

# Review of Solar Chimney Power Plant

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**ABSTRACT:** Solar technology is the novel technology which uses the natural sunlight to produce electricity. It uses the combination of three simple technologies that is turbine, vertical chimney of some longer height and glass roof collector for absorbing the sun radiations. By proper utilization of this technology the electricity can be generated in abundance and continuously for twenty four hours throughout the year in country like India where there is sunlight almost for nine months in the major part of the country. Much advancement has taken place in this technology for last three decades but the full utilization of this technology has not taken place because of various aspects. This paper presents the critical review of this important technology in the form of the advancements and developments taken place in various parts of the world and analyses its important aspects

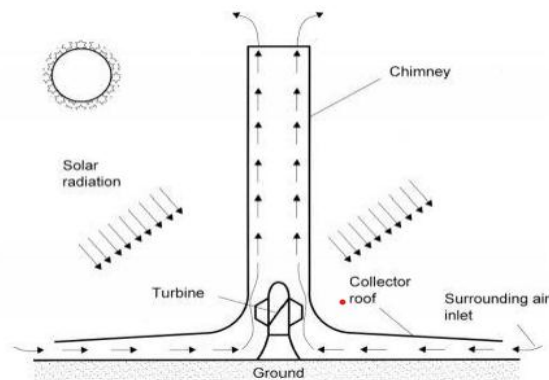
**KEYWORDS:** Solar Chimney Power Plant, Computational Fluid Dynamics

## I. INTRODUCTION

At present, a number of energy sources are utilized on a large scale such as: coal, oil, gas and nuclear. Continuation of the use of fossil fuels is set to face multiple challenges namely: depletion of fossil fuels reserves, global warming and other environmental concerns and continuing fuel price rise. For these reasons, the existing sources of conventional energy may not be adequate to meet the ever-increasing energy demands. Consequently, sincere and untiring efforts shall have to be made by the scientists and engineers in exploring the possibilities of harnessing energy from several non-conventional energy sources (solar, biomass, tidal, hydrogen, wind and geothermal energy) which they are seen as possible solution to the growing energy challenges. According to energy experts, unconventional energy sources can be used for electric power generation which receives a great attention. Power generating technology based on green resources would help many countries improve their balance of payments. 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.

## II. 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 rise at a speed of about fifteen meters per second. The suction of the air that occurs causes the wind turbines that are located in the chimney. Turbines are used with a generator and gearbox to generate electricity.



**Fig. 1.2 A solar chimney power plant**

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 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

### III. PROJECT OF SOLAR CHIMNEY IN VARIOUS PARTS OF THE WORLD

#### 3.1 Manzanares Prototype

Detailed theoretical preliminary research and a wide range of wind tunnel experiments led to the establishment of an experimental plant with a peak output of 50 kW on a site made available by the Spanish utility union Electrica Fenosa in Manzanaras about 150 km south of Madrid in 1981-82 (Jorg Schlaich & Wolfgang Schiel, 2000), with funds provided by the German Ministry of Research and Technology. The aim of this research project was to verify, through field measurements, the performance projected from calculations based on theory and to examine the influence of individual components on the plant's output and efficiency under realistic engineering and meteorological conditions. These results show that the components are highly dependable and that the plant as a whole is capable of highly reliable operation. This single global radiation is exploited and the thermodynamic inertia is a characteristic feature of the system. Continuous operation throughout the day is possible and even abrupt fluctuation in energy supply is effectively cushioned, the plant operated continuously even on cloudy days, albeit at reduced output.



#### 3.2 Enviro Mission

Enviro mission is set to build the tallest structure of solar chimney power plant in North America (Reid smith and Lisa Cohn, 2012) with its innovative solar updraft tower design, which provides base load power. The solar updraft



tower uses a solar energy collector canopy and a central tower to generate and updraft airflow that drives the rotation of pressure-staged turbines at the base of the tower and generates electricity. Enviro Mission plans to build its first commercial solar updraft tower on public lands in L Paz County, Arizona. If we imagine a sunny day in Arizona where the outside temperature would be 40degrees Celsius, the temperature under the collector would be 80 to 90 degrees Celsius and the temperature at the top of the tower would be 32 degree Celsius. This creates the ideal temperature differential that Enviro Mission desires.



### 3.3 Solar Technology Nigeria

Solar technology and its necessity in Nigeria were studied (Ngala & Suleiman, 2013). Nigeria which is located between longitude 30 and 140 East of Greenwich and latitude 40 and 140 north of equator has about 160 million people and a total land area of 923,768 km<sup>2</sup>. Nigeria lies within a high sunshine belt and thus has enormous solar energy potentials. It also describes the economics of power generation by using solar chimney. During operating period the SCPP avoids the CO<sub>2</sub> emissions from coal-fired power plant, which typically emits 0.95 kg of CO<sub>2</sub> per kWh power output. Large amount of carbon credits was therefore obtained for SCPP. In this study the details of SC power technologies are described and the status and development of this technology reviewed including the experimental and theoretical study status, as well as the economics for SC power technology. There are also potentials of citing this technology in Nigeria especially in the semi-arid region with solar sunshine hours of up to 9 hours, solar radiation of 7kW/m<sup>2</sup> /day and enormous flat land

### 3.4 Solar Chimney

In Botswana Import of huge proportion of electrical energy from the Southern African Power Pool, and the geographical location and population distribution of Botswana stimulated the need to consider renewable energy as an alternative to imported power. (Clever Ketlogtswa, 2008) a systematic experimental study on a mini-solar chimney system. Particular attention is given to measurements of air velocity, temperature and solar radiation. The result for the selected 5 and 6 clear days of October and November respectively are presented. These results enable the relationship between average insolation, temperature difference and velocity for selected clear days to be discussed.

## IV. RECENT DEVELOPMENT IN SOLAR TECHNOLOGIES

### 4.1 Structural Stability of Concrete Wind Turbines and Solar Towers Exposed to Dynamic Wind Action

The solar chimney operates like a hydroelectric power plant, but instead of water, it uses a hot air. This is particularly useful in arid area, which is plentiful in Africa, even south of Sahara. It comprises a transparent roof collector, a central chimney tower and one or more turbo generators at the base. Beneath the collector, (Reinhard Harte, 2007) a large, circular glass roof, air is heated. Through the coinciding change in air pressure, the air moves radially towards the centre, where it enters the tower, which creates an up-draught. By this suction effect, hot air is drawn in from the collector and as it rises up the chimney, it flows through one large turbine or numerous smaller turbines, the preferred option yet to be determined. These turbines are linked to conventional generators, whereby electricity is generated. The output of the solar chimney is proportional to its size. The scale of a 1000-1500m tall, 160m diameter chimney tower and a glass roof collector of diameter 4-7 km is proposed to produce an output of 200-400MW.

### 4.2 Reinforce Concrete (RC) Chimneys with Fiberglass Reinforce Plastic (FRP)

A simple method to calculate fire duration and flue gas temperatures for reinforced concrete (RC) chimneys with fiberglass reinforced plastic (FRP) liners based on experimentally determined burning characteristics of the liner

material was proposed (Artemis Agelariidou-Twohig, 2014). Implementation of the method to calculate fire durations and the transient heat transfer conditions is demonstrated for single and four liner chimney. A parametric study is carried out for chimney designs and geometries ranging from 100 m to 300 m in height and 7 m to 40m in diameter, with 1-4 liners and varying opening configuration. The results are used to identify a limited number of cases for which the RC chimney undergoes the most extreme reduction in its post-fire residual strength. Analytical estimations of the chimney residual strength after the fire are obtained using a method established based on the procedure outlined in the American Concrete Institute (ACI) 307 standard for chimney strength calculations. Calculations for a series of critical configuration of RC chimneys, with FRP liner geometries within the practical design limits detailed. This shows that the post-fire structural capacity of the chimney would not lead to catastrophic failures especially because the chimney is not expected to see other high design lateral loads such as wind or earthquake simultaneously.

#### 4.3 Constructal Geometry of a Solar Chimney

The study to describe the constructal-theory search for the geometry of a solar chimney was conducted. The objective of (A. Koonsrisuk, S. lorente, 2010) was to increase the power production over the area occupied by the plant. The ratio height/radius, maximum mass flow rate and maximum power under the constraints of a fixed area and volume are determined. The power generated per unit of land area is proportional to the length scale of the power plant. The analysis is validated by a detailed mathematical model. Pressure losses are reported in terms of the dimensionless length scale of the system and are illustrated graphically. They indicate that the pressure drop at the collector inlet and at the transition section between the collector and chimney are negligible and the friction loss in the collector can be neglected when the svelteness of the entire flow architecture is greater than approximately 6.

#### 4.4 Solar Chimney and Linked Renewable Energy Conversion Devices

A solar tower constituted (Denis Bonnelle, 2004) from a wide circular glass collector and a 1 km high chimney, where hot air flows upwards and drives some turbines; and a downwards tower where dry air is cooled down by the evaporation of sprayed water droplets. Each of both projects is born by a competent team, but their credibility is undermined by competitors, whose publication include serious basic errors. Some technical improvements are proposed for the solar tower, with the goal to be able to design a larger solar collector and a higher tower and boost the global efficiency. Possible effects on the global biosphere circulations are described, in order to find the most neutral or beneficent solution, e.g. a combination of energy towers and bigger towers having many common features with solar chimney

#### 4.5 Flows in Solar Chimney for an Optimal Design Purpose

Diversified approaches were used to find ways to improve the efficiency of a solar chimney (Atit Koonsrisuk, 2009). The approaches can be divided into categories of theoretical, experimental and numerical methodologies. He describes the objectives, the problem and rational and the methodology of the research. Dimensional analysis was used in to determine the scaling law for the flow in solar chimney systems and the results obtained were verified by using the computational Fluid Dynamics technique (CFD). Inspection of the mathematical model suggests the flow area ratio that can increase the plant performance. To support the idea, the mathematical analysis was carried out and then proved by CFD. The mathematical model of the system with a turbine was developed in to evaluate the plant performance. He shows the experimental performance of four small-scale physical models. Finally the method of constructal design was used to search for a better design of the flow system

### V. THEORETICAL AND EXPERIMENTAL STUDIES

#### 5.1 Maximum Fluid Power Conditions in Solar Chimney Power Plant

The objective of the study (Von Theodor, W. Backstrom, Thomas P. fluri, 2006) was to investigate analytically the validity and applicability of the assumption that, for maximum fluid power, the optimum ratio of turbine pressure drop to pressure potential. The study developed two analyses for finding the optimal ratio of turbine pressure drop to available pressure drop in a solar chimney power plant for maximum fluid power. It was shown that the constant pressure potential assumption may lead to appreciable under estimation of the performance of a solar chimney power plant, when compared to the model using a basic model for the solar collector

#### 5.2 Mathematical Modeling of Solar Chimney Power Plant

A solar collector, chimney and turbine are modelled together theoretically (Atit Koonsrisuk, Tawit Chitsomboom, 2013) 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



characteristics of large scale commercial solar chimney, indicating that the plant size, the factor of pressure drop at the turbine and solar 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 400m, respectively.

### 5.3 Solar Updraft Power Plants: Engineering Structures for Sustainable Energy Generation

This present (Reinhard Harte, Tudiger Hoffer, Wilfried b. Kratzig, 2013), the working principles of solar updraft power plants; followed by explaining climatic and wind-technologic design assumptions. Then the central solar updraft chimney and the power tower are treated in more detail: a thin ring-stiffened RC shell of extreme height, forming the utmost structural challenge of such plants. This part is followed by technical requirements for the collector constructions, by far the largest glass-covered areas ever built, and of the wind loading on the glazing. Then, further design aspects are extracted by the durability requirements for at least 100 years of operation in extreme desert climates. The paper closes with some cost estimates for the generated electricity. This present manuscript has concentrated their own cost-estimations on optimized smaller plants with 500m and 750 m of chimney heights

### 5.4 Solar Chimney Model with Uniform Wall

Heat Flux Experiments are carried out using an experimental solar chimney (Z.D. Chena, P.Bandopadhyay, J.Halldorsson, 2003) model with uniform heat flux on one chimney wall with a variable chimney gap-to-height ratio between 1:15 and 2:5 and different heat flux and inclination angles. Results showed that a maximum air flow rate was achieved at an inclination angle around 45° for a 200 mm gap and 1:5 m high chimney and the air flow rate is about 45% higher than that for a vertical chimney at otherwise identical conditions. It was found that the prediction method available in the literature can substantially over predict the airflow rate for the chimney geometry investigated in this work, especially for vertical chimneys with large gaps. The main reason for the over prediction of air flow rate was shown due to the underestimation of the pressure losses at the chimney outlet by using loss coefficients obtained for normal forced flows.

### 5.5 Behaviour of the Airflow In A Solar Chimney

An analytical and numerical study of the unsteady airflow inside a solar chimney was performed by (Cristiana B. Maia, Andre G. Ferreira, Ramon M. Valle, 2009). The conservation and transport equations that describe the flow were modeled and solved numerically using the finite volumes technique in generalized coordinates. The numerical results were physically validated through comparison with the experimental data. The developed model was used for airflow simulation in solar chimneys with operational and geometric configurations different from those found in the experimental prototype. Analysis showed that the height and diameter of the tower are the most important physical variables for solar chimney design.

### 5.6 Solar Chimney Simulation and Experiment

The use of solar chimneys in buildings is one way to increment natural ventilation and as a consequence, to improve indoor air quality (Clito Afonso, Armando Oliveira, 2000). They are similar to conventional chimneys except that the south wall is replaced by a glazing. In order to compare the behavior of a solar chimney with a conventional one, one of each was built in Porto. Results of measurements carried out in both chimneys are shown in this paper, as well as results of a thermal model specially developed for simulating solar chimneys, taking into account the wind effect. It was concluded that there is a significant increase in ventilation rate with solar chimneys and that the thermal model predicts with good accuracy the measurements carried out. Due to the variable nature of wind, the design of a solar chimney can be done without considering the wind effect, which will underestimate the real ventilation rates. In the design process, two parameters can be changed for satisfying the needed average flow rate: chimney section and chimney height; the average flow rate changes linearly with chimney section; for a given solar collection area, it is better to have a larger chimney width and a smaller height.

### 5.7 Solar Chimney Power Plant Systems Coupled with Turbine

Numerical simulations have been carried out on the solar chimney power plant systems coupled with turbine (Ming Tingzhena, Liu Weia, Xu Guolinga, Xiong Yanbin, 2008). 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 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 analysed which shows the validity of the numerical method advanced by the author. Thereafter, design and simulation of a MW-graded 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 presents a reference to the design of the large-scale solar chimney power plant systems.

### 5.8 Thermal Management of a Symmetrically Heated Channel Chimney System

A parametric study on a channel-chimney system was accomplished (Assunta Andrezzi, Bernardo Buonomo, Oronzio Manca, 2009). In this numerical investigation in order to evaluate some geometric optimal, configurations in terms of significant dimensionless geometric and thermal parameters. In the system, the channel walls are symmetrically heated at uniform heat flux. Temperature wall profiles, as a function of axial coordinate, suggested the evaluation of thermal performances of the channel-chimney system in terms of maximum wall temperatures for different expansion ratios, as a function of the chimney aspect ratio. For considered Rayleigh number values, the difference between the highest and the lowest maximum wall temperature increasing channel aspect ratio. This behavior was as greater as the extension ratio was. These differences decreased significantly for the highest Rayleigh number value. Correlations for dimensionless mass flow rate, maximum wall temperature and average Nusselt numbers, in terms of Rayleigh number and dimensionless geometrical parameters, were also proposed.

### 5.9 Research for Ventilation Properties of Solar Chimney with Vertical Collector

Theoretical research and numerical simulation for ventilation properties of solar chimney with vertical collector are performed (Zhou Yan, Jing Guang-E, Liu XiaoHue, Li Qing-Ling, 2011). They are compared with experimental results. Results show that: there are many factors to affect solar chimney ventilation that include heat collection height and weight, solar radiation intensity, inlet and outlet area ratio of chimney and air inlet velocity etc. When the collector height is increased, chimney ventilation is getting higher; but the ventilation increases slowly even decreases; the ventilation increases first and then decreases as growing of the air layer thickness under the same chimney height and width; there exists an optimal ratio between heat collector height and width which makes the ventilation largest; considering the urban architecture image and the influence of the air layer thickness on chimney ventilation, the best air layer thickness is between 0.2m and 0.4m. Besides the airflow temperature in solar chimney increases with chimney height in certain solar radiation intensity. It is consistent with the theoretical analysis and simulation results.

### 5.10 Solar Ventilation and Heating of Buildings in Sunny Winter Days Using Solar Chimney

The capability of solar chimney lonely to meet the required thermal and ventilation needs of individuals in winter days in investigated (A.P. Haghighi, M.Maerefat, 2014). In the analysis, the heat transfer by natural convection and surface radiation in a 2D vented room in contact with a cold external ambient is studied numerically. The dependence of the system performance on air gap depth of the solar chimney, size of openings, outdoor air temperature and solar radiation have been studied to determine the appropriate operation conditions, regarding thermal comfort criteria. The findings show that the system is capable of providing good indoor air condition at daytime in a room, even with poor solar intensity of 215 W/m<sup>2</sup> and low ambient temperature of 50C.

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