was proposed and analysed so as to improve the safety and effectiveness of the solar chimney power plant (SCPP). It was found that, for an SDCPP with 5MW configuration size, the average temperature rises of the horizontal and tilted solar collectors are 5.64K and 7.87K respectively. The highest wind speeds in the inner chimney and in the interlayer of the inner and outer chimney were 15.28m/s and 19.41m/s respectively. The average annual energy productivity and energy efficiency of the SDCPP was 4.72 MW and 1.2%. The energy productivity of the SDCPP was 1.59 times higher in contrast to the CSCPP and 2.77 times higher in contrast to the SSCPP.

11. Ghalamchi et.al [2016] In this work, a pilot plant was built to study the temperature fields and obtain new experimental data. The sensor roof was made of 4 mm soda-lime glass and black aluminum foils were applied to the sensor absorber. In this work the

temperature and velocity distribution in different pilot sizes and collector materials was described and compared. Lastly, the best condition was achieved and the maximum velocity of the fluid at the inlet of the chimney was 1.7 m / s and the best data with respect to the temperature of the absorber and the fluid were each 353.78 and 329.01 K. It has been noticed that reducing the size of the inlet has a positive effect on the performance of the solar fireplace, but this reduction has an optimum range and this optimum number is 6 cm for this configuration.

12. Hanna et.al [2016] In this research study, they had constructed an experimental setup for ten run days in Aswan, Egypt to appraise the operation of the turbine inside the lantern factory. It has been perceived that ambient temperatures, however, play a vital part in the effect on the production of electricity for solar energy. Most importantly, the efficiency of the solar cooker is proportional to the temperature of the air from solar collectors, especially in the range of 1:00 to 3:00. Based on the result, it can be judged that the rotational speed of the fan can be chosen at 1650 rpm, with the average fan efficiency of 57%.

13. Ohya et.al [2016] In this research, laboratory experiments and numerical analyses (CFD) for a solar tower were performed. The home-model experiments of buildings with a 2-meter-high sun height were used as examples of the reference used. In order to define the finest configuration of the building, they were examining the impact of the open half-hour exposure of the tower and tower towers, at the speed of the written push system. After changing the height of towers and openings with openings, the difference between the temperature between the air and the collection tools, different media has been tested by laboratory and digital analysis.

14. Mustafa et.al [2015] In this study mathematical and experimental models for circular solar collectors were implemented. The modelling methodology using the conservation equations of continuity, momentum and energy was presented and the solution of the model is obtained using a code developed in the MATLAB program. An experimental model of concentric circles of 8.8 m and 1.0 outside and inside diameters was designed and manufactured to allow the measurement of thermal processes and flow processes in the system. The roof was inclined at 8.5 °.

15. Amirkhani et.al [2015] In this paper, use of artificial neural network (ANN) and adaptive neuro-fuzzy inference system (ANFIS) in SCPP modelling had been discussed and the experimental data of the built pilot in Zanjan had been applied. The input parameters of this model were time, ambient temperature and solar radiation, while the only output is the air velocity inside chimney. In order to assess the performance of ANN and ANFIS models, 20% of the experimental data was utilized for model testing.

16. Driss et.al [2015] In this work, numerical studies were carried out to investigate the turbulent flow around Savonius' unconventional wind rotors. This study compares various rotor designs characterized by blade elbow angles equal to 60 °, 75 °, 90 °, and 130 °, while the other geometric parameters are kept constant. Under these conditions, the third case concerns a conventional Savonius wind rotor. The results revealed that the design of the blade had a direct impact on the local properties. In particular, it has been perceived that the depression areas increase with increasing nose angle of the bucket. The large depression zone appears with $\psi = 130^\circ$. It is positioned in the concave surface of the blade and downstream of the rotor.

6. Conclusion

Solar chimney is the easiest and renewable source of energy the performance of solar chimney depends on different process parameters like chimney height, collector slope angle, chimney divergence angle and many others. The performance of turbine that is placed inside the chimney is mainly depends on the maximum velocity of air inside the chimney, because air velocity is responsible to rotate the turbine. Though the installation cost of solar chimney plant is little more than the conventional power plant, but their running cost is very low, which compensates the installation cost.

References

- [1] Wilson Phua Yuen Zheng [2018], "Performance Enhancement of Inclined Solar Chimney Power Plant Using Underneath Air-Vents and Thermal Storage Medium", Master of Philosophy (Mechanical Engineering) of Curtin University. Open Journal of Fluid Dynamics, 2016, 6, 337-342.
- [2] Qingjun Liu, Fei Cao, Yanhua Liu, Tianyu Zhu, and Deyou Liu [2018], "Design and Simulation of a Solar Chimney PV/T Power Plant in Northwest China", International Journal of Photo energy Volume 2018, Article ID 1478695, 12 pages, doi.org/10.1155/2018/1478695.
- [3] Sivaram P.M., Sivasankaran Harish, Premalatha M., Arunagiri A [2018], "Performance analysis of solar chimney using mathematical and experimental approaches", International Journal of Energy Research · March 2018 DOI: 10.1002/er.4007.
- [4] Ahmed Ayadi, Abdallah Bouabidi, Zied Driss, Mohamed Salah Abid [2017], "Experimental and numerical analysis of the collector roof height effect on the solar chimney performance", Renewable Energy (2017), doi: 10.1016/j.renene.2017.08.099.
- [5] Aakash Hassan, Majid Ali, Adeel Waqas [2017], "Numerical investigation on performance of solar chimney power plant by varying collector slope and chimney diverging angle", Energy (2017), doi: 10.1016/j.energy.2017.10.047.
- [6] T. Mekhail, A. Rekaby, M. Fathy, M. Bassily, and R. Harte [2017], "Experimental and Theoretical Performance of Mini Solar Chimney Power Plant", Journal of Clean Energy Technologies, Vol. 5, No. 4, July 2017.
- [7] Zheng Zou, Hengxiang Gong, Xieshi Lie, Xiaoxiao Li, Yong Yang [2017], "Numerical Investigation of the Crosswind Effects on the Performance of a Hybrid Cooling-Tower-Solar-Chimney System", Applied Thermal Engineering (2017), doi.applthermaleng.2017.07.198.
- [8] Chiemeka Onyeka Okoye, Onur Taylan [2017], "Performance analysis of a solar chimney power plant for rural areas in Nigeria", Renewable Energy (2017), doi: 10.1016/j.renene.2016.12.004.
- [9] R.S. Vieira, A.P. Petry, L.A.O. Rocha, L.A. Isoldi, E.D. dos Santos [2017], "Numerical evaluation of a solar chimney geometry for different ground temperatures by means of constructal design", Renewable Energy 109 (2017) 222e234.

- [10] Fei Cao, Tian Yang, Qingjun Liu, Tianyu Zhu, Huashan Li, Liang Zhao [2017], "Design and simulation of a solar double-chimney power plant", *Renewable Energy* (2017), doi: 10.1016/j.renene.2017.05.100.
- [11] Rayan Rabehi, Abla Chaker, Zeroual Aouachria & Ming Tingzhen [2017], "CFD Analysis on the Performance of a Solar Chimney Power Plant System: Case Study in Algeria", *International Journal of Green Energy*, DOI: 10.1080/15435075.2017.1339043.
- [12] Mehrdad Ghalamchi, Alibakhsh Kasabian, Mehran Ghalamchi, Alireza Hajiseyed Mirzahosseini [2016], "An experimental study on the thermal performance of a solar chimney with different dimensional parameters", *Renewable Energy* 91 (2016) 477e483.
- [13] Magdy Bassily Hanna, Tarek Abdel-Malak Mekhail, Omar Mohamed Dahab, Mohamed Fathy Cidek Esmail, Ahmed Rekaby Abdel-Rahman [2016], "Experimental and Numerical Investigation of the Solar Chimney Power Plant's Turbine", *Open Journal of Fluid Dynamics*, 2016, 6, 332-342.
- [14] Yuji Ohya, Masaki Wataka, Koichi Watanabe and Takanori Uchida [2016], "Laboratory Experiment and Numerical Analysis of a New Type of Solar Tower Efficiently Generating a Thermal Updraft", *Energies* 2016, 9, 1077; doi: 10.3390/en9121077.
- [15] Ayad T. Mustafa, Hussain H. Al-Kayiem and Syed Ihtsham U. Gilani [2015], "Investigation and evaluation of the solar air collector model to support the solar vortex engine", *ARPN Journal of Engineering and Applied Sciences* VOL. 10, NO. 12, July 2015.
- [16] S. Amirkhani, Sh. Nasirivatan, A.B. Kasaeian, A. Hajinezhad [2015], "ANN and ANFIS models to predict the performance of solar chimney power plants", *Renewable Energy* 83 (2015) 597e607.

