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Use of Solar Chimney in Renewable Energy Applications–A Review

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Abstract
Nowadays, the arising problems of fossil petroleum oils have been widely raised. As a type of traditional energy resource solution, the scientists have recently looked for a new concept in order to face the problems involved in the traditional power sources. In this investigation, the solution depends up on the approaches to produce power from a clean and new source of renewable energy. Furthermore, the solution for the crude and traditional power source problems should focus on using the solar energy to generate electricity, either directly or indirectly. One of the most appropriate solutions for this problem is the solar chimney, which is one of the promising concepts in the renewable energy technology. Solar chimney is one of the solar energy methods that can be considered as the best option for electricity generation. In this review article, solar chimney is reviewed in order to find out the remarkable advances in understanding the solar chimney power plant (SCPP) performance investigation through extensive studies with different focuses on several aspects of the SCPP technology. In the present review article, solar chimneys are studied based on the historical viewpoint, design enhancements, basic working principles, components and effective electricity production factors, and advantages and disadvantages.

Keywords: *Solar chimney power plant, Renewable energy, Unconventional designs, Operating parameters.*

1. Introduction

Ingestion of energy is widely increasing every day due to the population growth around the world wide. The current energy resources like petroleum products may not stand for long in order to encounter the people's needs. The fast utilization of restricted fossil fuels and other conventional energy sources is the bigest reason for the lack of fuel in the world. Following this criterion of research has formed awareness about the alternative sources, and therefore, more research works are required for non-conventional energy sources. This mainly depends on the renewable energy sources in the forms of wind, solar, and tidal energy sources. The renewable energy sources are repeatedly reloaded by the nature as water, sun, heat of the Earth, and wind.

Nowadays, people use fossil fuels for heat and power for our homes, factories, and cars. It can be suitable to use coal, natural gas, and oil in order to meet our needs but we have a limited amount of fossil fuels. Finally, they will run out. Even if we have infinite sources of fossil fuels, using renewable energy is still better for the environment. We often call the renewable energy "green" or "clean" since they produce few pollutants. Burning fossil fuels produces greenhouse gases, trapping the heat, and participating in global warming. The scientists agree that the Earth's average temperature has increased in the past century [1]. If this movement continues, the sea levels will increase droughts, big floods, heat waves, and other extreme weather conditions. Other pollutants are out in the soil and water. Air pollution causes many diseases like asthma. Acid rain harms the plants and fish [2]. In the following section, we will present, in brief, some types of the renewable energy sources:

1.1 Hydropower

Hydropower is one of the major sources for renewable energy [3]. The hydropower plants convert the energy of flowing water into electricity. The most public hydropower system uses a dam on a river in order to hold a large amount of water; water flows through turbines to produce power. It is clear from the explanation that the hydropower plants do not produce air emissions but may affect the quality of water and wildlife habitats as it depends only upon the power generated from moving turbines by water flos (Figure 1).

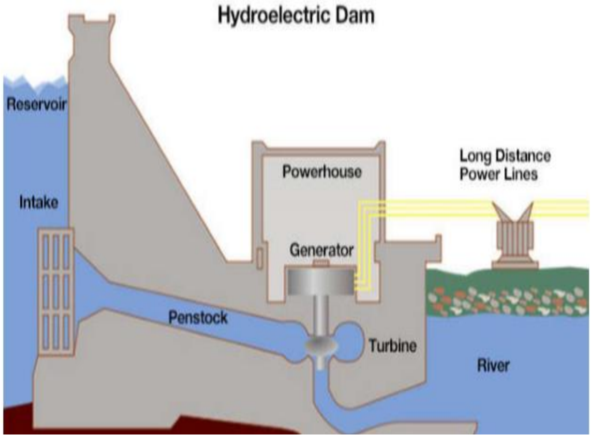


Figure 1. Concept of hydroelectric dam [4].

1.2. Bioenergy

This type of energy is the energy that results from biomass (a basic organic material) like plants. All the biomass resources do not directly come from trees or other plants. Several industries like those in the building or agricultural products can produce large amounts of unused or remaining biomass, which can help as a bioenergy source.

1.3. Biofuels

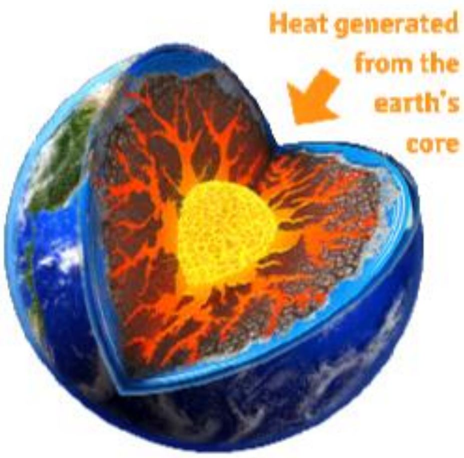
Furthermore, biomass can directly be converted into liquid fuels, named as biofuels. As biofuels are easy for conveyance and have a high energy density, they are preferred over fuel vehicles and stationary power generation. The most public biofuel is ethanol; its alcohol is manufactured by the fermentation of a high carbohydrate biomass. The present major source of ethanol is corn and its agricultural type of wastes.

1.4. Geothermal energy

In the core of the Earth, 4,000 miles under the surface [5], the temperature reaches 9000 °F, as presented in Figure 2a. This heat flows upward from the core, heating the nearby area, which can form an underground reservoir of steam and hot water. It may have a variety of uses such as generating electricity or heating buildings using the geothermal heat pumps (Figure 2b).

1.5. Wind energy

Wind is a very powerful type of green power present all over the world. The wind turbine technology is simply the wind thrusting the turbine blade to spin around a central hub; the hub is attached to a shaft connected to a generator to produce electricity. The turbines capture the wind energy using new blade designs (Figure 3).



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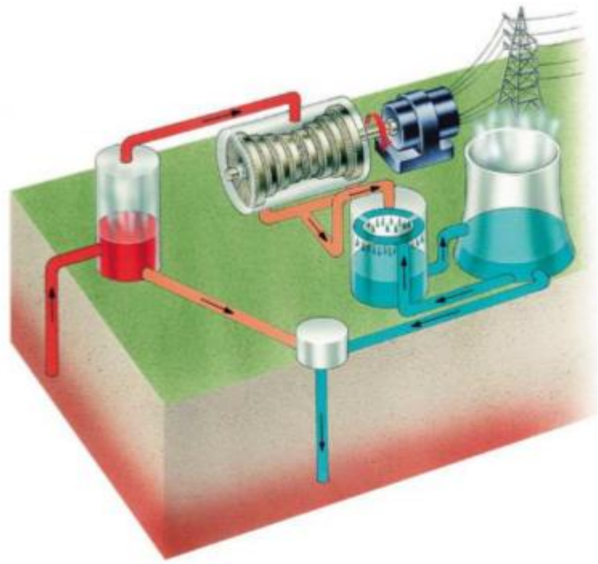


(B)

Figure 2. (A) Core of the earth [4]. (B) A geothermal power electrical station [4].

Figure 3. Wind turbines [4].

1.6. Ocean power energy (Tidal power)

Another source of renewable energy is the tidal or ocean energy. Oceans can produce two forms of energy: thermal energy from the sun and mechanical energy from the waves and tides [6]. The electricity systems use the warm or boiling water to run a turbine, which turns a generator. For the mechanical systems, a dam is used to convert the tidal energy into the electrical energy by flowing the water through turbines (Figure 4), rotating a generator. The wave energy uses the mechanical power in order to activate a generator directly. This movement can produce a high source of energy for electricity generation.

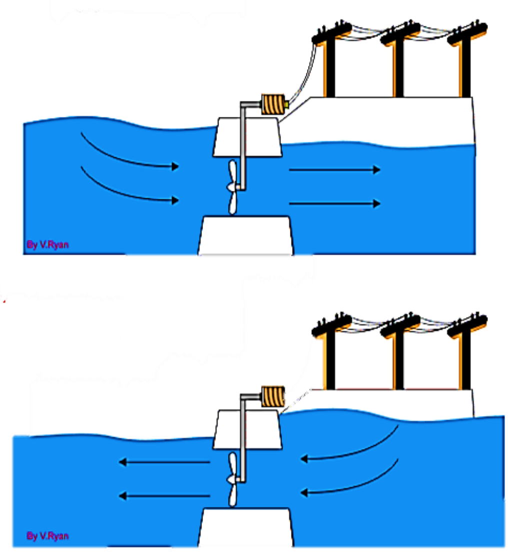


Figure 4. Tidal energy technology [4].

1.7. Solar energy

The solar energy technologies tap into the infinite power of the sun besides application of its energy in order to produce light, heat, and power, although several types of solar electric systems are existing today.

Mohammad Hossein Ahmadi, Mahyar Qazvini, Milad Sadeghzadeh, and others have presented a study on the solar energy technologies in order to find out the best option for electricity generation; some of these technologies are soar trough collectors, linear Fresnel collectors, central tower systems, and solar parabolic dishes [7].

One of these systems is the solar chimney power plant (SCPP); the SCPP technology is also known as the solar updraft tower (SUT). Solar chimney consists of three basic parts: collector, turbine, and chimney. It is equipped with solar collectors and a thermal storage system of little cost. Thus it can be used to produce electricity for 24 h/day [8] (see Figure 5).

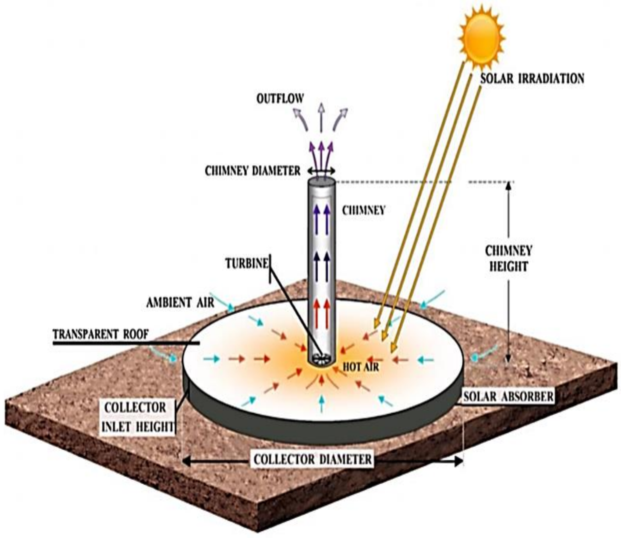


Figure 5. A 3D solar chimney power plant SCPP scheme [9].

Why do we use solar chimney power plants?

This section tilts the advantages of producing power using SCPP, and also the disadvantages compared to the other energy sources.

Advantages:

- SCPP usees diffuse and beam radiation [10].
- The plant can produce power even at nigh due to the absorber effect [11].
- The construction materials for such a plant are inexpensive and available.
- The plant runs with a simple technology.
- The plant does not require any non-renewable fuel for operation, and produces no emissions. Therefore, the plant would not have to deal with the rising fuel costs.
- At appropriate plant sites such as desert zones, the solar radiation is a reliable input energy source. Thus the energy produced by solar chimney will not produce power spikes, which can happen with systems like wind energy generation [12].
- The plant has a long working life (at least 80-100 years) [13].
- SCPP does not require any cooling water.
- Low maintenance cost.

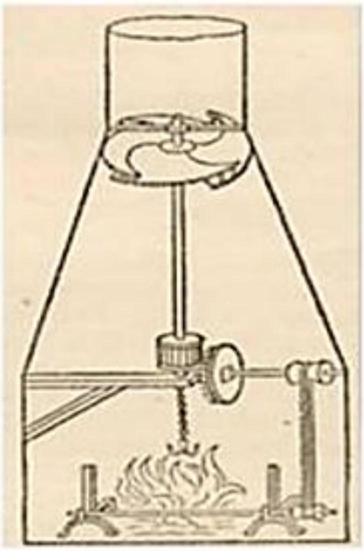
Disadvantage:

- To be economically practical, SCPP has to be constructed on a large scale. Due to its size, the initial capital cost is high.
- The power output is not constant during the day or year. The output during the peak demand times is low, while the power production is high in times of low demand.

Building of the plant requires huge amounts of materials. Such amounts may cause logistical problems.

2. SCPP historical review

Leonardo Da Vinci completed sketches of a solar tower named “a smoke jack” (Figure 6A). The idea for using a chimney in order to generate electricity was first offered by the Spanish engineer Isodoro Cabanyes in 1903 [14] (Figure 6B).



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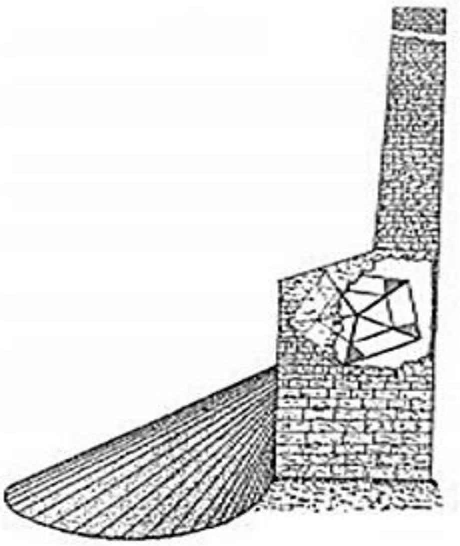

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Fig. 6. (a) Spit of Leonardo da Vinci [9]. (b) Solar engine project proposed by Isodoro Cabanyes [9].

The first modern quoting for a solar chimney concept appeared by Günther (1931). In his extensive studies, the plant would consist of a glass collector nearby the ground of a mountain and a big duct running up the hillside to a turbine. Heated air from below the collector would flow through the duct up to the turbo-generator.

In 1926, Prof. Engineer Bernard Dubos offered to the French Academy of Sciences the assembly of a solar aero-electric power plant in North Africa with its solar chimney on the slope of a high mountain (see Figure 7).

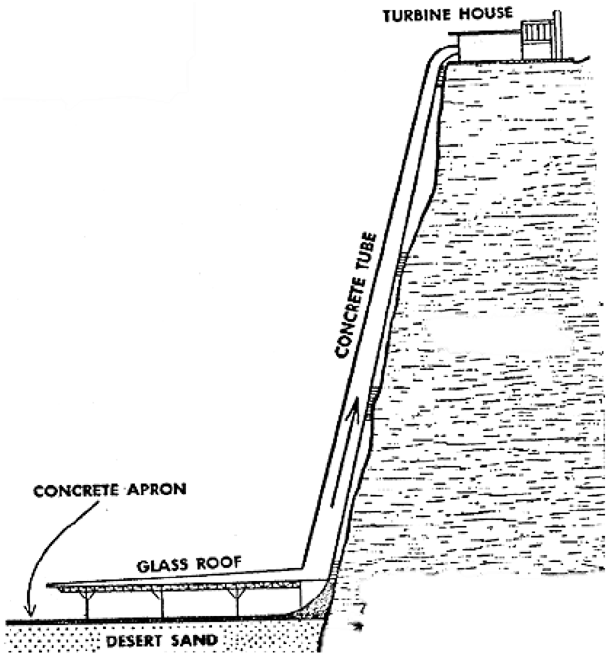


Fig. 7. Principle of Prof. Dubos’s power plant [15].

In 1956, Dubos filed his first design in Algeria. It would produce the original atmospheric vortex in a kind of round-shaped nozzle, and recover some energy over the turbines. Nazare received a scheme for this invention in 1964. In 1975, Lucier filed a clear request based on a more complete design [14]. After building the experimental SCPP in Manzanares, Haaf *et al*. (1983) discussed the principles of the construction, operation, and power generation of SCPP [14]. Haaf also made an indication of a similar concept used by Leonardo da Vinci, besides an earlier study by Simon (1976). Next to his research works in 1983, Haaf (1984) first tested the results of the Manzanares prototype plant with the experimental results, which matched well with the model one.

Mullett (1987) presented a study on the overall efficiency of SCPP [14]. He realized that the plant had a low overall efficiency; building a large-scale scheme was the only economically possible option. Padki and Sherif (1988) carried out a research work on the chimney in specific [14], and studied the effects of several geometrical configurations on the performance and efficiency of the chimney.

Schlaich (1994) approved using SCPPs for electricity generation. He also mentioned the details of the construction, materials, operation, and experimental data of the solar chimney in Manzanares (Figure 8). In addition to the book, water-filled black tubes were recognized as a possible way to improve the plant’s natural energy storage ability. Pasumarthi and Sherif (1998a) published an estimated mathematical model for a solar chimney, followed by an article (Pasumarthi and Sherif, 1998b), which validated the model alongside the experimental results from a small-scale model.

Kröger and Blaine (1999) studied the driving potential of SCPP. Several theoretical models were evaluated, and the effects of the usual ambient conditions were estimated. The study also says that a higher humidity increases the driving potential, and condensation may occur in the chimney under specific conditions. Kröger and Buys also mentioned developing radial flow among two parallel discs. They improved the analytical relations that could calculate the heat transfer coefficient and the pressure difference caused by the frictional effects. In a research work on the tension structures, Schlaich (1999) mentioned the construction methods, performance, and cost of a variety of solar energy generation systems containing SCPP.

Hedderwick (2001) derived the relevant conservation equations, counting a draught equation that estimated the heat transfer in addition to flow in SCPP. The equations were united with a numerical model that calculated the large-scale SCPP performance.

Von Backström and Gannon (2000b) followed another method regarding SCPP as an air thermodynamic cycle. Certain parameter relations were also developed in their study. An additional publication by Von Backström and Gannon (2000a) studies the compressible air-flow through large-scale SCPP. The study calculated all losses related to the chimney and the pressure drop contributions to the total pressure drop through the chimney. The related equations for SCPP were developed by Kröger and Buys (2001). A numerical model was established with the simulation results.

Gannon and Von Backström (2002) developed a collector model that was combined with a numerical model. The numerical model was used in order to simulate a small plant, and the results obtained were compared with the actual measures. The study also mentioned the power limitation by changing the turbine pressure drop.

Extensive studies were presented in 2003 with an analytical and numerical model developed by Bernardes *et al*., where a comparison was made between the simulated results and the experimental measurements from the plant at Manzanares. The simulation results predicted the performance characteristics of the large-scale plants [16].

In 2004, Pastohr *et al*. carried out a flow field analysis using a numerical CFD, and compared the results obtained with another numerical model. In the same year, Pretorius *et al*. presented a paper that evaluated the yearly power output of a large-scale SCPP. A numerical simulation solved the relevant equations using the specified inputs from a suitable plant in South Africa. He also presented the effects of chimney shadow and usual winds on the power output of the same SCPP reference. It was shown that the chimney shadow should have a negligible influence on the power generation, while the prevailing winds caused an important drop in the annual power output [16].

Ahmed Ayad (2016) presented a numerical and experimental study on the collector roof inclination angle effect on the performance of a SCPP. Aakash Hassan, Majid Ali, and Adeel Waqas presented a numerical study on the performance of SCPP by varying the chimney diverging angle and the collector slope [16]. In 2017, Kamel Milani and others presented a compassion analysis and a numerical simulation in order to optimize the effective parameters on the solar chimney to get the maximum power output potential. Also Ramakrishna studied the performance parameter valuation, materials choice, radiation, energy losses, energy storage, and turbine design process for a pilot scale solar tower. Xinping Zhou studied the effect of wind on a SCPP.

Mohammad Hossein Ahmadi, Omid Mohammadi, Milad Sadeghzadeh, and others presented a study on the exergy and economic analysis in order to find out the best location for construction of a solar chimney in different climates of Iran [17].

3. SCPP working principle

The solar chimney changes the solar radiation to electricity using three famous concepts: greenhouse effect, rising of hot air, and wind turbines [18]. Hot air is produced by the sun radiation under a huge glass collector. The direct and diffuse radiations are used. The amounts of these divisions depend on the incidence angle and characteristics of the glass. Then the transmitted radiation strikes the ground. A part of the energy is absorbed and the other part is reflected back to the roof, where it is again reflected to the ground. The numerous reflections of radiation continue, causing a higher portion of energy absorbed by the ground. With a natural convection mechanism, the warm ground heats the air forcing it to rise up into the chimney of the plant, and the ground becomes warmer due to the energy absorbed, while the radiation exchange also occurs between the warm ground and the cooler collector. While the air flows from the collector boundary to the chimney, its temperature rises, while the velocity stays constant due to the rise in the collector height. The hot air voyages upward the chimney, and it is cooled by the chimney walls. The pressure variation between the base and the outlet of the chimney can be obtained from the density variation. The pressure difference that drives the turbine can be reduced due to the friction loss in the chimney. While the collector air flows through the turbine, the kinetic energy of the air turns the blades of the turbine that drives the generator.

4. Solar chimney components

4.1 Collector

One of the main components of a SCPP is the collector, which is the part that produces the hot air using the greenhouse effect. It is made up of a plastic or glass film. Due to the height of the collector adjacent to the chimney base, the air enters the chimney with a minimum frictional loss. This material lets the short-wave solar radiation component and keeps the long-wave component from the heated ground [11]. Thus the ground below the collector heats the airflow radially from the outside to the chimney. The construction of the collector changes with the type of material used.

4.2. Chimney

A chimney is the main part of SCPP. A tower is located at the centre of the collector and considered as the thermal engine for the plant [19]. The tower makes a temperature difference between the top and the bottom that makes the chimney effect, which moves air from the bottom of the chimney out from the top. It is also an advantage to set the turbine in the chimney as low as we can in order to make its construction easier.
There are many different constructing methods for such a tower:

- Free-standing reinforced concrete tubes;
- Steel tubes supported by wires or cables;
- Such towers can also be constructed using additional technologies like guyed steel that is surrounded by nets of steel cables, membranes or trapezoidal metal films [20].

4.3 Turbines

The solar chimney power plant turbine is a very important part of the plant because it extracts the energy from the air and transmits it to the generator. It has an important impact on the plant because the turbine pressure drop is coupled with the plant mass flow rate. In solar chimneys, the turbines are ducted, and their maximum theoretical efficiency is consequently 100% [21]. The track of the airflow remains constant. The turbines are kept from harsh weather but have to handle higher temperatures. The large volumes of both the collector and the chimney prevent large fluctuations in the air flow speed.

5. Model projects for SCCP

In the following section of our review article, we will introduce some examples of the model projects already performed using the concept of SCCP.

5.1. Manzanares prototype

The prototype was designed, built, and operated by Schlaich Bargeman with a peak of 50 kW in Manzanares (150 km south of Madrid) in 1981 with funds from the German Ministry of Research and Technology. Creation of the plant was finished in 1981 [22], and after a period of enhancements, continuous production started in 1983 to 1989 (Figure 8).

Figure 8. Manzanares prototype [9].

The Manzanares plant achieved an electrical efficiency of 0.53% but Schlaich believes that it can be increased to 1.3%. In a large scale, the capacity factor measured at the Manzanares plant was 10% but it could increase to 29% in a 200 MW unit. In the mentioned power plant, the power output depends on the global irradiation and also on the environmental and meteorological conditions. The project was carried out for about eight years until the support wires of the chimney rusted out and it was blown over in a storm. However, it was proved that the concept was scientifically accurate. In order to get amounts of power out of such a system, building a taller chimney is required. The taller the chimney, the more power you can generate.

5.2. Enviro-mission power plant

Another solar chimney power plant introduced was the enviro-mission project, which announced in 2001 that it intended to build a 200 megawatts of SC in SW Australia. The proposed power plant could generate power 4000 times more than the Manzanares system [16]. In order to get this kind of power, a chimney with 130 m in diameter and 1000 m in height should be built. Also in order to produce sufficient warm air to flow through that chimney, we require a glass or plastic solar collection area of up to 35 square kilometers. The project cost is expected to be approximately $1 billion (Figure 9).

Figure 9. Enviro-mission plant [15].

A 1 km tower can be built from reinforced concrete, and reinforced by the horizontal metal supports. The air temperature under the collector will be about 30 °C, and the air speed will be around 32 km/h. There will be 32 turbines setting horizontally in the chimney cross-section area. The turbines will be made from light-weight alloy materials with 10 blades. The turbines will take air at about 60-70 °C.

5.3. Chinese solar chimney power plant prototype

Another plant was presented in the Jinsha bay Wuhai region (China). The plant was constructed for an experimental prototype of 200 kW SCPP [23]. The total planned capacity of this project is 27.5 MW with a total of 2.78 million m^2 collector and a total investment of 1.38 billion Yuan.

5.4. Botswana test facility

Working on the policies for long-term energy strategies, Botswana designed and constructed a small-scale solar chimney scheme for research works. This experiment was operated from 7th of October until 22nd of November 2005. The chimney had a 22 m height and a 2 m inside diameter; it was made of glass-reinforced polyester with a collector about 160 m^2. The roof was made of a 5 mm thick glass that was reinforced by a steel framework [24].

6. Unconventional solar chimneys

6.1. Sloped solar chimney

An example of a non-conventional solar chimney design is a sloped solar chimney offered by Bilgen *et al*. The basic concept was to build a chimney with a collector in a sloppy unit. Later, Panse *et al*. explored this idea, and considered that the inclined face of the mountain acted as the chimney in addition to the radiation collector. In another study, Zhou *et al*. recommended that a hole could be dug at the centre of a high mountain, considered as the chimney. The collector area was constructed around a mountain in order to produce more power [25].

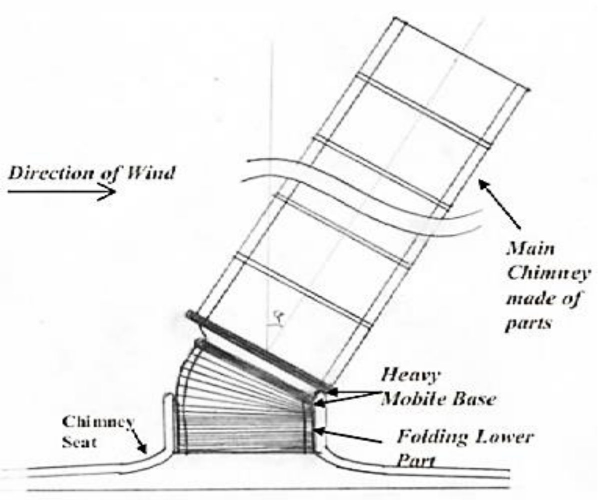
6.2. Floating solar chimney (FSC)

The floating chimney technology was offered by Papageorgiou. A floating solar chimney consists of three parts: a large transparent roof collector supporting a little distance above the ground (the greenhouse); a tall cylinder lighter than air in the center of the collector (the floating chimney) (see Figure 10a; and a set of air turbines connected to an electric generator placed inside the FSC (the turbo-generators).

The chimney in this scheme is made of a flexible material that can float on air with the aid of a lighter gas like helium. The chimney has a weighty base, and the walls are filled with helium. The support rings let air enter and pass through them easily (Figure 10b) so that the chimney does not yield under the wind pressure [26].

6.3. Geothermal solar chimney

In order to increase the efficiency of SCPP, some ways were suggested, for example, a hybrid geothermal SCPP. This approach allows the thermal adaptation by operating with the solar and geothermal energy [27]. This scheme allows the electrical energy generation even when there is no sunlight during a cloudy weather, and at night (Figure 11).



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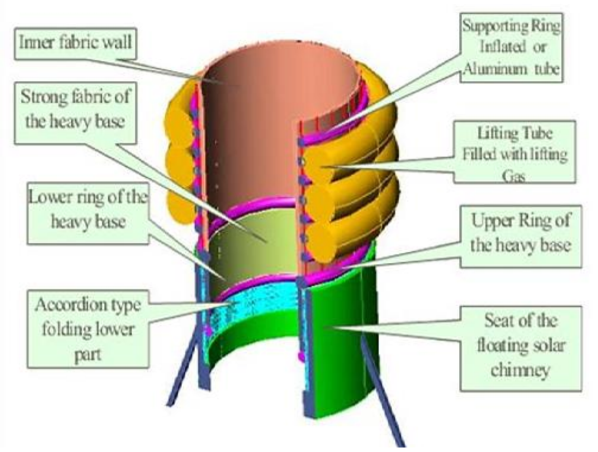

(B)

Figure 10. (A) Floating solar chimney scheme [9]. (B) Indicative presentation of FSC [9].

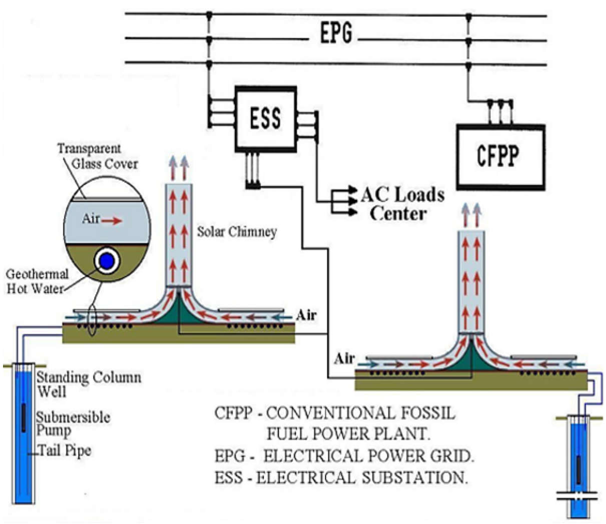

Figure 11. Hybrid geothermal solar chimney [15].

6.4. Hybrid cooling tower solar chimney

Futher studies were carried out by Zandian *et al*., who introduced a new concept to produce more energy by taking the rejected heat out from the condenser added to the solar energy gained from the collector [28].

In this research work, the working principle of the system is that the ambient air goes into the system and passes over the radiators in order to cool the condenser water during its path. Then the heated air passes below the transparent roof to gain more heat. The air flows to the system center, where some guide vanes guide it to the wind turbine. The air rotates the turbine and generates the electrical power.

6.5. Chimney solar pond combination

Extensive studies were performed in 2012. At Campus, a small prototype merging a chimney with the solar pond was built. The chimney was 0.35 m in diameter and 8 m in height, and the tower was built from flexible circular ducting, which was used in the local heating systems [29].

Later, Akbarzadeh *et al*. studied the idea of merging a solar pond and a chimney together in order to generate power in salty areas. The scientists offered two designs of a solar pond-chimney combination. In the first one, a non-direct contact heat exchanger was used, while in the second design a direct one was used. Heat was removed from the solar pond by extracting hot brine and pumping it through the tower heat exchanger. Then the water was returned to the solar pond bottom. Consequently, the ambient air was heated and the wanted draft was created (Figure 12).

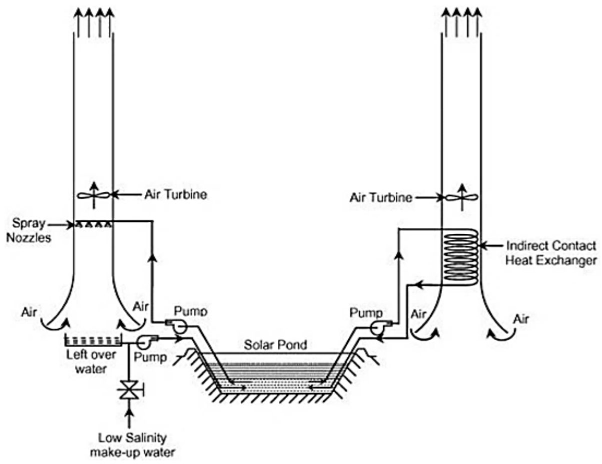

Fig. 12. Concepts for combining a chimney with a solar pond to generate power [15].

7. Effective factors of solar chimney power plant operation

We all know the simplicity of the solar updraft concept. However, there are many parameters affecting the solar chimney operation. These parameters can be divided into two main sectors, as follow:

7.1 Design parameters

7.1.1 Parameters related to collector

Collector roof glass quality: The glass quality can be determined according to some features such as the radiative properties, strength, stiffness, and surface finish. However, in terms of the SCPP performance, the optical quality has the greatest importance. The absorptivity and transmittance of the glass depend on the angle of the incident radiation, thickness of the glass, and refractive index of the glass. The refractive index remains almost constant for different types of glasses, while the glass thickness is unlikely to be changed due to the strength and cost considerations. Furthermore, for a semi-transparent medium like glass, a better quality means a better transparency and permitting more solar radiation transmittance [30].

Collector roof thickness: The collector thickness has a slight decrease in power [31], and this can be attributed to the fact that radiation is transmitted a little less efficiently through the thicker layer. Therefore, we have to choose the cheaper choice, especially in the huge area collectors (for large-scale plants) but can withstand the climatic forces like wind and even hail that prevail on site.

Collector roof reflectance: The reflectance of a surface is distinct with the ratio of the energy sent back from the surface to the total energy striking it. There are treatment processes that decrease the surface reflectance as a result of increasing the surface transmittance. The increased transmittance permits extra energy to pass through the roof and heats the ground[31].

Formerly, more power is transferred to the air below the collector, giving a larger power output through the day. Another advantage is that more energy is stored in the ground throughout the daytime. Therefore, more energy is released through the night time.

Collector roof emissivity: Emissivity is distinct with the ratio of radiation emitted by a surface to the radiation emitted by a black body.

Glass may be treated with the purpose of reducing its emittance. Consequently, this will reduce the collector radiation losses to the atmosphere. However, this treatment of the glass does not affect its transmittance anyway.

Collector roof shape: The relation that defines the collector roof height at a specific collector radius is as follows:

$$\mathbf{H = H_2 (r_2 / r_1)^b}$$

where H_2 is the height of the collector roof inlet, r_2 is the collector radius, and b is the roof shape parameter [32]. B varies from 0 to 1, which gives different shapes to the collector roof.

Collector inlet height: Increasing the collector height causes the pressure to increase [28], and owing to the ideal gas law, the temperature and output power together decrease. The efficiency curves for different heat fluxes have similar performances and decrease with increase in the collector height.

Collector radius: Flow power would be greater at more $R_{coll.}$. The main reason of the growth in the output power is the reduction in pressure caused by growth in the collector radius, which causes the temperature and air mass flow rate to increase. However, by increasing the collector radius, the area of heat transfer is increased and with regard to the constant heat flux, the efficiency is decreased.

7.1.2. Parameters related to ground

Various ground types: There are many properties related to the ground material affecting the solar chimney performance. Some of these properties are density, specific heat capacity, thermal conductivity, and heat penetration coefficient. These properties define the amount of heat that the ground can absorb and remit to the airflow above, and the amount of heat that the ground can keep to a specific time (at night) to use during the time that there is no solar radiation.

There are many materials that can be used as the absorber like granite, limestone, sandstone, sand, wet soil, and water [33].

Ground surface roughness: The effect of ground roughness on the solar chimney power output is negligible [33]. A plant with a smooth ground surface only produces a bit more power each year than a plant with a rough ground surface. This small effect in output can be attributed to the fact that the collector air in the smooth ground has less frictional losses than exists in the rough one.

Ground absorptivity: Absorptivity of a body is distinct with the capability of the absorbed radiation or the ratio of the radiation absorbed by a body to the amount reflected by the body.

The ground absorptivity value has a main effect on the daily SCPP performance. It is obvious that a higher ground absorptivity causes a larger peak power output [34]. With a larger absorptivity, more energy is absorbed by the ground and can be moved to the collector air, and also more energy is stored in the ground and out at night.

Ground emissivity: It is obvious that a lower ground emissivity value allows the plant to generate more power throughout the day. The increase in the output power is due to the reduced radiation losses from the ground to the environment through the collector roof. With a low ground emissivity, the ground surface radiates less energy to the roof, and the roof radiates less energy to the environment [34]. With more energy existing at the ground, more energy is transferred by convection to the air below collector, giving a more draught, and finally, more power output.

A lower ground emissivity produces a higher collector air temperature and a lower collector roof temperature. Consequently, the convection losses from the air below the collector to the roof will be greater. Nonetheless, even with these more convection losses, the total result of a lower ground emissivity increases the power output due to the reduced radiation losses.

7.1.3 Parameters related to chimney

Chimney divergent angle: The chimney divergent angle has a considerable effect on the electricity production. As its direct effect on the pressure gradient, velocity, and volume flow rate inside the chimney, it has been found that a bit divergent angle has a great enhancement on the above factors, and finally, on the energy production [35].

Chimney radius: The output power is increased when the chimney radius is increased [21]. The explanation for this matter could be the larger mass flow inlet due to the less chimney pressure.

Chimney height: A higher chimney leads to a lower air pressure, and a higher velocity and mass flow rate. An increase in the flow rate causes an increase in the output power [21].

Turbine inlet loss coefficient: The air below the collector flowing towards the turbine at the bottom of the chimney faces a pressure drop. This drop is related to a turbine inlet loss coefficient. Fortunately, there is no major difference in the annual plant power production [35].

Bracing wheel pressure loss coefficient: The chimney structure of SCPP is reinforced inside using regularly spaced spiked bracing wheels. These wheels apply a drag force on the air rising upward through the chimney. Like the turbine coefficient, the bracing wheel has a bit of effect on the annual power production [35].

7.2. Operating parameters

Ambient pressure: The driving potential that makes air to flow through the chimney is caused by a pressure difference between the column of cool air outside the chimney and a column of hot air inside the chimney [14]. Consequently, a larger ambient pressure causes a little improvement in the peak power output through the daytime process of SCPP.

Ambient temperature lapse rate: An ambient temperature has a considerable effect on the annual power output from SCPP. The higher temperatures predict a less dense ambient air outside the chimney, and subsequently, a smaller pressure difference between the air inside and the atmospheric pressure outside the chimney. This difference acts as the driving potential for the plant.

Solar radiation flux: Solar flux plays a significant role in the improvement of flow and power output of SCPP. It has been found that when the solar flux is increased, the average absorber temperature is increased with a considerable percentage, and therefore, the collector air gets a higher temperature and produces more power [28]. However, the overall efficiency of SCPP decreases significantly.

8. Conclusions

In this review article, we presented a mini-review about the solar chimney power plant (SCPP). In this research review, we recognized the importance of the renewable energy resources. The focus of this review was on SCPP as a source of green energy. The renewable energy resources, especially the solar chimney concept and its advantages, were reviewed, aiming to improve the performance and efficiency. We found that there were a great effects of the different parameters on the performance of SCPP. These factors start with the collector material quality, thickness, and reflectance, which are preferred to be as low as possible, and the emissivity and the ways to reduce it. The chimney height is preferred to be more, its radius is required to be more, and the divergent angle is required to be a slight positive value. All of the motioned parameters are important alongside the operating parameters, and come first the solar radiation flux that is the major input for the chimney, ambient temperature, and pressure that is preferred to be high. As a conclusion of our review, we can rely on the previous studies performed on SCPP as a source of information for further studies.

9. References

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