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A sustainable approachfor power generation: solar chimney, its application & theoretical considerations.

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ABSTRACT

The present paper offeringsan overview of the main physical characteristics of a novel kind of solar thermal claim called solar chimney power plant. It is a technology of electric power generation using solar energy by retaining basic physics that when air is heated it raises .Solar chimney (SC) is a natural draft device which uses solar radiation to deliver upward momentum to the in-flowing air, thereby transforming the thermal energy into kinetic energy. It uses a combination of three recognized technologies, namely, the greenhouse, the chimney, and the wind turbine. In this study the details of SC power technologies are described, with its application, working principal and different computational fluid dynamics study consideration. It also focuses on actual research and development of solar chimney projects.

Keywords—

Solar chimney (SC); Green house; solar energy; solar power plant;

I. INTRODUCTION

A solar chimney power plant comprises of subsequentcomponents: solar collectors, a chimney and a turbinegenerator unit. Conventionally, asolar chimney power plant installed on a parallelground surface at low autonomy consists of a circular translucentshelter raised at a certain height from the ground, with a chimney at its center [1]. A solar chimney power plant installed on a sloped ground surface at high latitude consists of a sloped collector having a triangular surface area with a chimney at its apex [1]. In both cases, the chimneys household one or more turbine-generator units positioned at their bases [2]. The chimney is considerably shorter in the second case. Solar radiation penetrates the observablecollector cover and strikes the ground below it. The ambient air enters from the periphery of the collectors and rises, being heated by the ground, to the Centre or to the apex where a vertical chimney is installed. The heated air below the collector flows towards and up into the chimney to initiative the turbine-generator units [2]. Using a turbine generator unit, the kinetic energy of the air flow converts into electrical energy. Three simple principles are used: the solar greenhouse effect, the chimney buoyancy effect and the wind power principle [3]. Therefore, the collector is the heat source, the chimney is the engine, and the turbine-generator group is the power conversion unit [3].

II. HISTORY

Many investigators around the world have introduced various ventures of solar tower. Around 1500, Leonardo Da Vinci made sketches of a solar tower called a smoke jack (see figure 1-a) [9]. The idea of using a solar chimney to create electricity was first proposed in 1903 by the Spanish engineer IsodoroCabanyes (figure 1-b).

Another earlier description was elaborated upon in 1931 by the German science writer Hans Gunther [10]. He proposed a design in the 25 August 1903 issue of

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―La EnergiaEléctrica‖, entitled ―Projecto de motor solar‖. In this bizarre contraption, a collector resembling a large skirt heats air, and carries it upwards towards a pentagonal fan inside a rectangular brick structure vaguely resembling a fireplace (without a fire). The heated air makes the fan spin and generate electricity, before it escapes up a 63.87 m tall chimney, cools, and joins the atmosphere [11].

In 1926, Prof Engineer Bernard Dubos proposed to the French Academy of Sciences the construction of a Solar Aero-Electric Power Plant in North Africa with its solar chimney on the slope of the high height mountain after observing several sand whirls in the southern Sahara [12] and many other advancement and studies are carried out here for further development.

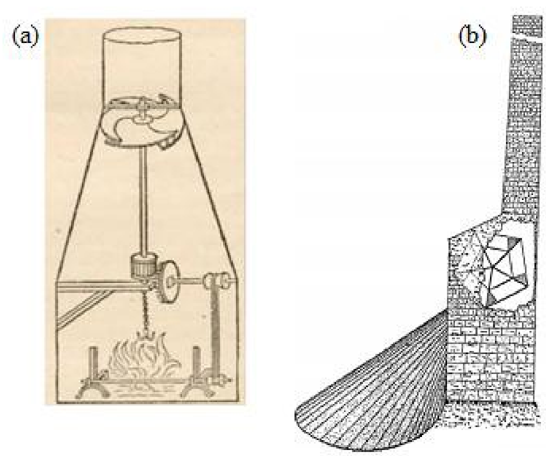

Fig.1.(a) The spit of Leonardo da Vinci (1452-1519) (Library of Entertainment and Knowledge 1919). (b) Solar engine project proposed by IsodoroCabanyes.

III. WORKING PRINCIPLE

The solar chimney is one of the skillbased on the buoyancy principle. Where's the air is heated through greenhouse influence which generated by solar energy (heat energy). The expenditure intricate is not so high. So many techniques can be used in cooling or heating of buildings. The solar chimney can be used in roof level or inside wall also. The solar chimneys are solar passive ventilation systems it means they are non-mechanical. The heat is passed out through convective cooling principle. The solarchimney is designed based on the fact that hot air risesupward; they reduce annoying heat during the day and exchange interior (warm) air for exterior (cool) air. The solar chimney mainly made of a black hollow thermal mass with opening at the top of chimney for exit the hot air. The air passed through the room andexit from the top of chimney. The two purposes are solved one is the better ventilation and secondly it reduces the temperature inside the room. It can be worked as reverse for heating the room also. The Thrombiwall is working as solar chimney.

Merits of solar chimney are: Merits: There is no mechanical part, Low maintenance, No electrical Consumption, No global warming, No Pollution and It can be used for both heating and cooling and demerit only is to increases the cost of building.

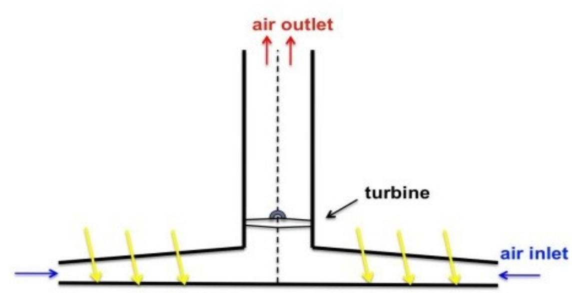

FIG 2 .Schematic cross section of a solar chimney, showing the system elements and working principle.

IV. CLASSIFICATION OF SOLAR CHIMNEY

The solar chimney is basically a solar air heater, its position may be vertical or horizontal and according to the position it will be a part of a wall or roof.
1. The solar chimney can be classified according the position as
(i) Vertical solar chimney and
(ii) Inclined solar chimney.
2. It can be classified according to position solar chimney for building ventilation is classified as
(i) Wall solar chimney or Thrombi wall
(ii) Roof solar chimney and

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(iii) Integrated wall and roof solar chimney.
3. The solar chimney is also classified according to the use for

(i) building ventilation (circulation)
(ii) Building heating (dwelling)
(iii) Air dryer (crop dryer) and
(iv) Power generation.

4. The solar chimney performance is depends on the glazing either single glazing, double glazing or triple glazing. The ventilation rate is mainly depends on the height of solar chimney, so it is one of the basis for classification

(i) Small height (ii) Medium height and
(iii) Large height.

5. The solar chimney classification also associated with cooling and heating of building. It means solarchimney can be classified with integrated approaches as

(i) Integrated with evaporative cooling system
(ii) Integrated with earth air tunnel heat exchanger and
(iii) Integrated with absorption and adsorption cooling.

6. The Solar radiation receiving area is covered with glass cover, the small radiations should be less entering to the system and large wavelength radiation minimum exit from glass cover so maximum greenhouse effect can be generated. The greenhouse effect is associated with solar radiation and number of glazing. The solar chimney classified according to number of gazing used as

(i) Single glazing and
(ii) Multi glazing.

V. DESIGN, CONSTRUCTION AND ANALYSIS

Collector

The main component of a solar chimney power station is the solar collector. Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The collector is the part of the chimney that produces hot air by the greenhouse effect. It has a roof made up of plastic film or glass plastic film. The roof material is stretched horizontally two or six meter above the ground the height of the roof increases adjacent to the chimney base, so that the air is diverted to the chimney base with minimum friction loss. This covering admits the short wave solar radiation component and retains long-wave radiation from the heated ground. Thus the ground under the roof heats up and transfers its heat to the air flowing radially above it from the outside to the chimney .The structure of the collector changes to the covering material we used.

Chimney

Chimney or tower tube is the main characteristic of the solar chimney station. The tower, which acts like a large chimney, is located at the center of the greenhouse awning and is the thermal engine for the technology. The tower creates a temperature differential between the cool air at the top and the heated air at the bottom. This creates the chimney effect, which sucks air from the bottom of the tower out of the top. The chimney of the plant is extremely high and will need a stable base while still allowing free flow of air through the turbine. It would also be advantageous to have the turbine as low as possible in the chimney to make its construction simpler. There are various different methods for constructing such a tower: free-standing reinforced concrete tubes, steel sheet tubes supported by guy wires, or cable-net construction with a cladding of sheet metal or membranes. The design procedures for such structures are all well established and have already been utilized for cooling towers; thus, no new developments are required. Detailed static and structural-mechanical investigations have shown that it is expedient to stiffen the tower in several stages, so that a relatively thin wall material will suffice.

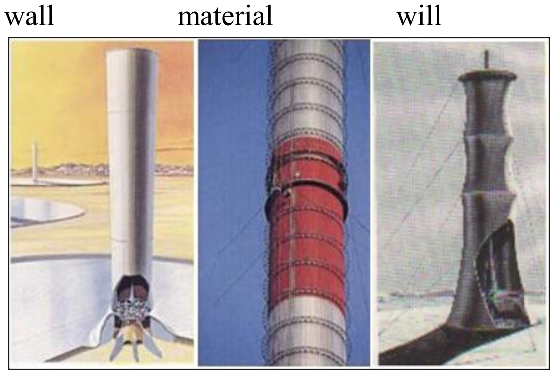

Fig. 3.Differenttechnologies ofchimney.

Turbines

The turbine of the solar chimney is an important component of the plant as it extracts the energy from the air and transmits it to the generator. It has significant influence on the plant as the turbine pressure drop and plant mass flow rate are coupled. The specifications for solar chimney turbines are in many aspects similar to those ones for large wind turbines. They both convert large amounts of energy in the air flow to electrical energy and feed this into a grid. But there are also various important differences. The following characteristic are typical for solar chimney turbines in contrast to wind turbines .

Turbine coupling

Using the Spanish prototype as a practical example, Tingzhen et al (2008) [13]. carried out a numerical simulation of a solar chimney power plant system coupled with a 3 blade turbine. This study showed that the average velocity of the chimney outlet and the mass flow rate decrease with the increase of turbine rotational speed. The authors concluded that the average temperature of the chimney outlet and the turbine pressure drop inversely, while the maximum available energy, power output and efficiency of the turbine each has a peak value .

Koonsrisuk et al. (2010) [14].conducted a study in which the collector, chimney and turbine are modeled together theoretically, and iteration techniques were then carried out to solve the mathematical model developed. It was developed to estimate power output of solar chimneys as well as to examine the effect of solar heat flux and structural dimensions on the power output. Results from the mathematical model were validated by measurements from the physical plant actually built. The results show that the plant size, the factor of pressure drop at the turbine and the solar heat flux are the important parameters for the performance enhancement.

Energy storage in the collector

The ground under the collector roof behaves as a storage medium, and can even heat up the air for a significant time after sunset. The efficiency of the solar chimney power plant is below 2% and depends mainly on the height of the tower. As a result, these power plants can only be constructed on land that is very cheap or free. Such areas are usually situated in desert regions. However, this approach is not without other uses, as the outer area under the collector roof can also be utilized as a greenhouse for agricultural purposes [15].

VI. CFD ANALYSIS FOR SOLAR CHIMNEY POWER PLANTS

[4] Axisymmetric Unsteady Reynolds-Averaged Navier-Stokes (URANS) simulations were performed for Solar Chimneys Power Plants (SCPP) of different scales. Overall, the present simulations confirm the cubic scaling of the available power with the plant dimensions as predicted by simple one-dimensional analysis (1). The temperature rise in the collector was shown to be inversely related to the scale of the plant. Nevertheless, the collector efficiency was found to increase considerably with increasing scale. The Reynolds numbers based on chimney diameter and collector height vary considerably with scale (from *ReD*= 104 to 108 for the smallest and largest scale, respectively). Large variations were also observed for the Nusselt numbers associated with the heat transfer from the ground.

[16] In this paper a thermo-hydrodynamic analysis for airmotion in natural convection, laminar flow and steady state has been presented for a solar chimney with prescribed boundary conditions Results showed that the maximum velocities are gotten at the inlet of the chimney tower and its values were increased by increasing the difference between ground and roof of the collector for all Rayleigh numbers.

[17] Theoretical simulations were conducted in order to evaluate the performance of solar chimney power plants. The relationships between the pressure ratio and the mass flow rate and between the temperature

rise across the collector and the power output were presented. It was found that, for the system with a constant driving pressure (available system pressure difference), the optimum ratio of the turbine extraction pressure to the driving pressure is 2/3. For the system with the non-constant driving pressure, it is obvioustthat this optimum ratio is a function of the plant size and solar heatflux. This observation would be helpful in the preliminary plant design. In addition, it was shown that the appropriate plant,which can serve the electricity demand for each village in Thailand and the investment cost would be affordable by the local government, is the one with a collector radius of 200 m and a chimney height of 400 m. The optimum pressure ratio for the proposed plant is equal to 0.84 approximately. The paper also proposes the simple method to primarily evaluate the turbine power output for solar chimney systems.

VII. APPLICATION

Solar chimney for ventilation of buildings:This stack effect described in principle of solar chimney can be used for multistory building by using wind tower or wind catcher for inlet air in the room and the solar chimney at other faces for each floor was suggested. This solar chimney at 30˚ inclination angle having collector area 3.0 m2 each with wind tower of height more than the building used by Bansal et al.

Solar Chimney for space heating and ventilation :The simple solar chimney or trombe wall can be operated in both applications as: space heating mode and ventilation mode. Gan (1998) used trombe wall for both heating and ventilation mode by controlling the positions of dampers so it can be used for both winter and summer season. He constructed a trombe wall in south facing by concrete and masonry with blackened and covered exterior by glazed glass and provided three holes as shown in Figure 6 where two holes in masonry wall at bottom and top position. A damper was fitted in top hole for closed it in summer season and open in winter season. One more damper was fitted at exit opening in the chimney for closing it in winter and open in summer.

Solar Chimney for space cooling and thermal comfort

Thermal comfort is not only space heating but it is space conditioning which integrated operation technique for controlling the air temperature, humidity and quality of air. It can be possible by solar chimney and integrated approaches.

[5] ***Barozzi et al.*** *(1992)* studied space conditioning in buildings is a function of temperature, relative humidity, irradiation and the method of controlling these parameters. The space conditioning is highly desirable in tropical countries like India, Africa and South America. Today's technology like passive solar applications can be used for thermal comfort of buildings (Hirunlabh, 2001). The first mathematical modeling for the solar chimney (Trombe wall) design was given by Bansal et al. (1993) and reported the concept of increasing the air flow by increasing solar irradiations. This theoretical study also reported an air change per hour with change in the coefficient of discharge. The ventilation provided by the solar chimney is not sufficient for large buildings but enhance the ventilation rate up to some extent. One important application of passive cooling for air ventilation and circulation in the form of wind tower was suggested

[6]Qirong et al. (2011) proposed an integrated approach of Trombe wall, roof solar collector and chimney

and investigated the effect of total length and width of chimney on the performance of the system. They reported that the performance of integrated system found better as compared to the single solar chimney. The numerical study also carried out to evaluate the performance parameters for ventilation rate as a function of inclined angle of the second floor, length ratio of vertical to inclined, and chimney inclined angle. The optimum ratio of length to width was 12:1 and optimal inclination angle is found to be 4º by numerical study. The length of solar chimney (vertical section height) should be as large as possible within the restriction of building code to increase the flow rate of air.

[7] Zamora and Phoenic (2009) used codes (version 3.6.1) for the numerical study of natural convection in channels or solar chimney. They used Reynolds turbulence model to simulate the turbulent case. Thesolar chimney was configured for a wide range of he Rayleigh number (varying between 105 to 1o12 for symmetrical isothermal heating), several values of wall to wall space and different heating conditions.

[8] Gan (2011) derived the general expressions for correlation of Nusselt number, Reynolds number and Rayleigh number and these expressions can be used for calculating the heat transfer rate and air flow rate in ventilation cavity for given height and width. The heat flux and heat distribution ratio also calculated.

CONCLUSION

The types, classification, application and computational methodology of available solar chimney technology for different application are reviewed in this paper.. The presentation mainly depends on the temperature and pressure differences. Applications are be contingent on the type and configuration of chimney. The heating and cooling of buildings by solar chimney aspects are clearly shown. The conventional air conditioning scheme can be fully replaced by accepting these integrated techniques for building space conditioning, it reduces the building energy load and sustainability will increase. The conventional building cost is cumulative slightly by use of solar chimney but in long term it will be beneficial.

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