

# Experimental study of solar chimney power plant

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**Abstract**—Solar chimney power plants are passive thermal systems that use greenhouse effect to produce electricity from the solar radiations. The performance of these devices vary from one climate to another. Indeed, the building site of the SCPP is a special parameter for its total effectiveness. The aim of this work was to present an experimental investigation of a solar chimney prototype under the climatic conditions of Sfax, Tunisia. In fact, Sfax is characterized by its arid and sunny climate. The impact of the climatic conditions of Sfax city on the aero-thermal characteristics of the considered prototype is carried out. The present outcomes show that the solar chimney power plant is an applicable device in Tunisian region Sfax.

**Keywords**—Renewable energy, Solar radiation, Chimney, Airflow

## I. INTRODUCTION

Tunisia is a Mediterranean arid region located in the north of Africa. It is characterized by a high level of the average solar radiation. The solar energy technologies are suitable to be applied in Tunisia especially in the south desert [1]. The Solar Chimney Power Plant (SCPP) is an attractive solar energy setup, which provides the environmental conditions of the surrounding air to produce electricity. Its simple principle is based on both the natural convection and the buoyancy of the air. Several researchers have been interested by the optimization of the solar chimney power plant in order to decrease the overall investment. The first prototype of the SCPP, built in Manzanares Spain, is conducted by Schlaich [2] to reveal the application of the agricultural greenhouses in the electricity production. This prototype was operated for eight years with the overall electrical power about 50 kW [3]. Since the successful technology of the Manzanares prototype, many small prototypes of the solar chimney systems have been installed in different regions around the world; in China. [4, 5], in Brazil [6-10], in Turkey. [11-12], in India. [13], in Northern Mongolia. [14], in Syria. [15], in Egypt. [16], in Jordan. [17], in USA. [18] and in Algeria [19]. Al-Kayiem et al. [20] presented a novel solar chimney layout, which is installed over the roof of a small room. Sangi [21] evaluated the effect of various ambient conditions and structural dimensions on the performance of the solar chimney power plant in Iran. Abdelmohimen and Algarni [22] performed a numerical study of the SCPP overall the year for the meteorological data of six regions of Saudi Arabia. They incorporated the Manzanares prototype as a case study to validate their numerical models. They reported that the south

of the kingdom present a benefit region to install the SCPP. However, their study did not present a real experiment of the system. Wei et al. [23] built a new combined solar updraft power plant in a desert of Wuhai, Inner Mongolia of China that receive both solar and wind energy to generate electricity. This technology produces the electricity from both solar and wind energy. Designers used several air intakes facing north to absorb the natural wind. The solar setup is characterized by a collector area equal to 5300 m<sup>2</sup> and a chimney height equal to 53 m, a chimney diameter equal to 10 m and a generated power of 200 kW. Najmi et al. [24] developed a feasibility study of a small solar chimney built in Kerman, Iran. They carried out the effect of some parameters on the SCPP performance. As a result, they noted that the double-glazing glasses on the collector roof and the installation of conical shape at the entrance of chimney could enhance the generated power. However, a limited work involves Tunisia regions effect on the feasibility of the SCPP technology. Jemli et al. [25] conducted an experimental study of a SCPP prototype at the Research and Technology Centre of Energy, Borj Cedria, northern Tunisia. They analyzed the impact of the ambient temperature and the solar radiation intensity on the SCPP efficiency while they changed the chimney height and the collector diameter. Another work has been reported by the numerical and the preliminary study of the SCPP for Tunisia weather. Bouabidi et al. [26] studied numerically and experimentally the influence of different configurations of the chimney pipe on the local characteristics of the airflow within the whole system. Ayadi et al. [27] carried out a CFD simulations of the proposed SCPP prototype with different chimney height. They indicated that the chimney height enhance the performance of the solar chimney power plant. In another work, Ayadi et al [28] investigated the turbine blade effect on the SCPP performance while reporting many 3D simulations with different turbine blade number. They noted that the performance factor of the SCPP turbine increases with the increase of the turbine blade number. According to these anterior published works, we could conclude that there are many solar chimney configuration sizes. This could be interpreted by the variation of meteorological and geographic conditions. The main objective of this work is the revealing of the effectiveness of the solar chimney power plant in Sfax, Tunisia. Indeed the thermal characteristics and the generated electric power were hourly investigated during the month of May 2016. This work is identified important to experimentally comprehend the behavior of an existing solar chimney power plant.

## II. METHODS

The commercial city Sfax is cited in the South East of Tunisia. The geographic data of Sfax are 34.72 of latitude and 10.72 of longitude. The prototype is exactly built at the National School of engineers of Sfax. Figure 1 shows a photographic photo of the experimental solar chimney for power generation. The schematic view and the dimensions of the different compounds of the prototype are represented in figure 2. The experimental prototype consists of a plastic transparent collector that is constructed from a polyethylene film and a chimney pipe of inelastic PVC. The collector is characterized by a radius equal to  $R=1375$  mm and a height equal to  $h=50$  mm. Furthermore, the chimney height is equal to  $H=3$  m and the chimney diameter is equal to  $d=160$  mm. The polyethylene is characterized by its high transmission of the visible and the ultraviolet waves of the solar radiation. The transitivity factor of the collector roof is equal to 0.88. The pipe is fixed on the wooden platform by a steel support.



Fig. 1. Prototype

The turbine-generator is installed at the chimney entrance. It present a six-blade turbine coupled with an electric generator. The generator is an asynchrony machinery with efficiency equal to 0.9. The absorber is a combination of wooden platform with 8 mm thickness with a black layer of paint. The wooden platform is painted black to promote a good absorption of sunlight. In this study, it can be assumed that the absorptivity of the black wood is equal to 0.8.

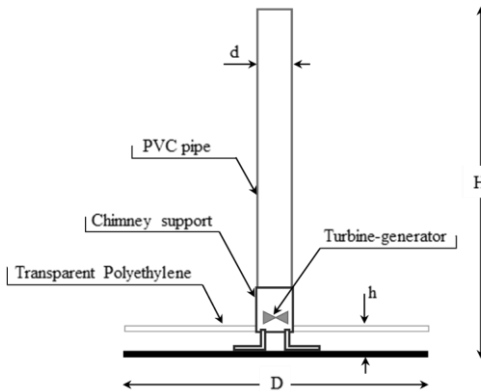


Fig. 2. SCPP schematic

To study the thermo-aerodynamic characteristics of the airflow within the proposed solar chimney prototype, four main parameters were tested such as the solar radiation, the temperature, the velocity and the electric power of the turbine-generator. The experimental data are directly depend on the measuring instrument accuracy. Therefore, the choice of different devices is required. The adequate device is generally the Hot-wires Anemometer to control the air velocity. It is a simple sensor required a high resolution for low air speed applications. The available instruments used during the experimental tests were shown in figure 3. An anemometer (Figure 3.b) with the accuracy of  $\pm 0.01$  m.s<sup>-1</sup> is used to measure the air velocity. However, the air temperature was simultaneously measured in many spots under the solar collector. Using a plot temperature change over time, the Uni Trend Model UT325 Thermometer is used (Figure 3.a). This device is based on microprocessor and is designed to use external J, K, T, E, R, S and N type thermocouples as temperature sensors. It has a Software and USB data cable, which allow the data transfer by the connection of the different sensors with a computer. From the literature, it is known that the solar collector is the responsible compound for the air heating by greenhouse effect. In this study, many sensors are fixed along the collector centerline in order to control the air temperature. Thermocouples J type were used to measure the air temperature. Six typical points (L1-L2-L3-L4-L5-L6) were investigated in the collector. The distance between two successive points is equal to 0.3 m in the east section through middle axis. This prototype provides researcher to freely adjust the sensor heights. The position L5 is implanted to measure the maximum velocity which is located at the chimney inlet.



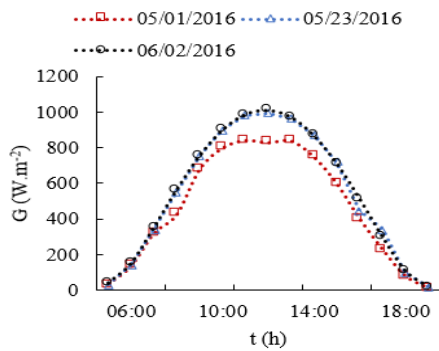
Fig. 3. Experimental devices

## III. RESULTS

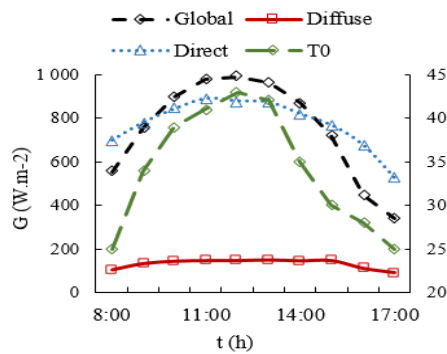
### A. Solar radiation

One of the benefits of the solar chimney power plant is its operation mode. In fact, this type of thermal system is able to capture of both direct and diffuse solar radiations. Therefore, the solar radiation is an important parameter in our experimental study and it is the essential to calculate the power output. To measure the solar radiation values and to record these values, the metrological data of SFAX is taken into account. Figure 4 shows the hourly variation of the average solar radiation during the experimental tests times.

The global radiation for different days of May and June is shown in Figure 4.a. According to these results, it is clear that the solar radiation presents the same evolution during the day for the different cases. The maximum radiation value appears at 12:00 h for all days. However, the weakest values are shown at the beginning and the end of the day. Besides, the global radiation values on May 1, May 23 and is slightly superior to the values of June 02. For this reason, May 23 is chosen as a typical day for further studies. The environmental parameters such as the global, the diffuse, the direct solar radiation and the ambient air temperature are mentioned for a typical day of May 23, 2016. Figure 4.b reveals the relation between global, diffuse, direct solar radiation and the ambient air temperature of the typical day of May 23, 2016. From these results, the global radiation is equal to  $G=991 \text{ W.m}^{-2}$  at 12:00 h whereas the maximum diffuse solar radiation is equal to  $G=146 \text{ W.m}^{-2}$ .



(a)



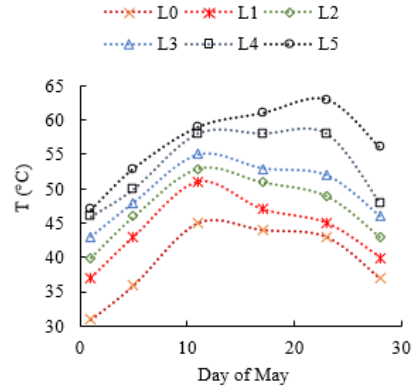
(b)

Fig. 4. Hourly solar radiation

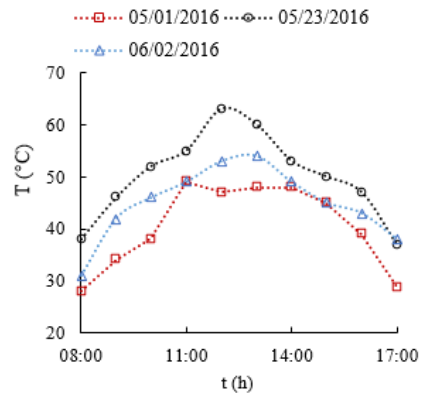
### B. Temperature

The temperature rise in the collector is the first parameter responsible to the creation of the airflow in the system due to the greenhouse phenomenon. In a first time, the daily temperature values in different locations along the collector centerline is controlled in same days of May and June 2016. In a second time, the temperature is measured at the collector outlet position on the considered typical day. The experimental data of the air temperature under the solar collector is recorded on May 01, May 05, May 11, May 17, May 23, May 28, June 02, and June 05. Figure 5 shows the daily evolution of the air temperature within the collector. Figure 5.a depicted the daily variation of the temperature for different positions in the collector that carried out at 12:00 h.

Figure 5.b shows the temperature variation in the location L5 consisting the collector outlet for the considered days from 08:00 h to 16:00 h. According to these results, it has been observed that the air temperature at L5 reached present the highest values on May 23 during the day. In addition, the maximum value appears at 12:00 h, due to the increase of solar radiation at this time. The air temperature presents the same profiles for all positions. In fact, these values are maximum on May 23. Indeed, the air temperature increases in the direction of flow to reached its maximum at the chimney inlet.



(a)



(b)

Fig. 5. Hourly temperature

### C. Air velocity

The measurements of the air velocity is required to reveal the kinetic energy of the airflow in the whole system of the solar chimney. Figure 6 shows the Daily evolution of the air velocity within the collector outlet. In figure 6.b, the air velocity curves are illustrated during the month for different times. In figure 6.a, the evolution of the air velocity during the day is represented for three days; May 01, May 23 and June 02. According to these results, it has been observed that the air velocity increases with the same behavior of the temperature for all days. Moreover, the temperature present the highest values during May 23. Indeed, the highest velocity values appears on May 23. the velocity presents the same distribution for all collector radius positions and it is maximum on May 23. According to these results, the velocity increases along the collector due to the greenhouse effect for all hours. This could

be interpreted by the temperature difference. However, the minimum velocities are reached at 08h and the maximum values are reached at 12h.

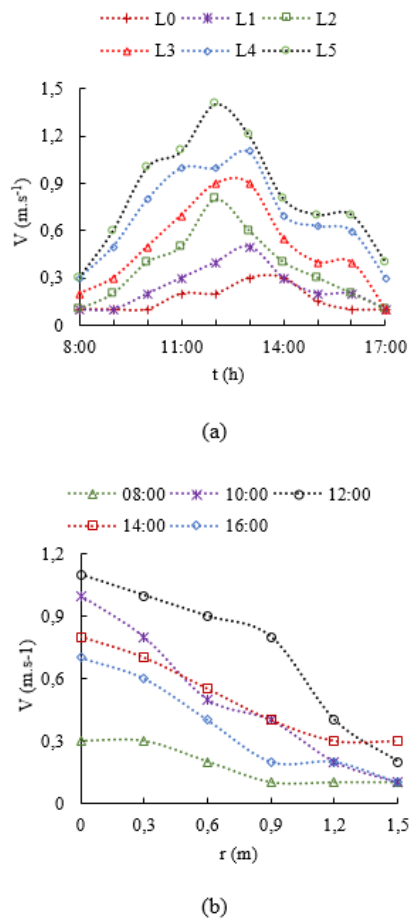


Fig. 6. Hourly velocity

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