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Thermal Study of Solar Parabolic Concentrator

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Abstract: *The advancement in parabolic dish technologies has led to the development of steam generation; a feasible and efficient solution that utilizes the sun's energy for heat supply in industrial processes as well as for thermal power generation. In this paper a solar parabolic dish with aperture area of 3.8 was designed, manufactured and evaluated is presented. In order to improve the thermal efficiency, reduce the heat losses and achieve steam production of the concentrator solar power (CSP), many experimental tests were carried out in the Research and Technology Center of Energy (CRTEn) in Tunisia. 2 m*

Keywords – *Oil, Parabolic dish, Steam generation, Thermal efficiency, Water.*

I. Introduction

In the last ten years, oil prices became very high as well as the reserves amounts have been decreased. Moreover, burning fossil fuels such as coal, oil and natural gas for energy generation causes global warming and pollution problems. Based upon these facts, new resources of clean energy are necessarily needed. Renewable energy is the promising solution to this problem. Therefore, significant researches have been reported on how to utilize renewable energy resources efficiently. One of the most important resources of renewable energy is the solar energy which has widely spreading applications. It has been used for water heating, direct electricity generation by means of photovoltaic, and for steam generation. It is estimated that earth receives approximately 1000 W/m2 amount of solar irradiation in a day [1].The CSP (concentrated solar power) is considered as the most prominent solar energy technology. There are four types of CSP technologies: parabolic trough, linear Fresnel, solar tower and solar dish [2,3]. In 1901, Eneas in Pasadena, California operated a solar steam engine which was powered by a reflective dish [4]. In the late 1970, Omnium [5] designed a parabolic dish collector system that would run a steam engine. It was constructed from panels of polyurethane foam with a reflecting anodized surface. Thomas [6] reviewed various aspect of solar steam generation using solar concentrator.

The model proposed by Folaranmi [7] was steam generator from a parabolic dish concentrator. Using this collector, heat from the sun is concentrated on a black absorber which is placed on the focal point of the dish concentrator. Water is heated at very high temperature to form steam. The model arrangement is mounted on a hinged frame supported with a slotted lever for tilting the parabolic dish reflector to different angles. This will make the sun always directed towards the collector at different period of the day. The test results from this model shows temperature above 200 ◦C on average sunny and cloud free day. N.D Kaushika and K.S Reddy [8] present the design and performance characteristics of a low cost solar steam generating system which incorporates recent design of parabolic dish technology. Preliminary field measurements and cost, as well as performance analyses of the system, indicate a solar to steam conversion efficiency of 70±80% at 4508C and a collector system cost of Rs 8000±9000/m2 (US$1=Rs, 40.0).

The Australian National University has worked for many years on paraboloidal dish solar concentrators and demonstrated a 400 m2 system in 1994. K.Lovegrove et al.[9] demonstrated a 500 m2 concentrator with 13.4 m focal length and altitude–azimuth tracking. It uses 380 identical spherical 1.17 m × 1.17 m mirror panels, which incorporate the Glass-on-Metal Laminate mirrors. The first on sun test was carried out on 29 June 2009. Vishal R. Sardeshpande et al.[10] proposed a test procedure for characterization of point-focus steam generating solar concentrators based on latent heating at different operating temperatures. This procedure can be used to estimate thermal efficiency of solar concentrator at different operating temperatures above 100 °C. Fareed.M.Mohamed et al.[11] designed and fabricated a solar dish concentration with diameters (1.6) meters for water heating application and solar steam. In this experiment, Water temperature increased up to 80°C, and the system efficiency increased by30% at mid noon time.

II. Experimental Setup

Our experimental setup is a solar parabolic dish designed and constructed in (CRTEn). The experimental system of the solar parabolic concentrator SPC is mainly composed of a parabola provided with an absorber placed by three arms at the focal position. A reflector embedded in a nacelle rotatable around two axes: the horizontal axis (elevation angle) from the support supported by a mast and the second is the vertical axis (azimuth angle) and counterbalancing. The characteristics of the SPC are given in Table 1.

Table 1: Parameters of reflector

Geometrical parameters	Value	Unit
Opening diameter of the parabola D_0	2.2	m
Aperture area of the parabola S	3.8	m^2
Depth of the parabola h	0.4	m
Focal distance f	0.75	m
Mass of the dish M	49.8	Kg
Position of the center of inertia G_p	0.26	m

The equation for the parabola in cylindrical coordinates is defined as:

$$Z = \frac{r^2}{4f} \tag{1}$$

The focal distance f is given by the following expression:

$$f = \frac{d^2}{16h} \tag{2}$$

The paraboloid surface S with opening diameter d is given by:

$$S = \frac{8\pi}{3} f^2 \left\{ \left[1 + \left(\frac{r}{2f} \right)^2 \right]^{3/2} - 1 \right\} \tag{3}$$

The opening surface of a paraboloid S_0 is given by:

$$S_0 = \frac{\pi d^2}{4} \tag{4}$$

Using concentrating collector, heat from the sun is concentrated on a black absorber located at the focus point of the reflector in which oil is heated to a very high temperature. It also describes the sun tracking system unit by manual tilting of the lever at the base of the parabolic dish to capture solar energy. The whole arrangement is mounted on a hinged frame supported with a slotted lever for tilting the parabolic dish reflector to different angles so that the sun is always directed to the collector at different period of the day (Fig 1).

Figure 1: Installation of parabolic solar collector.

In this experiment, we used 6 Thermocouples (Type K, precision ± 0.5 ° C) in order to determine the ambient temperature, inlet and outlet oil temperature, inlet and outlet water temperature, the temperature in the interior of water reservoir and a pyranometer CM 11 used to determine global radiation during this experiment. We used acquisition system of data CR5000 in order to control and verify the quality of established data.

III. Results and Discussion

3.1 Study of Solar Radiation

3.1.1 Estimated Direct and Diffuse Radiation

The estimation of global solar radiation is essential for utilization the solar energy, design wherever appropriate observations missing [12]. The measurement of global and diffuse radiations at ground was performed by a pyranometer. The Solar radiation who reaches the ground is formed by a direct radiation and a diffuse radiation which they are together form the global radiation [13] and [14], we dedicate these respectful radiation respectively by the letters *I* (direct), *D* (diffuse) et *G* (global), all these are calculated with W m−2.

The diffuse radiation D, the direct radiation I and the global radiation G obtained by simple integration:

$$I = E\tau_b \cos(h) \quad \textbf{(5)}$$

$$D = E\tau_d \cos(h) \quad \textbf{(6)}$$

$$G = I + D \quad \textbf{(7)}$$

E is the solar constant; h is the elevation angle, τ_b is the transparency of the atmosphere for direct radiation and τ_d is the transparency of the atmosphere for diffuse radiation.

The transparency of the atmosphere for direct radiation τ_b determined by the formula presented by Hottel (1976).

$$\tau_b = r_0 a_0 + r_1 a_1 \exp(-r_k k / \sin(h)) \quad \textbf{(8)}$$

a_0, a_1, k coefficients depending of Z.

$$a_0 = 0.4237\text{-}0.00821\ (6 - z)^2 \quad \textbf{(9)}$$

$$a_1 = 0.50550.00595\ m^2\ (6.5 - z)^2 \quad \textbf{(10)}$$

$$K = 0.2711 + 0.01858\ (2.5 - z)^2 \quad \textbf{(11)}$$

In our case Z =0

r_0, r_1, r_k coefficients depending of climate.

The transparency of the atmosphere for diffuse radiation τ_d determined by the following expression:

$$\tau_d = 0.2710 - 0.2939\tau_b \quad \textbf{(12)}$$

3.1.2 Experimental Study of Solar Radiation

Figures 2 and 3 present climatic conditions during the experiment which illustrate the temporal variation of global and direct solar radiation of parabolic dish and ambient temperature. We note that much of the global solar radiation is absorbed by the absorber placed in the foyer. We also observe that the direct energy increases with sunshine. For a maximum value of global energy 800 W at noon, direct solar radiation is 200 W for ambient temperature equal to 30°C.

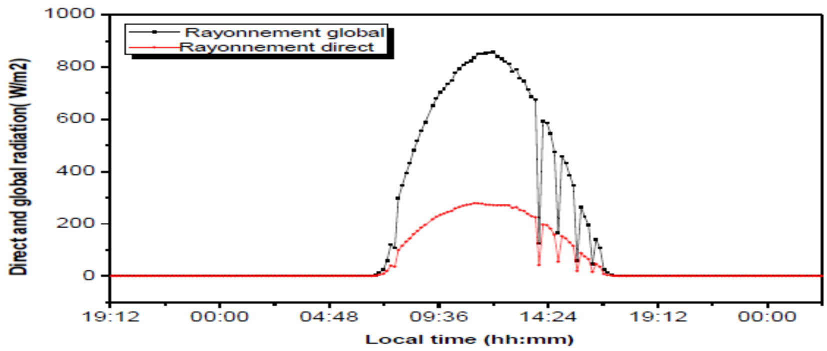

Figure 2: Temporal variation in the global and direct solar radiation.

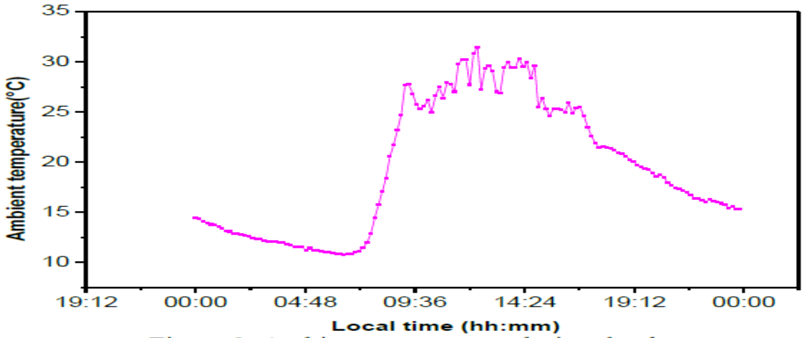

Figure 3: Ambient temperature during the day.

3.2 Study of the Variation of Oil Temperature

In this experience, we study the variation of the oil temperature in input and output as a function of local time (Fig 4). At the beginning of the day, we notice a small difference of temperature of the order of 5 °C then it increases rapidly and it becomes of the order of 30 °C. At the beginning of the day, the outlet temperature of oil of the order of 50 °C then it increases after 9 h30 until a maximum value 80 °C (Fig 4).

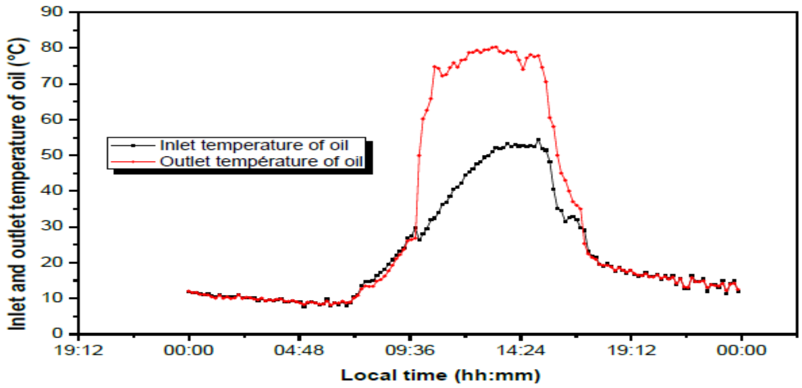

Figure 4: the variation of the oil temperature in input and output as a function of local time.

The heat flux u Q extracted by the absorber is expressed by the following expression [15]:

$$Q_u = \dot{m} C_p (T_{outlet} - T_{inlet}) \tag{13}$$

Using this equation, we obtained Figure 5 which presents the variation of the useful power of the oil as a function of local time. We can say that the useful power of oil is proportional to the temperature difference in inlet and outlet. The optimum value of the experimental useful energy varied between 10 W/$m^2$and 30W/m^2 , for maximum radiation equal to 800W/m^2 . Experimental fluctuations due to the precision of tracking system (Fig 5).

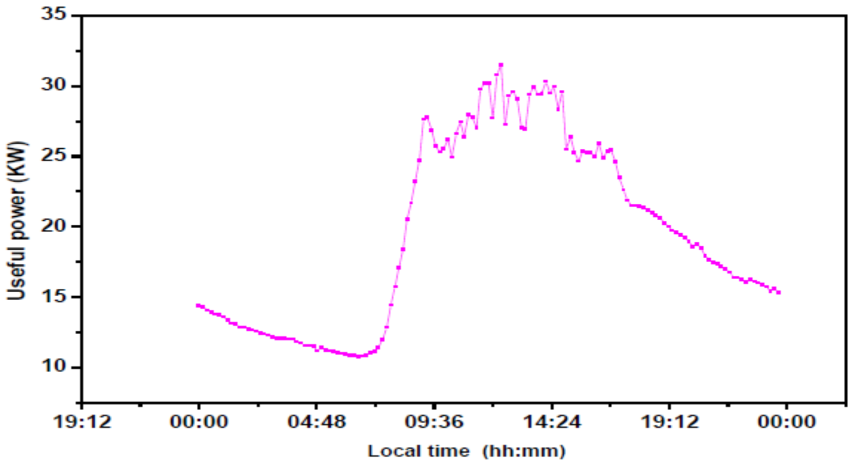

Figure 5: The variation of the useful power of the oil as a function of local time.

The thermal efficiency of the SPC is given by the following expression [15]:

$$\eta_{en} = \frac{Q_u}{I} \quad \textbf{(14)}$$

$$C_R = \frac{A_a Q_u}{A_{ab} I} \quad \textbf{(15)}$$

We carried out an analysis of energy efficiency of CSP. Figure 6 present the variation of experimental thermal efficiency and the concentration ratio as a function of local time. Therefore it is found that the thermal efficiency of CSP during the day varied between 40 % to 77 % and it represent a concentration ratio of the order of 150.

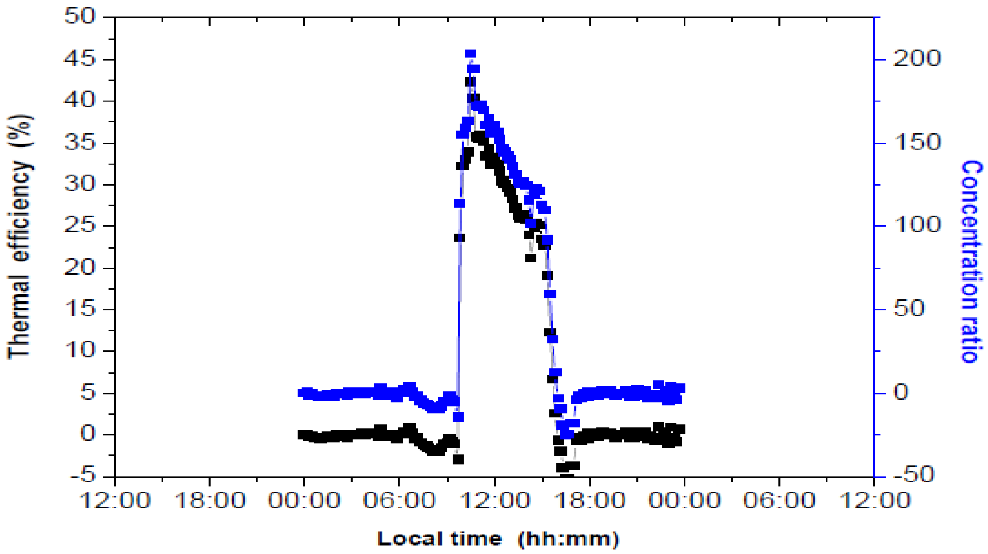

Figure 6: The variation of experimental thermal efficiency and the concentration ratio as a function of local time.

3.3 Study of the Variation of Water Temperature

Figure 7 shows temporal variation of the inlet and outlet temperature of water and temperature of water reservoir. Also according to the experimental study, it follows that we can achieve an outlet temperature of 85°C for a very high flow which shows that it may have an outlet temperature much more important for low flow and we can have other applications by the device such as steam generation.

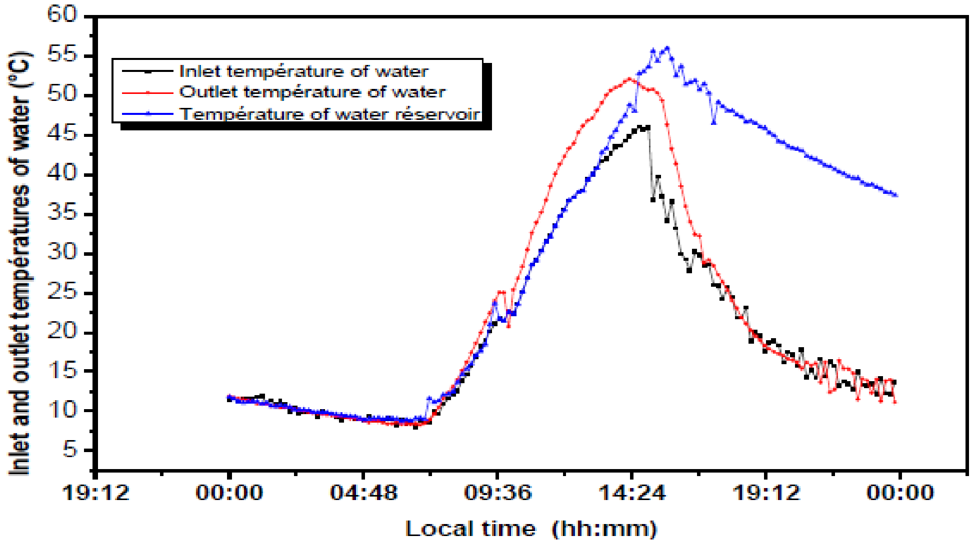

Figure 7: Temporal variation of the inlet and outlet temperature of water and temperature of water reservoir

IV. Conclusion

This work is a contribution of a solar parabolic concentrator equipped with a manual tracking. Using this collector, heat from the sun is concentrated on a black absorber which is placed on the focal point of dish concentrator. Water is heated at very high temperature to form steam. In this experiment, we find that for a maximum value of global energy 800 W at noon, direct solar radiation is 200 W, for ambient temperature equal to 30°C. We find also that the outlet temperature of oil of the order of 50 °C at the beginning of the day then it increases after 9 h30 until a maximum value 80 °C. The average concentration ratio and average energy efficiency are respectively around 150 and between 40 % to 77 %. This device can be used for different applications like pasteurization and detoxication.

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