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EXPERIMENTAL ANALYSIS MODELLING OF TOWER SOLAR CHIMNEY

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***Abstract*— Solar Tower Chimney (STC) is one of the sustainable sources. The aim of the experiment is to study the effect of different air temperatures (ambient temperature) on the airflow inside the chimney as well as on the power generated by (STC) during the summer period and the possibility of installing tower solar Cchimney in Basrah region. The experiment result shown that the power produced by the chimney will increase per hour, when the outside temperature increases. In the present work, different values of the air velocity inside the chimney (height 7.2 m) were measured, the maximum was reached at 2:00 pm (2.9 m/s) afternoon when the ambient temperature was 45.8 C°. The absorbing surface effect is discussed. It was noted that the high level of humidity and the excessively flying dust in most days of the year are considered to be the most important determinants of this type of systems. The present study included developing a simplified mathematical model depending on the conservation of energy and mass for the present solar chimney.**

Keywords*— *Solar Cchimney; experiment; thermal energy; air velocity; power output; convection, tower.

I. INTRODUCTION

There are more designs concept of a renewable energy power plants for generating electricity from low-temperature solar heat. Air is heated under a very wide covered collector structure, resembling a greenhouse, surrounding the central base of a tall Chimney Tower (Figure 1). Mostly the solar chimney is insulated to prevent heat exchange between the air inside chimney and its out surrounding [1]. The resulting convection causes an upward flow of hot air in the cooling tower due to the chimney effect. This airflow drives the wind turbines placed in the flue updraft or around the base of the flue to generate electricity [2]. Thermal energy of air is converting to mechanical energy by a turbine to generate electricity. There are many researchers interested in experimental design to improve (STC), and how to receive the highest efficiency. Nowadays, many types of research are developed to study solar chimney in order to produce electricity. The first Solar Chimney Power plant was in Spain in 1983 [3,4]. Azeemuddin et al. predicted that the parameter to increase the system power output is to increase its size. Their study deals with simulation work to validate results of pilot plant and include the effects of waste heat from a gas turbine power plant in the system and the effects show continuous night operation, lead to increase in power global solar irradiation at daytime and also lead to increase in overall efficiency [5]. Md. Sakir, et al, presented theoretical and experience for making a small and less expensive prototype plant which can be built on rooftops of residential buildings, the experimental results showed that the average power output varies from 3 to 20 watts and the efficiency was maximum 0.11% [6]. A. Shyaa et al. investigated experimentally and numerically, the reduction area of solar collector and they performed numerical study using ANSYS Fluent, they focus on study the effect of change the height of reduction area to the design velocity [7]. A. Bejalwar and P. Belkhode analysis solar power generating unit in which a solar collector and solar chimney was used to generate a solar induced air flow which drives turbine to generate electricity, they presented formulation of mathematical model for experimental setup of a small chimney [8].

Iraq southern cities are ideal to generate electricity by (STC) technology due to the very height temperature degrees.

The aim of the study is to create experiment model (in Basrah) of a solar chimney to study temperature differences, velocities and airflow (in collector, ground and chimney) per day. The main measurements were to analyze of different parameters which are affected on power output. It was noted that the high level of humidity and the excessively flying dust in most days of the year are considered to be the most important determinants of this type of systems. The present study included developing a simplified mathematical model depending on the conservation of energy and mass for the present solar chimney.

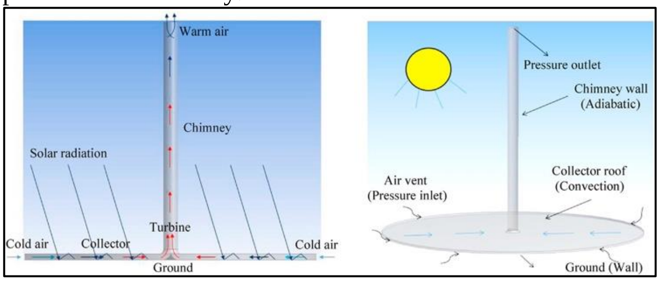

Fig.1. Principle of tower solar chimney

II. MATHMALTICAL MODELING

The principle of the conservation of energy and mass of the present solar chimney Fig (1). There are three unknown temperatures T_{co}, T_g, $T_{air,\ out,\ collector}$ and air mass flow rate can be determined by solving eenergy balance equations. Air flow inside Solar Chimney and between collector and ground is natural convection (Free buoyancy). The mathematical model is developed by assumptions:

1.One dimension flow towards center collector.

2.Steady-state flow air inside collector.

3.The ambient temperature is equal to inlet collector temperature.

The energy balance equations of the tower solar chimney is presented by:

Energy balance equation for collector:

$$A_{Co} + h_{radiation,glass,co-radiation} * A_{glass}\left(T_{glass} - T_{co}\right) - -h_{convection,Co,air} * * A_{co}(T_{co} - T_{air}) - L_{loss} * A_{co} = 0 \quad (1)$$

S: The solar rotation absorbed by the absorber plate;
h: Convection heat transfer coefficient;
A: area (m^2);
T: Temperature of glass, collection and air C°;
L_{loss}: Total heat losses.

Heat transfer convection coefficient calculated by Duffine and Beckmann [9]:

$$h_{heat,conv,coff,co-ambient} = 2.8 + 3.0 * U_{wind} \quad (2)$$

U_{wind}: The velocity of wind (m/s), T_{sky} is the temperature of the sky (C°) [10].

Radiation heat transfer coefficient between outlet of collector to the sky by Bansalet al [11]:

$$h_{r,co-sky} = \frac{\sigma * \varepsilon_{co} * \left(T_{co} - T_{sky}\right) * \left(T_c^2 - T_{sky}^2\right) * \left(T_{co} - T_{sky}\right)}{\left(T_{co} - T_{ambient}\right)} \quad (3)$$

Heat transfer coefficient between collector and the ground given by Bansal [11] and Acre [12]:

$$h_{r,ground-co} = \frac{\sigma * \left(T_{ground}^2 + T_{co}^2\right)}{\left(1/\varepsilon_{ground}\right) + \left(1/\varepsilon_{co}\right) - 1} \quad (4)$$

Energy balance equation of airflow in the collector:

$$Q_{air} = \left[h_{convection,co-air} * A_{co}(T_{co} - T_{air})\right] + +\left[h_{convection,ground-air} A_{groung}\left(T_{ground} - T_{air}\right)\right] \quad (5)$$

Energy balance equation of ground:

$$S_{ground} * A_{ground} = \left[\left(T_{radiation,ground-co} A_{ground}(T_{ground} - -T_{co})\right) + \left(h_{convection,ground-air} * A_{ground}\left(T_{ground} - -T_{air}\right)\right) + +\left(L_{d,loss} * A_{ground}\left(T_{ground} - T_{ambient}\right)\right)\right] \quad (6)$$

Mass flow rate inside the collector:

$$\dot{m}_{ch} = \rho_{air} * V_{ch} * \pi/4 * D_{ch}^2 \quad (7)$$

ρ_{air}: Air density;
V_{ch}: Air velocity (by designer);
D_{ch}: Solar chimney diameter.

III. Experiment Procedure

Suitable site is choosing which exposed to the sun for a long period of time. The site does not contain shadow areas, and containing some ground prominences that were disposed by work Manual as shown in (figure 2). The experiment has done in Basrah City (Iraq). North of equator Latitude: 30°34'08.1"N Longitude: 47°44'59.3"E.

Fig.2. Removing obstacles

The equalization of ground was carried out using a mechanical compactor to obtain a flat surface free from aliasing as in Fig .3.

Fig.3. Ground leveling process

The ground was covered with a piece of clear plastic, and three layers of wood were laid out, thermal conductivity of the used wood is (0.16 w/m.K), layer of aluminium with a high conductivity of 247 W/m.K and thickness of 4 mm was used and fixed with wood layer together by screws. The aluminium is painted with black colour to get high possibility of absorbing heat as shown below (figure 4),as well as to decrease losses of heat.

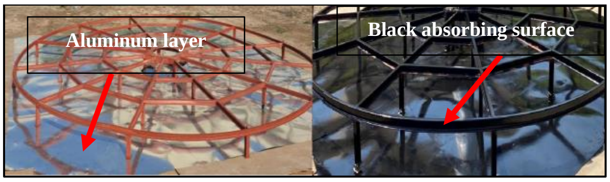

Fig. 4. Aluminum layer

The final design of the collector has is drawn by the Auto CAD program (figure 5). For our plant the Collector is a round-shaped drawing to obtain a highest efficiency of diameter of 5 m, as well as the diameter of the chimney and its height was chosen to be 15.24 cm and 6 m height, these dimensions were chosen using previous research, that have similar weather conditions to ours [6], (approximately) was selected considering availability of material in the local market. The height between the collector and the ground taken to be 20 cm.

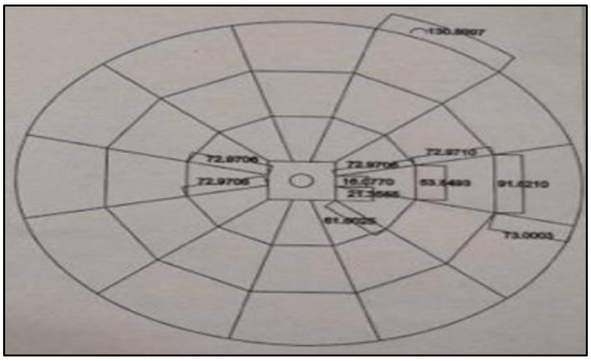

Fig. 5. Project design (top's view)

The connection between the solar chimney and diffuser is designed to decrease losses of air velocity because of friction by sharp edges. The diffuser height is 1.2 m so after connection the total height becomes 7.2 meters

The main reason of covering solar chimney by thermal insulation material is to prevent heat exchange between the internal air of SC and its outside circumstances, as shown below Fig. 6.

Fig .6. Diffuser

Transparent glass with high transmittance in figure (7), and thickness of 4 mm is used to penetrate the largest possible amount of solar radiation.

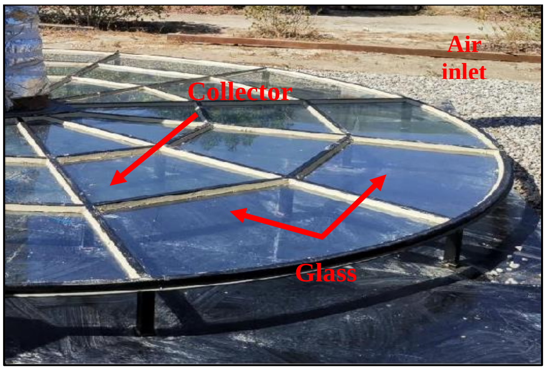

Fig. 7. Collector and glass

For measurement temperatures were used ten thermometer devices. Five of them are placed on the ground surface. The distance between them is 60 cm, one of them is located below center solar chimney (SC). Three thermometers are used for measuring air temperature, and one sensor is located at the entrance of the chimney. Collector temperature is measured by two sensors, as shown below Fig. 8.

Fig. 8. Temperature sensors

The final design of the solar chimney tower is in figure.9.

Fig. 9. Solar chimney tower

IV. EXPERIMENTAL RESULTS

The MATLAB program was used to find unknown temperature values, Thus, the possibility of calculating the performance of the system. The program is designed using the Gauss-Seidel iteration method. The following temperature were obtained (T_{glass}= 75 C^0, T_{co}= 58.16 C^0 and T_{air} = 60 C^0).

The temperature of the experiment is collected on 21st of August 2020 year by ten hours from 8:00 am to 17:00 pm according to Basrah weather conditions. Air velocity is recorded inside solar chimney by the Anemometer model (HTA105) at a height of 150 cm, as well as at five points on the internal surface of (SC) and the center point. Minimum and maximum ambient temperature between 41 C° At 8:00 am and 46.4 C° at 13:00 pm as shown in (table 1). The maximum air velocity is 2.9 m/s at 14:00 pm (table 2).

TABLE 1. RESULTS OF EXPERIMENT DURING A DAY .

Time (hr)	Temperature (collector, air, ground and ambient) C°			
	$T_{collector}$	T_{air}	$T_{ambient}$	T_{ground}
8	40.2	43.3	41	49.9
9	39.9	44.3	42.3	52
10	47.1	50.7	43.5	75.6
11	49.7	54.2	44.5	81.2
12	55.2	54.1	45.6	70.8
13	53.3	51.1	46.4	66
14	53.3	51.6	45.8	67.8
15	52.1	49.5	45	64.9
16	50.5	48.6	44.7	61.3
17	45.2	44.8	43	52.9

TABLE 2. RESULTS OF EXPERIMENT DURING A DAY .

Time (hr)	Velocity inside solar chimney and ambient velocity (m/s)	
	$V_{ambient}$	$V_{Chimney}$
8	0.46	1
9	0.59	1.2
10	0.75	1.7
11	0.86	1.8
12	1.12	2.1
13	1.35	2.4
14	1.2	2.9
15	1.1	2.5
16	0.92	2
17	0.85	1.6

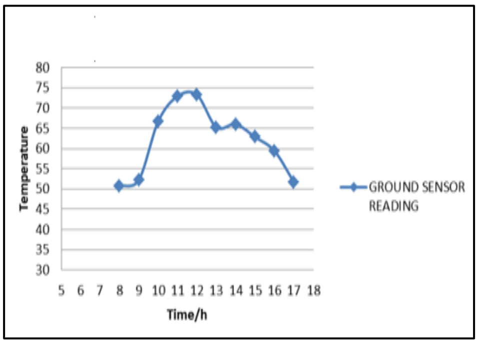

Fig. 10. Ground temperature per hour

In figure. 10. Maximum temperature of the ground surface is about 75 °C average temperature in the period of (11:00 -12:00) the temperature is decreasing till 17:00 pm, where the temperature is 52 °C. There is more than one measurement value of ground temperature due to the readings were taken during the daytime from 8 am to 17 pm.

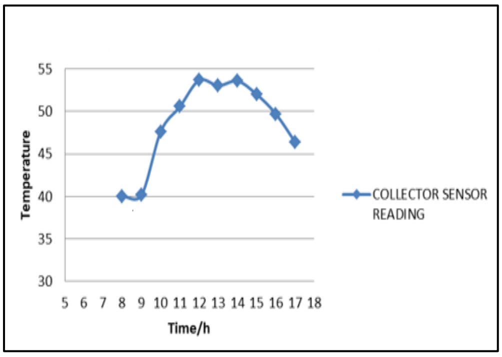

Fig. 11. Collector temperature per hour

Figure above is shown that is the maximum collector temperature is between 55 C° to 53.3 C° at (12:00-14:00) pm. |The minimum glass temperature is 40 C° at 8:00 am.

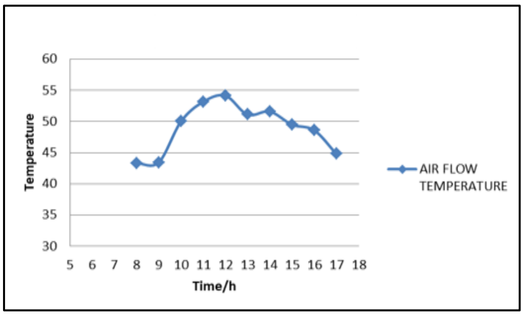

Fig. 12. Airflow temperature per hour

The air temperature between the ground and glass surface at 12:00 pm is 54.3 °C, and the minimum air temperature value is 40.6 °C (at 8:00 -9:00) am (Figure 12). The different temperature between maximum and minimum is 13.7 °C.

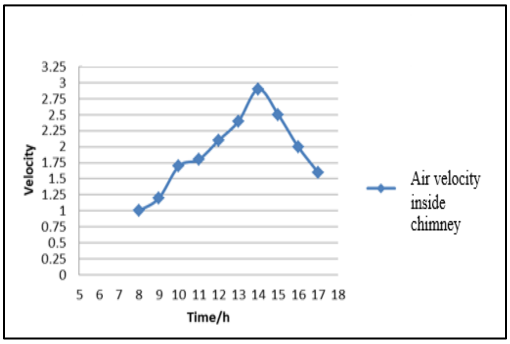

Fig. 13. Air velocity inside chimney per hour

It has been shown the minimum value of air velocity is 1 m/s at 8:00 am after the velocity is increasing to a maximum of 2.9 m/s at 14:00 pm. The decreasing of the velocity starts from 14:00 pm to 17:00 pm where the velocity is 1.6 m/s as shown in (Figure 13).

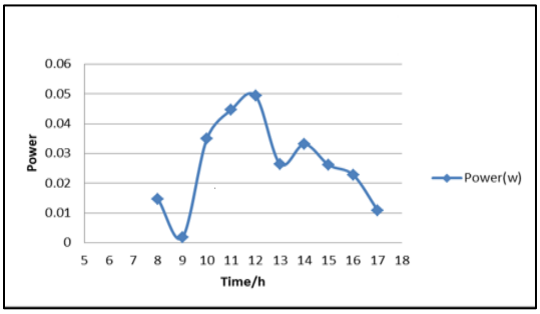

Fig. 14. Power per hour

The different value of power depends on the temperature difference between air inside solar chimney and its circumstances ambient temperature, as well as, depending on mass flow rate. The highest power value is 0.049376 watts at 12:00 pm.

V. CONCLUSION

According to the experiment it has been shown that is possible to use tower Solar Chimney Technology in Basrah City (Iraq), due to the availability of suitable conditions where the temperature is able to reach 56 °C. The maximum power value was reached at the highest point during the day. The air velocity inside the chimney (2.9 m/s at 14 pm) depends on the temperature difference between the outside air temperature and air temperature flowing among the ground and the collector. The presence of dust on the surface glass leads to a decrease solar radiation due to the decreasing of absorption. The temperature increases gradually as we get closer to the center (SC) because the effect of the outside air on cooling surfaces is decreased as we move away from the edges. Power, air velocity and collector and ground temperature increasing from period 14:00 pm to 17:00 pm during the day. Turbine rotation depends on fan blades that must be light and the angle proportion to inlet airflow to the solar chimney. The heat balance equations are discussed for collector, airflow inside collector and ground to calculate temperatures.

REFERENCES

[1] Davood Toghraie, Amir Karami, Masoud Afrand, Arash Karimipour, "Effects of geometric parameters on the performance of solar chimney power plants, Energy", Vol. 162, pp. 1052-1061, 2018.

[2] Jing-yin Li, Peng-hua Guo, Yuan Wang.2012. Effects of collector radius and chimney height on power output of a solar chimney power plant with turbines. School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China. Renewable Energy 47; 21-28, (2012).

[3] Ming Tingzhen, Liu Wei, Xu Guoling, Xiong Yanbin, Guan Xuhu, Pan Yuan, "Numerical simulation of the solar chimney power plant systems coupled with turbine Renewable Energy," Issue 5, Vol. 33, pp. 897-905, 2008.

[4] W. Haaf, K. Friedrich, G. Mayr, and J. Schlaich, "Solar chimneys, part I: principle and construction of the pilot plant in Manzanares," International Journal of Solar Energy, vol. 2, no. 1, pp. 3–20, 1983.

[5] A. Islamuddin, H. Al-Kayiem .S. Gilani" Simulation of solar chimney power plant with an external heat source" IOP Conf. Series: Earth and Environmental Science 16 (2013) 012080.

[6] T. Sakir, B. Khan ,B. Piash & S. Akhter" Design, Construction and Performance Test of a Small Solar Chimney Power Plant" Global Journal of Researches in Engineering Mechanical and Mechanics Engineering Volume 14 Issue 1 Version 1.0 Year 2014.

[7] A. Shyaa, R. Albaldawi, Maryam, M. Abbood "Experimental and Numerical Study of Collector Geometry Solar Chimney Performance etry Effect on solar chimney performance" Al-Khwarizmi Engineering Journal,Vol. 12, No.4, P.P. 59- 71(2016).

[8] A. Bejalwar and P. Belkhode "Analysis of Experimental Setup of a Small Solar Chimney Power Plant" 2nd International Conference on Materials Manufacturing and Design Engineering, Procedia Manufacturing 20 (2018) 481–486.

[9] S.W.Churchill , H.H.S. Chu "Correlating equations for Iaminer and turblant free convwction from a vertical plate,"18, pp 1323-1329, 1975.

[10] J. Mathur, S. Mathur, Anupma. "Summer- performance of inclined roof solar chimney for natural ventilation. Energy and Building,"[] 38, pp 1156-1163, 2006.

[11] N. Bansal, R. Mathur, M.Bhandari "Solar chimney for enhanced stack ventilation building and Environment," 28, pp373-377, 1993.

[12] J. Arce, J.P . Xaman, G.Alvarez, M. Jimenez, R. Enriquez, M.R. Heras. "A simulation of the thermal performance of a small solar chimney already installed in a building,"Journal of solar Energy Engineering, 135, pp. 1741-1747, febuary 2013.