A REVIEW ON SOLAR CHIMNEY POWER PLANT PERFORMANCE

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Abstract: **Solar chimney power plant is the vast area for research, it is the most prominent and eco-friendly area of research for power generation now a day. Solar Chimney Power Plant [SCPP] Solar chimney power plant (SCPP) is a low temperature solar thermal system that combines three technologies (greenhouse technology, chimney technology and wind turbine technology) in a serial alteration of solar energy to electrical energy. The SCPP energy conversion processes include the conversion of solar energy into thermal energy at the collector absorber, conversion of the thermal energy at the absorber to kinetic energy in the buoyant air, conversion of the kinetic energy in the air into mechanical work using the turbine and conversion of the mechanical work into electrical power through the rotation of a connected shaft from the turbine to the generator. This papers includes the complete review of solar chimney power plant and their different aspects.**

Keywords: **Solar chimney power plant, performance, review, mechanism**

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 × 1014 kW/hr interception on the earth surface out of the total 3.8 × 1023 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.

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

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 which receive a reasonable quantity of solar radiation would not have issues with the reliability of energy supply.

2. Conversion of Solar Energy

Converting solar energy into electricity is possible by either using a solar photovoltaic device or by converting the solar energy into thermal energy and subsequently converting the thermal energy into electric power. The later technology is known as solar thermal technology.

A solar thermal technology can either be
i. A concentrating technology or
ii. A non-concentrating technology.

The concentrating technologies employ powerful collectors that are able to generate high temperature thermal energy to initiative either steam turbines or gas turbines to produce power. The parabolic trough, the dish technology, and the heliostat are examples of concentrating power technologies simply put as CSPs. The non-concentrating technology oppositely employs collectors that are unable to concentrate the solar radiations i.e. they capture both the direct and diffuse solar irradiation. Invariably they are unable to attain very high temperatures. The solar chimney power technology to be investigated in this literature review falls under the non-concentrating power technologies. The current renewable energy technologies employed to adapt solar energy into heat and electricity. According to energy needs and conditions farms, this energy carrier has three operating sectors of the energy.

3. Solar Chimney Power Plant [SCPP]

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

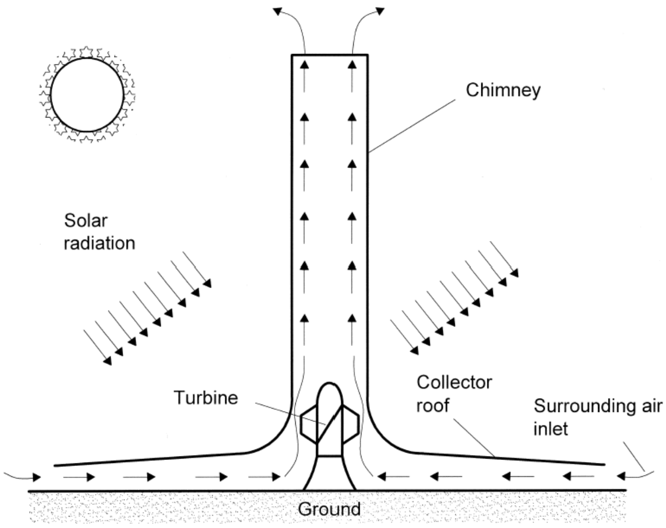

Fig 1.2 Ref [18] A solar chimney power plant

3.1 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.
- The effectiveness of the solar chimney power plant is below 2%, and depends mainly on the height of the tower (the taller the chimney the greater the draught obtained).
- However, the outdoor area under the roof of the collector can be employed as a greenhouse for agricultural purposes.

3.2 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.

3.3 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.

4. Existing Work

In later past years, the usage of solar energy and solar chimney power plants have expanded the interest of engineers and researchers to simulate their studies & results with computational, experimental and numerical methods. A lot of research works has been being carried out which involved the construction of experimental prototypes to investigate the potential of solar chimneys power all over the world.

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/m^2. 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 (SCPVTPP) 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 SCPVTPP 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%. The contradictory influences of the increase in temperature and the cooling of the air flow lead to a decrease of 11.81% of the average power capacity.

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. The average daily and maximum experimental airflow rates in April are 0.5 and 0.88 m / s, respectively. The optimum operating conditions are an inclination angle of 75 °, an absorption area of 0.63 m^2 and a chimney height of 0.48 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. In fact, an increase in the power generated is recorded while the height of the roof of the collector is reduced. Since the optimization of the chimney device is characterized by high costs, this document could be a solution to improve the power generated by an existing chimney solar system.

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. But at collector slopes higher than 60, the air flow has not remained uniform and the air return, vortices were detected below the collector due to density gradients formed by uneven temperature distribution, which could block the air from entering the chimney, thus reducing the overall performance of the SCPP.

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. This model was used to predict the production of a larger model of chimney height 20 m, collector 30 m 2 and chimney diameter of 1 m, which is still under construction. The results revealed that the largest model can produce a theoretical power of about 600 times the smallest. This study helps to select the power of the generator for the largest model.

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. The higher the cross wind speed, the greater the heat dissipation capacity.

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 CO_2 emissions forecasts. In addition, the effects of seasonality on solar radiation, ambient temperature and energy were investigated. The outcomes revealed that the SCPP with a collector diameter of 600 m and a stack height of 150 m on a typical day under Nigerian conditions would yield an average power of 154 to 181 kW. Over a lifetime of 40 years, the cost of electricity is between € 0.216 and € 0.254 / kWh, compared to € 0.563 / kWh for widely used diesel generators, and the annualized decline in CO_2 emissions is between 162 and 191 tonnes.

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 e-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. By comparing with the CSCPP literature, the SDCPP can increase its energy productivity by 21% to 55%. SDCPP is a auspicious means for generating solar thermal without concentration.

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. The diameter of the chimney is the most influential geometric parameter in the performance of the solar chimney.

12. Hanna et.al [2016] In this research study, they had constructed a 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%. The conclusion is that this digital model is a valid basis for the system to generate solar thermal output and the simulation model can easily be employed to predict the efficiency of any solar exhaust system. The results and results of the test results are good. Finally the maximum effectiveness of the solar chimney power plant in this study is specified as the high value than it is in previous work according to the site that the study was performing in Aswan, Egypt.

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. As a result, it has been perceived that the diffuser building with a half-degree openness of 4 ° is the best shape, producing the highest speed in differing temperature, both in laboratory experiments and in analytical calculations.

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 °. The results perceived that with the same solar radiation the temperature of the air stream, the screen and the ground increases by decreasing the radius. As the inclination of the cap increases, the temperature of the airflow decreases and the temperature of the cap increases for constant solar radiation.

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. The evaluation of the ANN and ANFIS models indicated the good predictive capabilities of ANFIS model. The most important advantage of the models based on soft computing techniques in comparison with numerical methods was the drastic reduction of the computational cost.

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 $\psi = 130^o$. It is positioned in the concave surface of the blade and downstream of the rotor. The acceleration zone, in which the maximum speed values are recorded, is formed in the convex surface of the rotor blade and increases as the arc angle of the blade increases.

17. Al-Azawie et.al [2014] In this work, the conversion capacity of six different base materials that may be available in Malaysia has been investigated experimentally and numerically. An experimental device was built to record the measured data. In the FLUENT software environment, a numerical model was created to model and simulate the energy conversion process. The materials chosen were ceramics, black chalk, sawdust, dark green lacquered wood (DGPW), sand and pebbles. The results of the simulation showed good agreement with the experimental results in terms of air flow rate and energy conversion efficiency. Ceramic and black stone showed better performance on other materials. However, due to its availability, black stone is recommended as absorbent material in the solar chimney in Malaysia and the countries of the region.

18. Asante et.al [2014] In this work, The mathematical model as a tool has been employed to analysis the design and performance of the SCPP. Mathematical derivations where provided to predict the theoretical power output of the SCPP based on the climatic weather conditions in Takoradi city. As an input to the model, a small scaled plant with the following physical parameters were considered: 25 m diameter collector, 50 m tall and 4 m internal diameter solar chimney. A collector with a single glazing was considered. With a monthly average solar irradiance of 208.79 W/m^2 the plant output a theoretical electrical power of 48 kW.

19. Fasel et.al [2013] In this thesis, the solar stackers are numerically analysed with ANSYS Fluent and a code developed internally by CFD (Computational Fluid Dynamics). Analytical scaling laws are substantiated by considering a wide range of scales with tower heights from 1 meter (lab model) to 1000 meters (largest plant considered). A model with a tower height of approximately 6 m is currently being built at the University of Arizona. High-resolution detailed time-based flow simulations in the manifold and in the model stack provide detailed information about fluid dynamics and heat transfer mechanisms.

20. Gholamalizadeh et.al [2013] This study underlined the significance of the greenhouse effect for the flow and heat transfer properties associated with the buoyancy of the system. For this purpose, an unstable three-dimensional model with the RNG turbulence k e-ε was developed with computer-aided flow dynamics techniques. In this model, the discrete ordinate (DO) radiation model was employed using a dual band radiation model to solve the radiative transfer equation. To simulate the effects of solar radiation, the sun ray tracking algorithm was coupled with the calculation via a source term in the energy equation. Simulations were supported out for a system with the geometric limits of the Manzanares power plant. The effects of solar radiation and pressure drop in the turbine on the flow and heat transfer of the system were taken into account.

Conclusion: Through literature survey it is concluded that the installation cost of solar chimney power plant is high and most of the cost is mainly related to chimney. Through literature it is also observed that the power generation capacity of turbine place inside the chimney also depends on the velocity of air achieved inside the chimney. So in order to reduce the installation cost of the system and to increase the velocity of air inside the chimney.

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