Thermal Efficiency of a Locally Manufactured Concentrating Solar Power System Located in Fayoum Region-Egypt

M. Abdelmonem, G. Said, N. Yasein and H. Hassan

Abstract— A locally manufactured concentrating solar power system LM-CSPS is designed and constructed in Fayoum-Egypt in order to study its thermal efficiency and the heat power output which could be probably used in the solar exploitations. LM-CSPS was built on the theoretical background of the parabolic solar collector and its total thermal efficiency was calculated being on average 27.5% with a heat power output 15.0 MJ/day which represents an important good result for extracting free and clean energy.

Index Terms— Concentrating Solar Power, LM-CSPS, Thermal Efficiency, Heat Power Output.

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1 INTRODUCTION

The sun radiates an enormous amount of energy through the process of nuclear fusion. The high pressure and temperature in the sun's core causes electrons to be stripped from hydrogen atoms, freeing the hydrogen nuclei to combine (fuse) to form one helium atom, producing radiant energy in the process. Every hour the earth receives from the sun as much energy as the world consumes in an entire year. In this study a simplified LM-CSPS was employed to estimate the solar radiations in Fayoum region-Egypt, Abdelmonem et. al **[1-2].**

Concentrating solar power technologies use solar radiation to achieve high temperatures and to generate steam or air with high energy density. Also, solar radiation can be converted directly to usable energy through a variety of technologies, and that energy can be used for small-scale applications such as powering hand-held calculators, powering solar vehicles, or heating water for residential applications. Solar thermal power generation will play an important role in a well-balanced mix of renewable energy sources, efficient power technologies and rational use of energy. Solar energy can also be used for large-scale commercial applications such as generating electricity in solar power plants.

Concentrating solar power CSP technologies employ reflecting surfaces such as mirrors to concentrate the sun's light energy and convert it into high temperature heat to create steam to drive a turbine that generates electrical power generator.

The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts the heat energy to electricity. Trough systems use large, parabolic reflectors that have oil-filled pipes running along their center, or focal point. The mirrored reflectors are tilted toward the sun, and focus sunlight on the pipes to heat the oil inside to as much as 400°C. The hot oil is then used to boil water, which makes steam to run conventional steam turbines and generators **[3-7]**.

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which can be drawn for use at night or at cloudy days.

2 PARABOLIC CONCENTRATOR GEOMETRY

Kalogirou **[8]** stated that the linear concentrators with parabolic cross section have been studied extensively both analytically and experimentally, and have been proposed and used for applications requiring intermediate concentration ratios and temperatures in the range of 100 to 500^{o}C.

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A cross-section of a parabolic trough collector is shown in Fig. 1, where various important factors are exhibited.

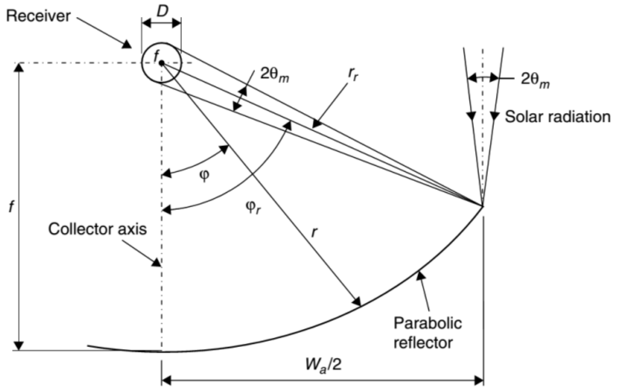

Fig.1: Cross section of a linear parabolic concentrator

The incident radiation on the reflector at the rim of the collector (where the mirror radius, rr, is maximum) makes an angle ϕ_r with the center line of the collector, which is called the rim angle. The equation of the parabola in terms of the coordinate system is:

$$y^2 = 4fx \tag{1}$$

where f = parabola focal distance .

For specular reflectors of perfect alignment, the size of the receiver (diameter D) required to intercept all the solar image can be obtained from trigonometry and given by:

$$D = 2r_r \sin(\theta_m) \tag{2}$$

where θ_m is the half acceptance angle .

For a parabolic reflector, the radius, r, shown in Fig. 1 is given by:

$$r = \frac{2f}{1+\cos(\phi)} \tag{3}$$

where ϕ is the angle between the collector axis and a reflected beam at the focus.

As ϕ varies from *0* to ϕ_r, r increases from f to r_r and the theoretical image size increases from $2f\sin(\theta_m)$ to $2r_r\sin(\theta_m)/\cos(\phi_r+\theta_m)$. Therefore, there is an image spreading on a plane normal to the axis of the parabola. At the rim angle ϕ_r, Eq. (3) becomes :

$$r_r = \frac{2f}{1+\cos(\phi_r)} \tag{4}$$

The aperture of the parabola, W_a is given by :

$$W_a = 2r_r \sin(\phi_r) \tag{5}$$

From eqs. 4 and 5 we can get :

$$W_a = \frac{4f\sin(\phi_r)}{1+\cos(\phi_r)} \tag{6}$$

which reduces to:

$$W_a = 4f\tan\left(\frac{\phi_r}{2}\right) \tag{7}$$

3 LM-CSPS SYSTEM

The Locally Manufactured Concentrating Solar Power System (LM-CSPS) is a simple type of parabolic trough collectors (PTCs). PTCs are systems have high performance and they give high temperatures with good efficiency. Also, PTCs have light structures with low cost technology and they can obtain process heat applications up to 400 °C. PTCs can effectively produce heat at temperatures between 50 and 400 °C. LM-CSPs and therefore PTCs are normally made by bending a sheet of highly reflective material into a parabolic shape **[9-20]**.

A metal black tube, which can be non-covered or covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver. When the parabola is pointed towards the sun, parallel rays incident on the reflector are reflected onto the receiver tube.

It is sufficient to use a single axis tracking of the sun and thus long collector modules are produced. The collector can be orientated in an east–west direction, tracking the sun from north to south, or orientated in a north–south direction and tracking the sun from east to west. The advantages of the former tracking mode is that very little collector adjustment is required during the day and the full aperture always faces the sun at noon time but the collector performance during the early and late hours of the day is greatly reduced due to large incidence angles (cosine loss). North–south orientated troughs have their highest cosine loss at noon and the lowest in the mornings and evenings when the sun is due east or due west. Many studies presented solar projects and its applications **[21-44].**

4 MANUFACTURING LM-CSPS

LM-CSPS was manufactured by a limited grant (~$1000) funded from Faculty of Science, Fayoum University and in collaboration with a local company experienced in applied industries. Table 1 shows the main components of the LM-CSPS system and Fig. 2 shows the LM-CSPS diagram consisting of two tanks, solar collector, two pumps, six valves, heat exchanger, measuring meters and steel piping system. Figs. 3 and 4 show LM-CSPS system and its components after its installation above the building of Faculty of Science, Fayoum University-Egypt.

Table 1: The components of the system

Component	Details
Tank 1	Stainless. Steel material, radius 0.2 m, height 0.5 m
Tank 2	Steel material, radius 0.2 m, height 0.5 m
Solar Collector	Stainless steel sheet, 1.2x2.4m
Pump 1	P=2 bar
Pump 2	P=1.8 bar
Valves (6) (V1, V2, V3, V4, V5, V6)	6 steel valves
Heat Exchanger (H.E)	Steel material
Solar radiation, pressure, temperature and mass flow rate meters	Measuring the required data
Piping System	Steel material

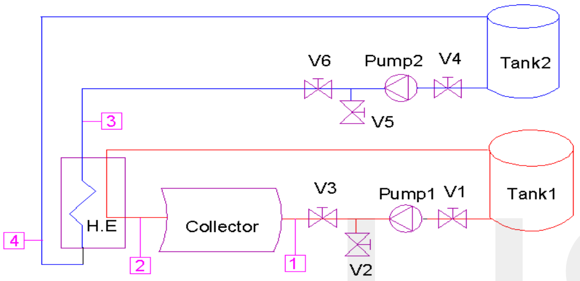

Fig. 2: LM-CSPS diagram.

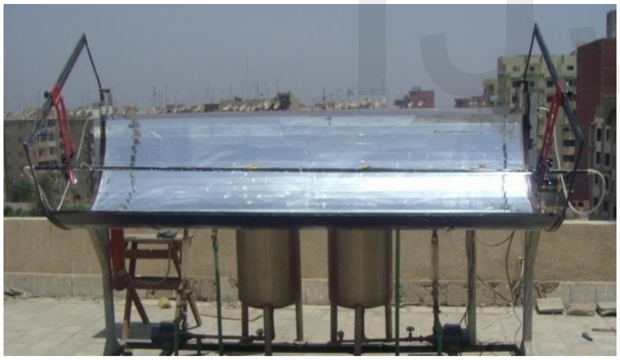

Fig. 3: Front view of LM-CSPS after its installation on Faculty of Science building -Fayoum University.

Fig. 4: Back view of LM-CSPS.

5 THERMAL EFFICIENCY OF LM-CSPS

Five thermocouples were used to measure the temperature of inlet and outlet fluids. The inlet temperature T_{in} (°C), outlet temperature T_{out} (°C) and the solar radiation R_c incident on the collector were measured while the useful heat output Q_c (J/s) and the efficiency η_c were calculated.

Li and Wang [11] stated that the useful heat power output Q_c (J/s) can be calculated from:

$$Q_c = m^* c_p (T_{out} - T_{in}) \qquad (8)$$

where m^* (kg/s) is the mass flow rate, c_p is the specific heat of the fluid (J/kg.K), T_{in} (°C) the inlet temperature and T_{out} (°C) the outlet temperature. The instantaneous efficiency η_c of the collector can be estimated from:

$$\eta_c = \frac{Q_c}{(A - A_{shade})\rho R_c} \qquad (9)$$

where A is the area of parabolic curved mirror accepting sunlight, A_{shade} is the shade area of solar collector, ρ is the reflectivity of the concentrating mirror and R_c is the solar radiation incident on the collector.

6 RESULTS

The thermal efficiency of the present locally manufactured concentrating solar power system LM-CSPS requires the useful heat output, total solar radiation incident on the system, the area of the surface of the collector and the reflectivity as in eq. 9. However, the useful heat output requires the measurements of the inlet and outlet temperatures, mass flow rate and knowledge the specific heat of the fluid as in eq. 8. Figs 5 to 8 show the thermal efficiency η_c of LM-CSPS located in in Fayoum region in the various days of 2010.

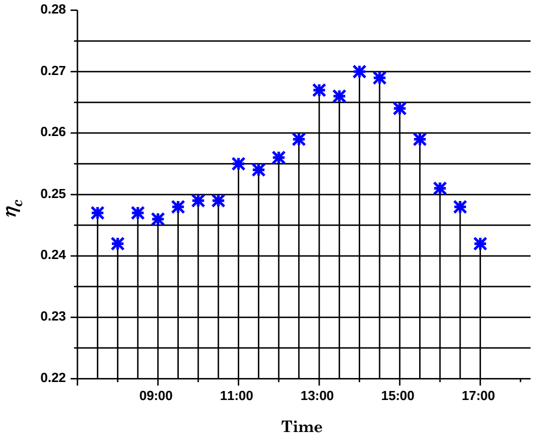

Fig. 5: The thermal efficiency of LM-CSPS, 17 Jan 2010

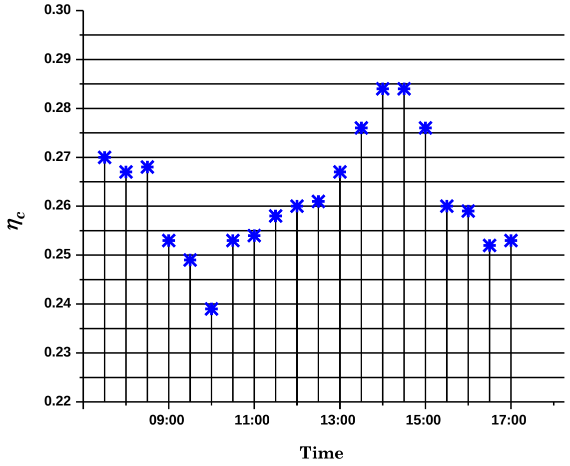

Fig. 6: The thermal efficiency of LM-CSPS, 27 Apr 2010.

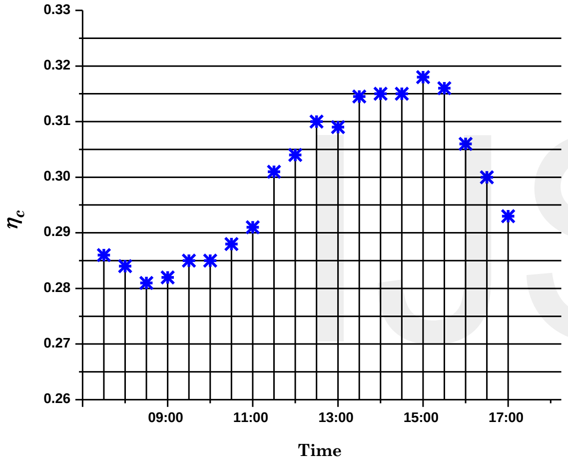

Fig. 7: The thermal efficiency of LM-CSPS, 20 Jul 2010.

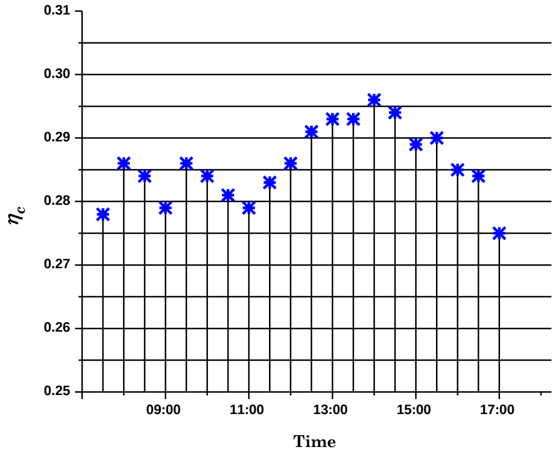

Fig. 8: The thermal efficiency of LM-CSPS, 17 Oct 2010.

The total average of the thermal efficiency η_{total} of LM-CSPS system can be calculated from the averages of the efficiency in the various days being 0.275 as is shown in Table 2.

Table 2: The total average of the thermal efficiency of LM-CSPS

	Average of η_c
17 Jan 2010	0.254
27 Apr 2010	0.262
20 Jul 2010	0.299
17 Oct 2010	0.286
Total Average η_{total}	**0.275**

The total average of the instantaneous heat power output Q_{total} of LM-CSPS system is calculated from the averages of the of heat power output in the various days of 2010. This was found to be Q_{total} = 416.6 J/s as exhibited in Table 3.

Table 3: The averages of the heat instantaneous power output of LM-CSPS

	Average of Q_c (J/s)
17 Jan 2010	276.34
27 Apr 2010	435.45
20 Jul 2010	531.75
17 Oct 2010	422.89
Total Average Q_{total}	**416.60**

In Table 4 the hourly, daily and yearly averages of the heat power output of LM-CSPS, where the daily average solar duration time in Fayoum region is about 10 hours.

Table 4: Hourly, daily and yearly averages of the heat power output of LM-CSPS

Hourly average of Q_c	1.50 MJ/hour
Daily average of Q_c	15.0 MJ/day
Yearly average of Q_c	5.47 GJ/year

7 CONCLUSIONS

We have calculated the efficiency η_c of LM-CSPS during selected days in 2010 while the total average of the instant efficiency of LM-CSPS system being 27.5%. In a more advanced concentrating solar power system (CSPS) with vacuum and using thermal fluid, Qibin et. al [44] concluded that the collector efficiency of the CSPS can be obtained in the range of 40% – 60% .

Moreover, the total average of the instant heat power output Q_{total} of LM-CSPS was found to be Q_{total} = 416.6 J/s. Also the hourly, daily and yearly total heat power output were predicted and calculated to be 1.50 MJ/hour, 15.0 MJ/day and 5.47 GJ/year respectively and this result is very important because it shows the hourly, daily and yearly amounts of the free heat energy that LM-CSPS can give.

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