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Comparison Experimental Study with Simulation 3D of Varying the Temperature on the Performance Solar Chimney Power Plant

R. Naceur *[1], M. Bousmaha [2], A.Baroudi[1], A. Akriche [2], A. Ould Abbas [1], K. Djakhdane [3], I. Hattabi[2] , M.A. Bezzerrouk [2]

1. Laboratoire de matériaux et énergies, département de Physique, Faculté des sciences, Université Abu Bakr Belkaid, B.P 119, Tlemcen-13000, Algerie.

2. Conception of materials and electronic devices in diagnostic in veterinary medicine, Reproduction of farm animals Laboratory, Veterinary sciences institute, University of Ibn Khaldoun Tiaret-14000, Algeria.

3. Physics department, Faculty of materials sciences, University of Ibn Khaldoun, Tiaret-14000, Algeria.

Abstract— **A prototype solar chimney power plant was constructed, which consisted of a chimney with 6 m height and 3m collector diameter. The air temperature distribution, air velocity and the humidity were measured. The study realize comparison between experimental air temperature and simulation with validate mathematical model in COMSOL5.1 under collector and chimney, for one day May, 28th 2017.**

Keywords— **Solar chimney, airflow, Temperature, Collector.**

I. Introduction

Nowadays, we note a permanent evolution of the gas rate with greenhouse effects in the atmosphere. The challenge, now, is to find systems of production of energy, which do not generate the preceding problems. Of this concept, it is thus necessary to develop a means of exploiting renewable energies. The solar chimney power plant (SCPP) is a technology allowing the conversion of solar energy into electricity. The power station with a solar chimney consists of three essential components, the solar heat collector, the chimney or the tower and the turbine. SCPP is power plants, which use the force of an ascending draft. The concept of the solar chimney has been proposed for more than 100 years. In 1903, Isidoro Cabanyes, a colonel of the Spanish army, was originally proposed a solar stack power station, in the store "La energia eléctrica" [1]. In 1931, a German researcher, Hanns Günther advanced a solar chimney energy generation technology [2]. This technology simply used the chimney effect and the greenhouse effect to drive a turbine. The first prototype experimental work in the SCPP was built in manzanares; spain in 1982, by a German structural engineering company, Schlaich Bergermann, the plant had a collector diameter of 244 m and 194.6 m height, 10 m diameter of the chimney, to produce 50 kW peak [3]. In 1983 Krisst et al [4]. Built four pilot SCPPs, including a “backyard type” device with 10 m high chimney, 06 m collector base diameter and a power capacity of 10 W in West Hartford. In 1985, Kulunk [5]. Built a miniature SCPPS demonstration unit in Turkey. The chimney of the apparatus measured only 2 m high, the diameter of the chimney was 70 mm and the collector surface of 9 m with an average power of 0.14 W. Pasurmarthi and Sherif [6]. In 1997, built for solar chimney power in Florida to assess a demonstration model its theoretical and experimental two experimental modifications were tried on the collector: (1) extending the collector base and (2) introducing an intermediate absorber. In china, Zhou et al [7]. Was built A small pilot experimental solar chimney consisted of an air collector 10 m in diameter and 08 m tall chimney. The temperature distribution in the solar chimney power setup was measured. The previous papers presented important concept in terms of height and diameter of the chimney, the velocity, the temperature distribution in collector and the air inlet size with various absorbers. This study reports the comparison between experimental air temperature and calculated temperature with COMSOL in the collector and the chimney on the performance of solar chimney power plant.

II. Mathematical Model

Three modes of transferring thermal energy, conduction, convection and radiation transfer in solar chimney power plant, analysis of energy transfer necessitate the application of conservation of energy principals. More energy conservation laws are expressed in terms of temperature.

2.1. Energy conservation equation

$$\frac{\partial(\rho C_p T)}{\partial t}+\frac{\partial(\rho C_p uT)}{\partial x}+\frac{\partial(\rho C_p vT)}{\partial y}+\frac{\partial(\rho C_p wT)}{\partial z}=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \quad (1)$$

2.2. Continuity equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \quad (2)$$

2.3. To model heat conduction and convection

$$\rho C_p \frac{\partial T}{\partial t}+\rho C_p u\nabla.T=\nabla.(k.\nabla T)+Q \quad (3)$$

2.4. For transport conduction and convection, the heat flux vector approximated by

$$q=-k.\nabla T+\rho C_p T u \quad (4)$$

2.5. Heat flux

$$n.(k.\nabla T) = q_0 + h(T_{inf} - T) + C_{const}(T_{amb}^4 - T^4) \quad (5)$$

2.6. Model radiation heat transfer with the surrounding environment

$$C_{const}(T_{amb}^4 - T^4) \quad (6)$$

$$C_{const} = \varepsilon\sigma \quad (7)$$

III. VALIDITY OF THE MATHEMATICAL MODEL

To estimate the mathematical model were simulated by a model heat transfer, surface-to-surface radiation, COMSOL 5.1.The results obtained from this model were compared to experimental results of a realized prototype consisting of the parameters in Table (1).In this study, the phenomenon to be evaluated is natural convection, the boussinesq hypothesis was used. Reynolds number is low inside the solar chimney is defined the nature of airflow (laminar flow).

TABLE I
GEOMETRICAL PARAMETERS OF THE SOLAR CHIMNEY PILOT

Parameter	**Figure index**	**Size (m)**
Chimney radius	$r_{Chimney}$	0.110
Collector radius	$r_{Collector}$	0.300
Collector height	$H_{Collector}$	0.100
Chimney height	$H_{Chimney}$	0.600

A. BOUNDARY CONDITIONS

TABLE III

Boundary conditions of prototype solar chimney power plant

Place	Type	Description
Absorber	Wall	q_0
Roof	Wall	T=303K
Chimney	Wall	$n.k.\nabla T = 0$
Collector inlet	Pressure inlet	P atm
Chimney outlet	Pressure outlet	P atm

B. EXPERIMENTAL SET-UP

The prototype solar chimney power plant was constructed in University Ibn Khaldoun Tiaret, (35.35N; 1.3131 N). The pilot scale solar chimney power plant (SCPP) consists three components: (03) metre radius of collector, (06) metre height of chimney and ground black (Absorbor). The Temperature measuring of the air under collector and in the chimney, we used (14) thermal sensors planted in the collector and chimney as shown in Fig (1) .For performing this study of comparison between the values of the experimental air Temperatures and the values of the simulation Temperature, we selected a day of May,28th 2017. The climatic condition are used ideal, the ambient Temperature T=39°C , the wind speed V=1.11m/s, Humidity level H=30% and Pressure P=1018 hPa at 12 pm.

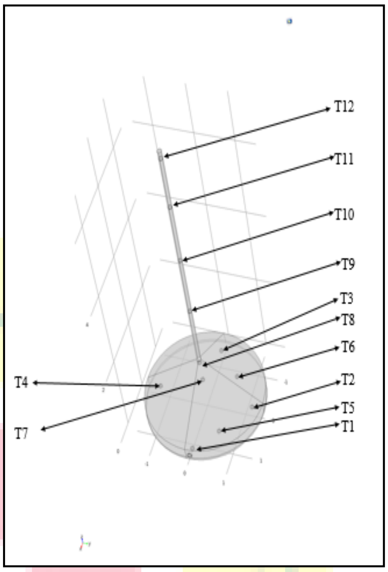

Fig.1. sensor location in the prototype solar chimney power plan

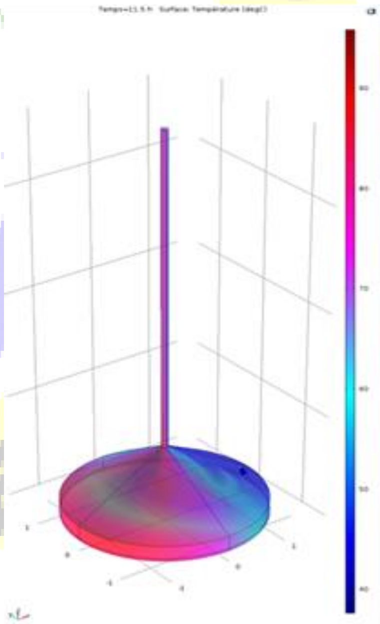

Fig.2. Temperature of SCPP with COMSOL5.1.

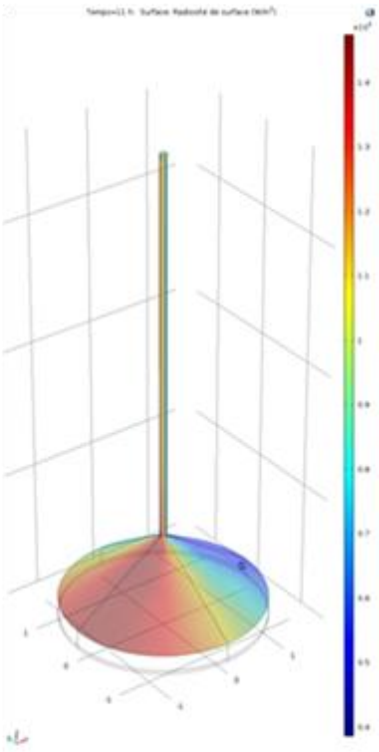

Fig.3. The Radiosity of SCPP with COMSOL5.1.

IV. RESULTS AND DISCUSSION

A. AIR TEMPERATURE CHANGE UNDER COLLECTOR

Under the collector have located eight thermal sensors measure various air temperature (T1, T2,T3,T4,T5,T6,T7,T8)

The Fig.4.(A)and (B). Shows changes the Temperature in 24 hours, the temperature has to be observed in T1 sensor maximum T=55(°C) at 12:00 h in data experimental, but in the model COMSOL the Temperature indicated T=45(°C) at 14:00 h. in the T1 sensor there is a wide input phase shift between the experimental temperature and the temperature calculated by COMSOL up to T = 10 (° C) and also a phase shift of time up to 2 hours , but in T2 sensors showed simultaneous variety values of temperatures with got even peak almost, the experimental air Temperature say maximum T=72°C at 12:00 h, same Temperature model COMSOL say T= 70°C at 12:00 h. The difference between the two graphs the width between the growth and the decay of the temperature values, the experimental air temperature. The values of the experimental temperatures exceed 45°C over a wide range up to 4 hours, whereas the model keeps the same temperatures over a period of 3 hours. The T3 sensors indicated difference between temperatures, at 12: 30 h the sensor record 74 ° C but the model mark 81.8° C. There is a similarity between values experimental air Temperature and simulation.

T4 sensor demonstrate the same pick Texp=74.29 °C, TCOMSOL=75.61 °C at different times 12:16 h , 14:56 h . In the T5 thermal sensor the two graphs are spaced the maximum experimental temperature variation 71.36 °C to 12: 06 h, but the temperature that computed by COMSOL mark 53.75 °C at 12: 06 h, the two graph are very similar, Texp = 74.29 °C , TCOMSOL =73.87 °C at 12:16 h in T6 sensor.

In the T7 sensor show that the experimental air temperature indicate maximum values 73.8 °C, to 12: 00 h, but the simulation temperature mark maximum values 62.65°C to 14: 46 h.

T8 thermal sensor located between the entrance of the chimney and the collector, the flow phenomenon air start with power at this point generally the air velocity marked very interesting data .In Fig.4. (A) and (B). Say the Temperature variation; it has to be spotted maximum bay 64.52 °C in experimental and 66.4 °C, in simulation at 13:36 h.

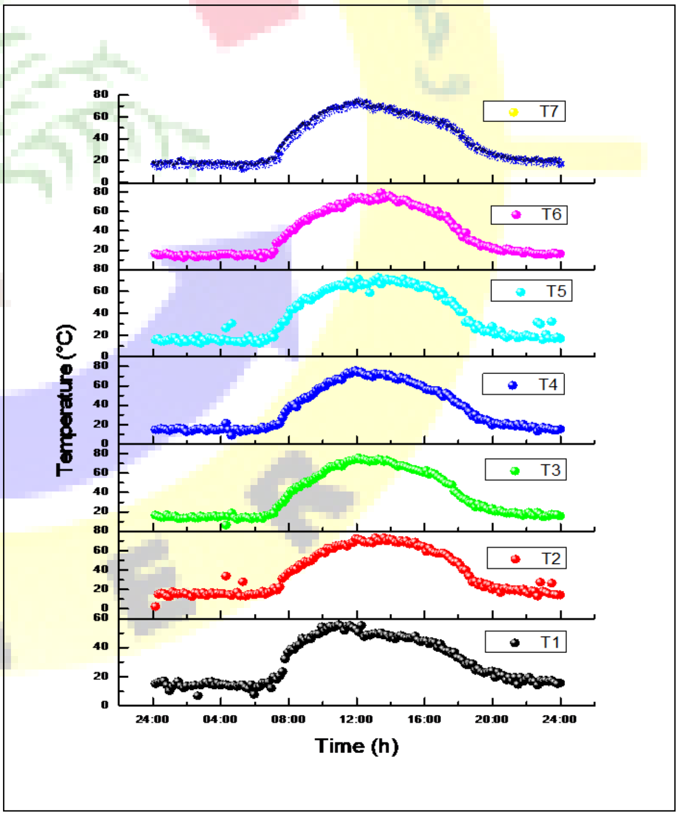

Fig.4. (A).Temperature changes experimental in collector

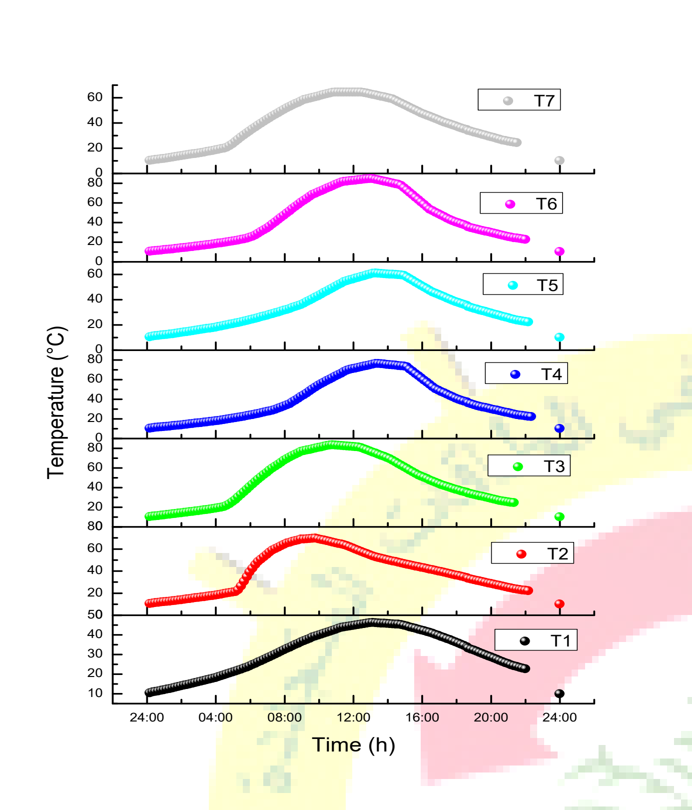

Fig.3 .(B). Temperature change simulation (COMSOL) in collector

B. AIR TEMPERATURE CHANGING IN CHIMNEY

The most important parameter for creating an artificial wind is the temperature gradient. The air is heated by a greenhouse in a collector and led by a chimney thus making it possible to take advantage of the difference in temperature, in Fig.4. (C) and (D), we are noticing several factors:

a- A temperature gradient between the collector, chimney and the ambient temperature.

b- The temperature under the collector marked maximum values up to 74°C experimental and simulation values up to 81°C, but in the chimney indicate remarkable decrease of experimental air temperature data 53.7°C in T12, 70.13 °C calculated by COMSOL at 12: 00 h .

c- The shape of the graphs is very close in the thermal sensors T9, T10 and T11.

d- In T12. Marked same pick 53°C, in the experimental data at 12: 00h but at the COMSOL data at 16: 25 h

e- The temperature in the chimney does not exceed 55°C experimental, 64°C calculate by COMSOL.

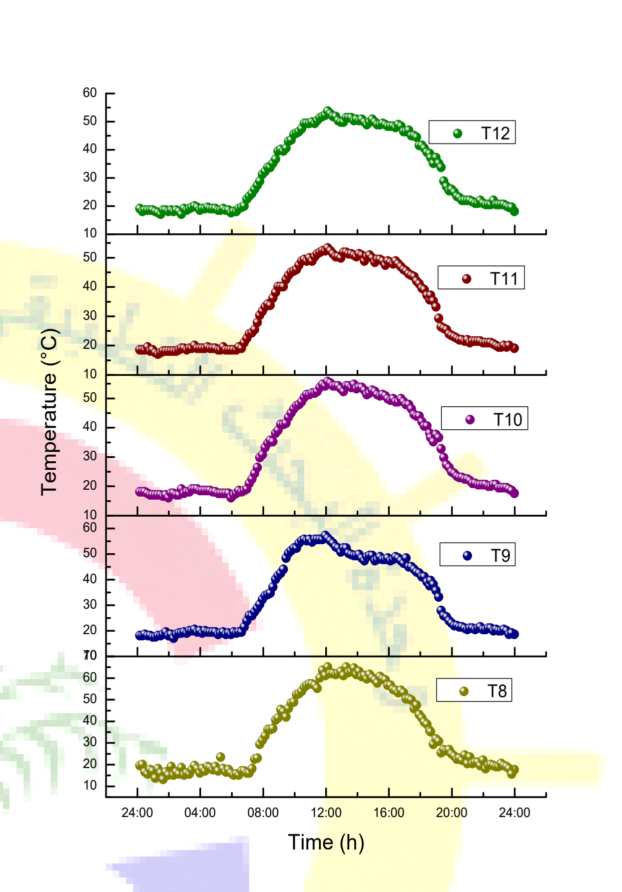

Fig.4. (C) .Temperature changes experimental in chimney.

B. DISTRIBUTION OF AIR TEMPERATURE FROM THE COLLECTOR

TABLE III

The temperature data for COMSOL evaluation in collector

Sensor	COMSOL (°C)	Experimental (°C)	Variation value (°C)	Error (°C) (%)
T1	46.72	56.29	9.57	20.48%
T2	70.30	72.26	1.96	2.78%
T3	84.64	77.11	7.53	8.89%
T4	77.51	76.91	0.6	0.77%
T5	61.51	70.83	9.32	15.15%
T6	85.44	80.68	4.76	5.57%
T7	65.83	71.36	5.53	8.40%

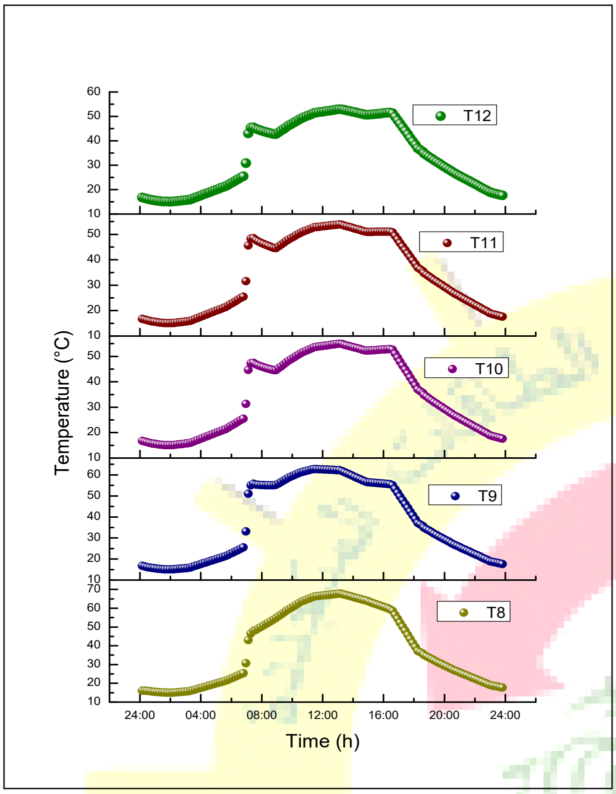

Fig.4.(D) .Temperature change simulation (COMSOL) in chimney

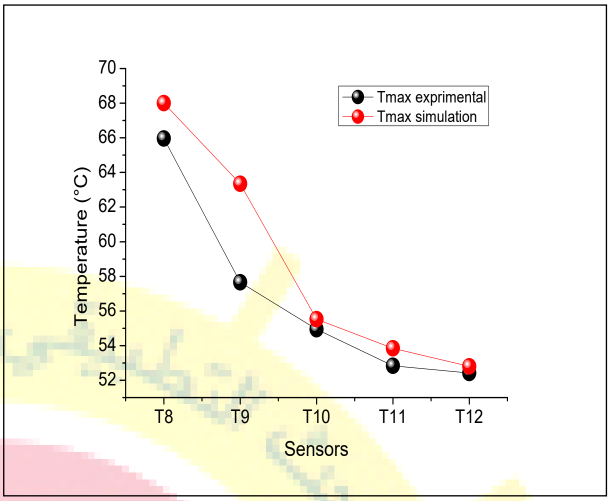

Fig.5.(F). Temperature changes of sensors at different place chimney

TABLE IV

The temperature data for COMSOL evaluation in chimney

Sensor	COMSOL (°C)	Experimental (°C)	Variation value (°C)	Error (°C) (%)
T8	68.00	65.96	2.04	3%
T9	63.34	57.66	5.68	8.96%
T10	55.52	54.94	0.58	1.04%
T11	53.85	52.83	1.02	1.89%
T12	52.80	52.42	0.38	0.71%

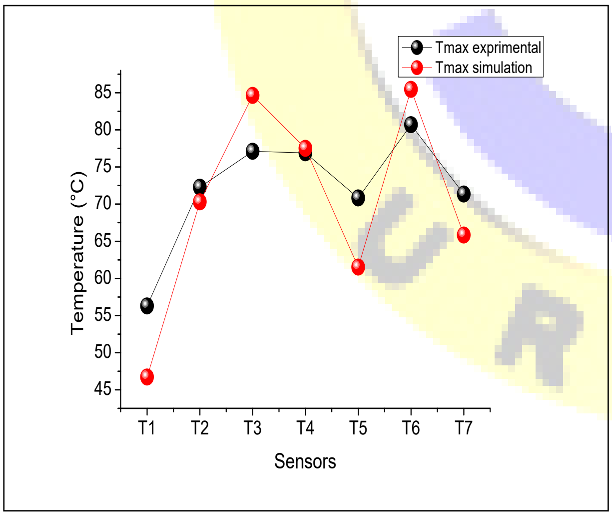

Fig.5.(E).Temperature changes of sensors at different place collector

In this experimental work and Simulation with COMSOL we chose twelve (12) typical points where our sensors (T1 to T12) were used to measure the air temperatures in the solar chimney (SCPP). The temperature changes were obtained during a full day. According to Figure.5. (E) and (F). which illustrates the variation of air temperature maximum in the collector and along the chimney, we note that the topology of the graphs is the same for the all sensors, we can see clearly that there is an increasing of temperature from T1 to T6 corresponding to the incoming cold air from outside, at the same time there is a decreasing of temperature along the chimney (T8 to T12) because of the cooling by the internal walls of chimney. We can also notice that we have an air temperature gradient between the sensors located at collector (T1 to T7) and chimney (T8 to T12). This gradient will generate airflow (heated air inside solar chimney to cold air outside) this phenomenon creates a air velocity that is used to turn the turbines for the production of electricity. The variation of air temperature is in good agreement.

V. CONCLUSIONS

Solar chimney power plant is considered as renewable power source which is used as clean source of electricity production. A small experimental solar chimney was built with three (03) meter of collector diameter covering by Low-density polyethylene (LDPE), six (06) meter for chimney height using the Polyvinylchloride (PVC) and two types of absorbers, Aluminum and black plastic. Thermo-Hygro-Anemometer, LM 35, Arduino maga were used as measuring devices and data processing. We have resorted to many factors to achieve this work; climatic conditions such as temperature, time of sunshine, solar radiation and humidity. These factors will help to increase temperature under collector by greenhouse effect which creates an air flow that can generate electricity. In our optimization, we have found A simulation study with COMSOL to improve the solar station with several factors to integrate in the solar chimney to have a maximum efficiency and to minimize the cost of investment. The results obtained with the COMSOL simulation model are very close with the results that mark with the experimental study.

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