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Solar Chimney Power Plants: A Mini Review

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ABSTRACT

The main investigations of a novel solar thermal application known as Solar Chimney Power Plant (SCPP) are summarized in this paper. It is a method of producing electricity from solar energy that relies on the fact that air rises when it is heated. SCPP has three main components: collector, chimney, and turbine. When the heated air is collected in the collector, a thermal updraft occurs in the chimney where a turbine is installed and turned by the updraft flow to generate electricity. In this paper, different design, specifications, and approaches for research on SCPP are reviewed.

1. Introduction

Earth has many valuable resources and newly developed technologies that are used to generate electricity for making our lives easier. There are two types of energy resources on the planet: Non-Renewable and Renewable. Non-Renewable was the only source of energy where wood was used for energy production until the late 1800s. After which, coal was first used to generate electricity for homes and factories. By 1961, coal had become the substantial source that is used to generate electricity. Along with the use of Non-Renewable resources to generate electricity, in the mid-1800s the first hydropower plant has been installed. Looking at it from another perspective, those non-renewable resources –as their name states- are non-renewable and will be depleted sooner or later. Besides, they have multiple negative environmental effects on the planet. In consideration of the foregoing; renewable energy will be the next generation for primary energy as its safer, environmentally friendly, cheaper, unlimited and pollution free. The renewable energy sources can be wind, solar, geothermal, nuclear, tidal, and hydro-power-energy. Renewable energy sources are being used in many countries and its power production grew by 17% in 2017 providing 8% of worlds electricity [1].

There are two kinds of solar energy harvesting which are direct and indirect conversion. Direct conversion for instance is through photovoltaic (PV) cells an example to indirect conversion methods is the Solar Chimney Power Plants (SCPP) to be enacted in this paper. SCPP is an integration of solar and wind energies as a hybrid renewable energy system. SCPP consists of four main parts: chimney, collector, turbine, and energy storage unit [2]. By selecting a proper conducting material for the collector, the air is heated inside the collector. A tower in the middle of the collector is installed to let the air flow through a thermal updraft. The air flow passes by a turbine installed at the entrance of the chimney, rotating it to generate electricity using a generator. The storage unit is used for storing the energy for unproductive days or during night [3] [4].

The first description for SCPP was made in 1903 by Isidoro Cabanyes. He made a proposition for a SCPP connected to a home. A type of wind propeller was installed inside the property with the intention of producing power. [5]. The idea of modern SCPP in its current formstarted in 1970 by professor Schlaich who built a SCPP with a height of 194.6 m in Manzanares in south Madrid, Spain. Its collector has an average power output 36 kW and a capacity of 50kW. This plant was planned to operate for three years. The SCPP could produce up to 100MW and electricity cost may go down below 0.07€/kWh which equals 1.26 LE/kWh. The tower's wires were not protected against corrosion and failed due to rust and storm winds [6] [7].

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In this paper, the main approaches in research on SCPP are reviewed. They are categorized into two main categories: experimental studies, and analytical studies. State-of-the-art research is summarized based on those two main categories. This paper is structured into the two main categories, followed by a conclusion which summarizes the whole paper, and which approaches were most effective.

2. Experimental studies

Multiple SCPP (SCPP) models have been developed, constructed and evaluated in the past few decades. First and foremost, in 1981 A firm of structural engineering in Germany. S. Bergermann [8], constructed the first SCPP prototype. This was located 150 kilometers south of Madrid in Manzanares, Spain, and only produced a maximum power of 50 kW. The plant included a SCPP with 194.6 meters in height and 5.08 meters in circumference, a metallic wall thickness of 0.00125 meters, and a collector with a radius of 122 meters and a PVC roof covering and a four-bladed single-rotor turbine system at the foot of the chimney. This plant is considered one of the most prominent and famous SCPP experiment to this day. They list the essential Manzanares SCPP characteristics. From 1982 until 1989, the prototype's electricity production was connected into the regional power grid.

Consequently, many experts had a keen interest in this technology, and extensive research on SCPP started in many regions. After that, large-scale SCPP projects have been suggested in a number of nations. Prime example being that the construction of The Australian government will provide money for a 200 MW SCPP in Mildura. The Australian plant had a collector with a 7000-meter diameter and stood 1000 meters tall. The facility produced enough electricity to power roughly 200,000 homes, and the same electricity was distributed to a number of homes in Hobart, Tasmania, reducing greenhouse gas emissions by more than 900,000 tons per year [9].

Moreover, Krisst [10] developed four pilot SCPPs at a small scale in West Hartford in 1983, Featuring a 10 m tall chimney, a 6 m circumference collector base and a 10 W power output, this is a backyard device. In addition, in 1985, Kulunk [11] created a 0.14 W micro-scale power plant in Izmit, Turkey, involving a 9 m^2 collector, a SCPP that is 2 m tall, and a circumference of 7 cm.

Zhou and Yang built a 5 W pilot SCPP on the top of a building in China in 2016. The pilot plant, which had an 8-meter-high chimney and a 10-meter-wide collector, was rebuilt multiple times for multiple reasons. The framework was covered with a single sheet of reinforced plastic glass fiber to protect the collector from the unexpected weather condition and to improve the thermal conductivity [12].

In 2002 Chena et al [13] suggested SCPP model features with a consistent heat flux on one wall of the chimney, a chimney gap ratio that can vary from 1:15 to 2:5, in addition to various inclination angles and heat flux. According to the experimental results, high and gap chimney may flow air at their greatest rate when inclined at an angle of about 45 degrees, Nevertheless, under otherwise identical conditions, the airflow rate was higher than that for a vertical chimney by around 45%.

At the Ozama Engineering Campus, A solar power generator is being designed and constructed by Eduardo D. Sagredo [15]. A solar collector made of Concentric Vacuum Tubes made up the system. The chimney was 60 m tall and had an area of 2.2 m^2. The natural draught required for a tiny axial air turbine (windmill) to propel an electric generator is produced by the chimney. In order to force convection within the solar collector and utilize the entire length of the vacuum tubes without reaching the stagnation temperature, the turbine was installed to rotate a small air compressor.

In Turkey's Southeastern Anatolia region, Bugutekin [16] developed a SCPP to test the impact of the collector’s diameters on the temperature and air flow rate in the chimney. Based on the results, the system's performance increases positively with decreasing the collector air inlet height. Additionally, it has been discovered that SCPP systems’ performance is significantly impacted because the high air entrance part of the collector disrupted the equilibrium of heat and air movement between the collectors. During the times of peak solar radiation and ambient temperature, the ground beneath the collector absorbs some heat. By distributing the heat from the collector until the morning hours, when the ambient temperature was at its lowest, it also kept the system operating. Additionally, the system and the ground are only little affected by the ambient wind speed.

Kasaeian et al. [17] developed a SCPP pilot in 2011 that was built using two-layered polycarbonate sheets covering a collector with diameter 10 m and a chimney made of 12 m diameter polyethylene pipe. By taking air velocity and temperature at different positions of the collector, the maximum chimney temperatures and air velocity were calculated. On both cold and warm days, a rise in air inversion at the bottom of the chimney has been noticed after sunrise, but the effects of the inversion were minimized by raising the daytime temperature, resulting in producing a continuous air flow inside the chimney.

A small-scale SCPP was built in 2012 in Kerman, Iran [18]. Approximately 60 meters high and 3 meters in diameter is the chimney of this unit. The collector of this unit is 80m^2. In this inquiry, many SCPP designs were employed, and ultimately provided some methods for generating efficient power. The use of asphalt or rubber in the collector's bottom, double-glazed windows in the collector's roof, and lowering the collector height to 1.3 m were a few of these applicable solutions and installing a conical shape in the chimney's entrance. The output power can be increased by up to 7 kW if all of these strategies are used. The price of creating electrical energy lowers as the chimney's length increases. In actuality, it is affordable to construct a sizable SCPP. By using an optimization process on the SCPP, the cost of production can be decreased. However, compared to other types of solar power plants, the cost of production per kWh of energy in a SCPP is frequently higher.

In a study by Mehla et al. on solar updraft towers consist of air collectors with diameter 1.4 m and chimneys with height 80 cm [19], a ratio of 0.1 was found between chimney diameter and chimney height. Also increasing and decreasing chimney diameters result in decreased and increased velocity, respectively. The ground temperatures increase with the material that has high transmittances to solar radiation resulting in higher flow temperature. Flow temperatures in the cover fall with increasing tower radius.

Furthermore, in Jordan, Al-Dabbas has built the first pilot solar updraft power plant [20]. It was that Solar irradiation, ambient temperature, and other factors influence power generating capacity. The turbine and collector efficiency, height, and surface roughness inside the solar updraft are all critical for system success. Increasing solar collector area and solar updraft height results in power generation capacity boosting under certain conditions. It has also been discovered that as the solar irradiation gets higher, the component efficiencies and the power generation increases. The ambient temperature, on the other hand, has only a tiny impact on the solar power plant's electricity generation. As the solar irradiation increases, the maximum height H_{max} steadily rises. Similarly, as sun irradiation increases, the pressure differential (P) grows.

Khanal and Lei [21] achieved an investigation on an experimental approach of passive inclined wall SCPP (IPWSC) in 2014. This model's heat flux was uniform on the active wall, on a scope from 100 W/m^2 to 500 W/m^2. It has been discovered that the air gap width has a huge shock on the air velocity.

Shahreza and Imani [22] built a SCPP in 2015 that utilized two intensifiers to increase solar radiation. The results showed that both numerical and experimental investigations found that both velocity and temperature of air raising is greater. The greater power generation output is around noon. As a consequence of utilizing intensifiers, the chimney's velocity magnitude increased, resulting in more power. In fact, it was demonstrated that the amount of power generated and the speed at which the air rises are directly related. Additionally, the air discharge velocity rose as greater the heat flux entered the SCPP or (SC) (through the 24 hour), which led to a rise in the amount of power generated. The most significant finding from this research was a maximum achievable velocity is 5.12 m/s, which is noteworthy given the limited size of the SCPP structure. However, the arising power in the reported, there was nothing particularly special about SC hight due to the chimney's narrow transection. It is anticipated that employing a greater size of this SC type will significantly boost the output power.

Al-Azawie and Hassan have investigated six different ground materials using experimental and numerical methods. Sun radiation was converted to kinetic energy using sawdust, ceramics, dark green painted wood, sand, pebbles, and black stone. In comparison to other materials, the reaction between black ceramic and stone had better functionality. Although ceramic materials have higher heat storage capacity, The substance for the absorbent was suggested to be black stone in SCPPs due to its availability [23].

Aja et al. studied how an inclined SCPP facing south performed in relation to wind direction and wind speed. The velocity of the wind at the region has an impact on the performance of a SCPP. One key issue that has not been studied in terms of its impact on plant performance is wind direction. In this paper, the impact of wind direction and speed on system air velocity was investigated. The system mass flow rate and air velocity were the two main elements that controlled how much of SCPP power is produced. It was found that, for a collector oriented southward, velocity of wind does not result in energy loss via the cover, despite the fact that wind velocity often results in energy loss through the cover. During windy conditions, the loss is greater when the wind comes from the north, east, or west, but when the wind comes from the south and heading north, the system is much more efficient since the wind flows into the collector. Established on this finding, the work suggests reducing the heat loss from the collector using the inlet guide vanes at the periphery of traditional SCPP as a result The hot air in the collector is swept away by the wind [24].

In 2014, Li and Liu examined the effectiveness of SCPP with Phase change material (PCM) in different three heat fluxes: $600 W/m^2$, $500\ W/m^2$ and $700\ W/m^2$and the results showed that although at the $600\ W/m^2$ and $500\ W/m^2$, PCM does not entirely melt, the absorber surface temperature changes for the three heat fluxes for the same charge period of 7 h 10 mins are the same during the phase change transition period . In contrast to the discharge sensible heat period, the surface temperatures drop relatively slowly throughout the phase shift period until the latent heat is completely released. For all of the examples studied, the phase change periods are roughly 13 h 50 min. The flow rates of air change in response to the temperature of the absorber surface. The air flow rate for $700\ W/m^2$ is 0.04 kg/s, which is somewhat higher than the 0.039 kg/s for $600\ W/m^2$and 0.038 kg/s for 500 W/m^2. During the early ventilation period, the SCPP reaches its peak thermal efficiency of approximately 80% for all cases. However, the biggest minimum efficiency of 63 percent is driven by $500\ W/m^2$ [4].

In 2014, Tan and Wong examined the impact of internal heat load and ambient air velocity on the classroom's interior thermal environment caused by SCPP ducts. Results from experiments and calculations showed an increase in the air speed inside the SCPP ducts at an ambient air speed of more than 2m/s. The internal air speed of the classroom is found to be enhanced by both high and low ambient air speeds. However, when solar irradiation was more than 700 W/m^2, the importance of ambient air speed decreases. Furthermore, Cross ventilation operates better than SCPP in tropical weather circumstances with high sun irradiation and low ambient air speed; as a result, SCPP is advised to be used below zero ambient air speed. Finally, the findings indicate that the effects of internal heat load on the air velocity and temperature within SCPP ducts and the inside the classroom are minimal [25].

In 2015, Nasirivatan et al. investigated how the Corona wind affected the efficiency of the SCPP. The outcomes show that corona wind improved the convective the coefficient of heat transfer of the absorber, which led to an increase in air velocity and the output power of the SCPP. When a voltage of 15 kV was applied to the pilot, the amount of heat transfer rose by more than 14.5%, and the speed in the chimney improved by almost 72% [26].

In 2016, Ohya et al. showed that to improve the air velocity in the turbine, a diffuser tower was employed rather than a cylinder-shaped one as shown in Figure 1. A semi-open diffuser tower with an angle of 4° has been found to be the optimal design for generating a rapid updraft at each temperature difference, according to both laboratory tests and numerical calculations. Temperature disparity and/or tower height have been demonstrated to be related to thermal updraft speed. The thermal updraft velocity was found to be related to the temperature difference or the root of the tower height squared. The results showed that this model produced from 2.6 to 3.0 times more power compared to the convectional cylindrical form by increasing air velocity by roughly 1.38–1.44 times [27].

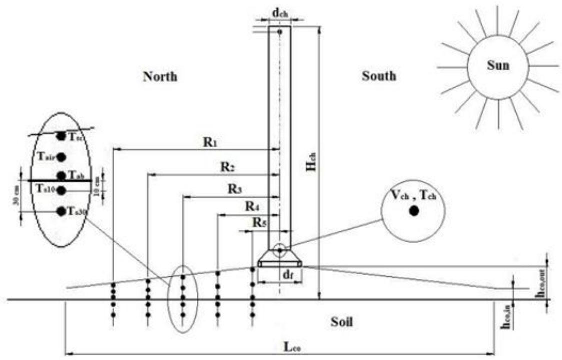

Figure 1 Schematic diagram of solar chimney with the measuring positions [27]

Jemli et al. Studied a solar tower power plant (STPP) performance with the effect of chimney based on the renewable energy suggested for electricity generating. This resulted in the creation of the first STPP in Tunisia, which had a collector with 8 m diameter and a chimney of 2 m height. The outcome revealed that during the summer and winter, the obtained electric power density was in the range from 0.3 W/m^2 to 0.1 W/m^2, respectively. This study suggests that sunshine plays a significant impact in the electricity generated by a solar tower. The amount of electricity generated depended on the amount of sunlight and chimney height as well as the surrounding temperature [28].

Ayadi et al. constructed an experimental prototype of the SCPP in the University of Sfax, Tunisia in the North Africa. The first model had a chimney with a diameter of 160 mm and a height of 3000 mm, a collector with diameter D = 2750 mm, and a collector height of h = 50 mm. To study how the height of the chimney affects the specifics of the airflow within an SCPP. The result showed the chimney pipe was reported to be the main component in the SCPP's optimization. Moreover, the local characteristics were influenced by the height of the chimney. Otherwise, with a variation of H = 3 m, the magnitude velocity is increased by 176%. Because the collector size is limited by space, optimizing the chimney size is a good option [29].

In 2018, Fadaei et al studied phase change material on a SCPP, both numerically and experimentally. As shown in Figure 2, paraffin wax has been placed as a phase change material within the tiny SCPP that was built on the University of Tehran campus. It had a 1.5 m collector radius, a 3 m chimney height, and a 20 cm chimney diameter. According to the results when solar radiation was at its highest, the absorber surface temperature was also at its highest. The temperature values for the system without and with PCM were 69 °C and 72 °C, respectively. When PCM was used, the maximum air velocity for the SCPP raised from 1.9 m/s to 2 m/s. Finally, the mass flow rate was increased by 8.33%, increasing the SCPP's efficiency by employing the phase change material [30].

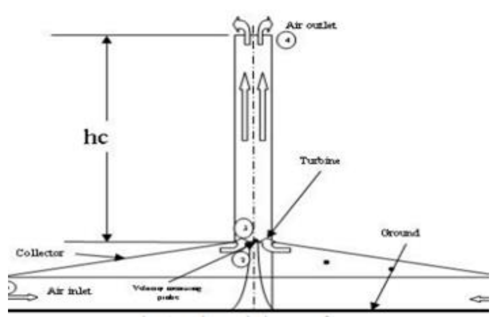

Figure 2 Schematic layout of SCPP [30]

3. Analytical studies

The fundamental ideas behind SCPPs are laid out as straightforward estimations. The conclusion that power generation cost-effectiveness will be attainable with large-scale plants created for up to 400 MW/pk can be drawn from the correlations between the scale on the one hand and the physical principles and building costs on the other. A few of the design elements of the Manzanares pilot plant are also detailed [31].

In 1984 W. Haff made the Federal Republic of Germany's Minister of Research and Technology ordered the design and building of the SCPP pilot plant at Manzanares as well as the investigations detailed below. The study was managed by Kernforschungsanlage Jülich GmbH's energy research project management division. This was the world's first SCPP, and it has been running continuously since it was commissioned on June 7, 1982. With help of 24-hour records, frictional pressure losses, individual energy balances, turbine section losses and collector efficiency figures, are analyzed. The results are in good agreement with those of previous model simulations. [32]

In 1987 Mullet made a study in Manzanares in Spain to conduct the efficiency analysis for a 200 m SCPP, In 1988 Padki and Sherifto revised and developed the governing differential equations for SCPP efficiency [7] [27], [26].

M. Padki and S. A. Sherif conducted research for scaled power generation for village settings in 1989. A methodology has been created to assess the effectiveness and performance of SCPP. The use of that analytical model was built to get the equations for variable power and efficiency. The model demonstrated how the power plant's performance is impacted by its geometrical and operational parameters. This model's inaccuracy was discovered to range from 4 to 6% [33].

Lodhi conducted a thorough analysis of SCPP efficacy in 1999. It was discovered that the cost of operating a 100MW SCPP in developing nations was computed using an annual energy production rate of 876 million KWh over a 20-year period for plants with a 1 Km height chimney and 2 Km^2 collector area [29]. Christomboon demonstrated in 2000 that there is linearity between the efficiency, power, and the tower height, but that the efficiency is constant in response to the diameter, size of the roof, and the amount of isolation. [15]. In 2001, Niloufar Fadaei created a thermomechanical analytical model for performance forecasting of the SCPP. By taking into account flow in the chimney tower through the slight pressure difference and flow interactions in the greenhouse, this model differed from earlier ones. [30]. Dai et al, In 2003, studied a few important variables including the ambient temperature, collector circumference, chimney height, wind turbine efficiency, solar irradiations and found a non-linear increase in power output with plant size [33], [34].

Also, in 2003 Schiel et. al. compared the SCPP to down draft power plant. For the investigation, they constructed a simple thermodynamic model, and they discovered that SCPP produced three to five times more electricity than down draught tower of the same size. [35]. The turbine pressure drop is a critical aspect for maximizing the electric power output for a particular situation. Haaf was the first to note a pressure drop ratio in turbines of 2/3 [36].Backstrom and Fluri in 2006 revealed larger values of this factor in later investigations [37]. Bernandes looked at the impact of using tubes of filled water on the collector ground to act as a heat storage in 2004. As a result, the quantity of heat needed to produce warm air to power the turbine is lowered, increasing output power at night [38].

Backstrom et al. proposed a design of SCPP with top-installed turbines [40]. Bonnelle compared between the static pressure of air flow at the chimney base and summit. It was claimed that mounting the turbine at the top and base of the SCPP, respectively, relative positive pressure and negative pressure appeared in the SCPP. Later they made another study outlines in detail the experimental program that was run to see whether the SCPP idea was viable. The theoretical and experimental performance of a demonstration model was assessed after it was conceived and constructed. Two experimental changes were made to the collector: the collection base was lengthened, and an intermediate absorber was added. The first change raised the air's temperature, while the second raised the mass flow rate and air temperature inside the chimney. The combined chimney power output increased thanks to these improvements. Part I developed in the mathematical model used to predict the performance of much larger systems, and the results of this study's theoretical and experimental performance testing are provided for this demonstration model [41]. By comparing the outcomes of the mathematical models to data on the SCPP system that was put in place at Manzanares, Spain, the models' conclusions were confirmed. The system costs are also evaluated economically and presented by Pasumarthi and Sherif in 1998. [42]

In 2006, Denantes and Bilgen evaluated the effects of two counter-rotating turbines, one with an inlet guiding vane and the other without, on three distinct SCPP scales. They discovered that the model without guide vanes performed worse off-design and had lower design efficiency [43].In 2007 Pretorius studied the case of a large-scale SCPP to improve the powerplant operation at night. He made a double roof collector but found that it reduced the power plant performance [44]. Kirstein and von Backstrom run a CFD simulation of the flow through the SCPP's HTVTS using the CFX application. Because the Reynolds number scaling effect was not taken into consideration in earlier iterations, the values of this simulation were lower [45]. Moreover, in 2007 Fluri and Backstorm studied the performance of alternative turbo-generator using analytical models. There were four different layouts tested: a single rotor turbine without and with guide vanes and a counter rotating turbine without and with guide vanes. It was discovered that even small adjustments to the SCPP turbines' modelling had a huge factor on the performance prediction. [46].

Also, in 2007 Tingzhen et al. made analytical simulations on SCPP system with a 5-blade turbine and 3-blade turbine. The results showed a power output of 10 MW from the five-blade turbine system and turbine efficiency of 50% [47].

Additionally, a break-through was achieved in 2008, when Xinping Zhou et al. linked between the maximum power generated by the plant and the optimum chimney height based on an analysis and validation with the dimensions and measurements of the Manzanares first model using a theoretical model. This model concludes that there is a maximum height for the chimney, that when the height exceeds this number, negative buoyancy will occur. This proves that the plant will have the maximum energy conversion efficiency at this specific height [48].

In order to investigate a plume in an atmospheric cross flow from a SCPP that generates power, Xinping Zhou et al. developed a numerical simulation model in three dimensions. By comparing the data generated by their simulation model with the results of the numerical simulation for one-dimensional buoyancy-driven compressible flow in a hypothetical 1500 m high SCPP, the simulation model is proven to be accurate. The flow's parametric performances at the geometry's symmetry plane, cross planes with height 2700 m, 750 m are simulated in that article. The relative humidity field, static pressure temperature, density, and streamline are some examples of these parametric performances. It has been found that the relative humidity of a plume increases dramatically when it is jetted into a cooler environment. Additionally, it has been found that precipitation likelihood and potential precipitation areas increase as air relative humidity rises with increasing chimney height, lowering wind speed, or both. The latent heat produced by the condensation of supersaturated vapor may further aid the plume's ascent [49].

Two designs for SCPP output power control were presented by Pretorius and Kröger. In numerical simulations, turbine flow drop, and volume flow were taken into consideration as the movable parameters. They utilized climatological input data from Sishen, South Africa (Latitude S26.67°), which Pretorius and Kröger reported in 2007, as well as heat transfer coefficients that demonstrated total-to-static efficiency and total-to-total efficiency of 75–80% and 85–90%, respectively [50].

In 2011, a study for the performance of the SCPP showed graphs and relations between the dimensions and power output and efficiency relating to climate condition in Egypt. The study compared between numerical and experimental performance. Without taking into account the financial limitations, it was determined that there was no ideal physical size for such plants. The performance of the chimney was significantly impacted by the chimney height. If the SCPP were constructed on a big scale, it would appear to be essentially a power generator in Egypt in terms of annual performance. [51].

In order to evaluate the functioning of a SCPP, a complete theoretical model was integrated and published in 2012. This model was validated by the experimental results of the Spanish Manzanaris first model. The impacts of flow and heat losses, as well as the rates of temperature lapse inside and outside the chimney, are all taken into account by this model. Due to flow and heat losses, as well as the placement of the turbines, a specific SCPP has a maximum power production under a specific solar radiation situation. Additionally, it has been found that power output benefits from the turbine's design flow rate in the SCPP system being lower than that at the highest power point. Furthermore, the maximum collector radius is constrained by the greatest power that the SCPP can produce, while chimney height is not constrained by modern building technology [52].

In 2013 Fei Cao et al. mimic an SCPP performance using the TRNSYS program. As shown in Figure 3, it is discovered that the SCPP power output is more dependent on the local sun irradiation than on the surrounding temperature. As seen in Figure 4, the SCPP with a higher generation capacity has better cost-benefit characteristics [53].

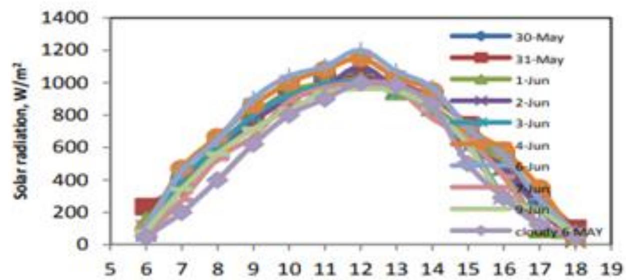

Figure 3 Hourly variation of solar radiation [53]

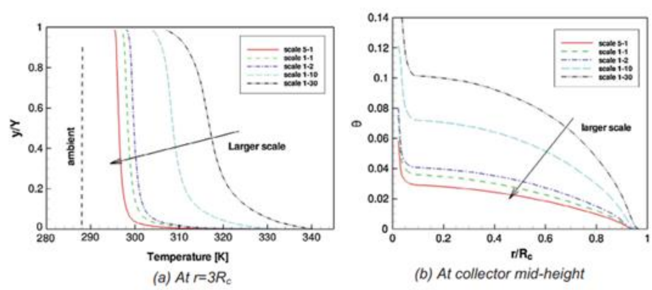

Figure 4 Temperature distributions in collector [53]

A sloped-collector SCPP fluid movement, heat transfer, and pressure were all described mathematically in a model created by Xinping Zhou et al. in 2013. Using the mathematical model, the performance of sloping collector is comprehensively compared to traditional horizontal collector SCPP. When employing the driving force expressions with no integral, as suggested in the literature, the power outputs for Sloped collector and horizontal collector are compared to those using the essential expression. Results demonstrate that the horizontal collector expression based on a compressible fluid model is precise [54] [55].

A. Dhahri presented an analytical study on the performance of a SCPP in 2014 using a cylindrical coordinate system and 3D steady state Navier-Stokes and energy equations. The k-ε turbulence model was used to simulate the fluid flow inside the chimney on the assumption that it was turbulent. On the basis of the characteristics of the Spanish prototype, numerical simulations were run. The author discovered that an optimal cover height of about 1.6 m [56].

In 2015, Vieira et al. gave a numerical analysis of the fundamental physical concept of a SCPP and demonstrated how certain geometric parameters affected the SCPP's available power. The primary goals were to determine whether the investigated numerical model could be used in future research on SCPP geometric optimization and to determine how the collector inlet height and chimney output diameter affected the device's available power, as shown in Figure 5 [57].

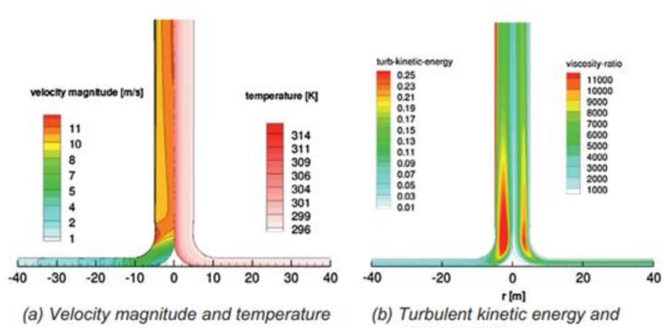

Figure 5 Fluent calculations for reference (Manzanares) scale [57]

A SCPP model was numerically simulated in 2017 by Hooi and Thangavelu using the ANSYS Fluent software. The pertinent equations were solved using the discrete ordinates (DO) radiation model and the standard k-ε turbulence model. Based on the findings of temperature distributions (see Figures 6 and 7), velocity, and static pressure distributions. A parametric study was conducted to assess the performance of an SCPP. This study concentrated on the air velocity at the chimney base, temperature rise in the collector, and pressure drop inside the chimney. By comparing a model with the experimental data of the Spanish first model Manzanares, the results showed dependability. Theoretically, efficiency and power capacity were examined based on the numerical data. Results showed that a larger prototype and more powerful solar radiation will enhance SCPP performance [59].

Hardi and Atrooshi employed a CFD model in 2019 to simulate the relationships between heat and transport in the chimney and collector area. In order to ensure consistency, the geometry, mesh design, and current analytical models were compared to the experimental results from the Spanish Manzanares facility. The procedure compared the output to the pressure, velocity, and temperature optimum profiles. Graphs and tables of matching dimensions were created based on the analysis of 180 cases in 15 groups for collector size versus chimney height and diameter and additional 180 examples in 15 groups for collector height. Because of this work, it is now possible to decide on consistent dimensions for a SCPP plant with more accuracy [60] [61].

The Mendez and Bicer research study examined the viability of developing a combined system for producing freshwater and power in 2020. The major tenet of this study was SCPP technology. In order to examine how much electricity is generated and how much heat is transferred to the SCPP's storage system, a preliminary analysis based on literature is conducted. A seawater thermal desalination is also added with the intention of boosting the SCPP's overall effectiveness. A hydro-storage system with a water turbine is also integrated to continuously meet the need for electricity and freshwater. Implementing an integrated system with a SCPP as its primary source of energy results in an overall energy efficiency of 8.4%, which is significantly greater than the efficiency of a single SCPP. [62] [63].

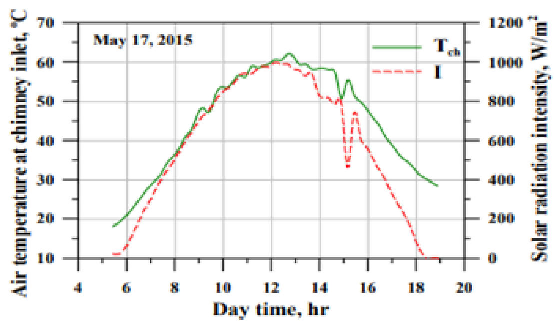

Figure 6 Air temperature at chimney inlet [59]

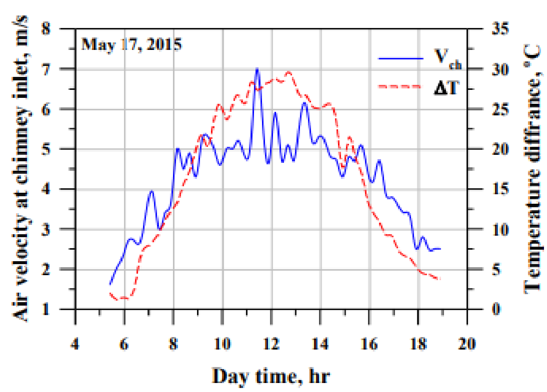

Figure 7 Chimney inlet air velocity and temperature air difference between chimney inlet and ambient. [59]

In 2021 Raj et al. published an article that includes three-dimensional turbulent investigation on The Manzanares (Spain) plant to examine the impacts of collector inclination angle. For the analysis, several (30-0°) ranges with more than 15 models were taken into consideration. Based on the projected values for variables such as air velocity, pressure drop, absorber and air temperatures, an optimum value for power generated, collector efficiency, and overall efficiency, has been provided. At the chimney base, compared to the horizontal collector plant, there was an increase in theoretical power of 9.16% and an increase in air velocity of 10.68% at a collector inclination angle of 6°. Any additional rise in more than 7° collector inclination angle caused air particles to circulate inside the collector canopy, obstructing flow [64].

4. Conclusion

Over 60 studies on SCPP systems conducted over the past 33 years are reviewed in this literature review. Most research findings are summarized to provide a broad overview of each system. The findings revealed that just a small percentage of all the investigations were conducted experimentally. The findings indicated that the height of the chimney, collector radius, and turbine geometry are the main factors that influence output power. Additionally, it has been observed that the majority of experiments are based on tiny scales, which are not cost effective advantageous and require the construction of a big-scale system.

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