Experimental study of solar parabolic concentrator efficiency used as a solar water heater

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Abstract

Production of energy by using a parabolic solar dish was carried out in Alexandria, Egypt (The latitude 31.20, and the longitude is 29.92). Factors affecting the production of energy like: i) the parabolic dish opening diameter, ii)Reflecting surface material, iii) Tank size, iv)Kind of absorber, was studied using a dual axies sun tracking system. The economical cost has been calculated for the present solar system. It has been recomended that the parabolic dish of an opening diameter of 1.8 m covered with solar film, conected to a 15 L tank and receiver with cavity absorber is able to produce 2898 KJ in December and cover its cost after 6.89 years.

Key words: Parabolic dish, Concentrating Solar Power, solar water heater.

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Nomenclature

CSP: Concentrating Solar Power.
CSPP: Concentrating Solar Power Plant.
G_{sc}: the average extraterrestial solar radiation received by the earth outside the atmosphere at the mean distance between the earth and the sun is equal to 1353 W/m^2.
$I_\circ$: the hourly extraterrestrial radiation received by a horizontal surface (Joul /m^2).
m: Amount of water heated (Kg).
n: day number
SWH: Solar Water Heater.
t: Solar time.
T_{T1}: Tank tempreture at the beging of the experiment (°C).
T_{T2}: Tank tempreture at the end of the experiment (°C).

Q_{act} : The output energy (KJ).
δ°:Angle of declination (deg)
ϕ:latitude (deg)
θ_z: Solar zenith angle, the angle between the solar ray and vertical axis.
ω: Solar hour angle, the angle in the equatorial plane between the projections of the solar ray at a certain time and that at solar noon.

Introduction

Concentrating Solar Power (CSP) technologies [1,2] only use direct sunlight, concentrating it several times to reach higher energy densities in the focus of solar thermal concentrating systems. The solar parabolic dish collector [3] is one of the most efficient energy conversion technologies among the concentrating solar power (CSP) systems. The conventional ways for generating electricity around the world face two main problems, which are gradual increase in the earth's average surface temperature (global warming) and depleting fossil fuel reserves. So switching to renewable energy technologies is an urgent need. Concentrating solar power (CSP) technologies[4] are one of renewable technologies that are able to solve the present and future electricity problems. For this purpose, a prototype of a 50 MW CSPP for electricity generation in Jordan is proposed and analysis of its economic feasibility has been performed [5].

CSP parabolic dish has been experimentaly studied several times [6,7,8]. Also, A three-dimensional model of parabolic dish-receiver system were developed to simulate the solar energy concentration into the receiver [9] and to estimate heat losses from solar parabolic dish [10]. The solar receiver [11] plays a key role in the performance of a solar dish electric generator. The total heat losses from three configurations of modified cavity receiver [12] of solar parabolic dish were investigated using 3-D numerical model.

CSP can be used in many applications, such as generation of clean electricity [13], water desalination [14,15], and water heater [16]. Solar domestic hot water heating [17] is considered one of the most important solar energy applications. A portable solar water heater was designed, built and tested [18]. The payback period of residential SWHs [19] has been studied . The integrated collector storage solar water heater [20] has the disadvantage of its high night losses.

The factors that affect the efficiency of CSP [21] has been reviewed. An example of soiling accumulation after a period of one year for the systems installed in Egypt. The energy production results showed a dusty module produced 25 and 35% lower energy compared to a clean module after a period of three months and one year, respectively[22,23].

Experimental Setup The present experiment consists of four main parts: Parabolic dish, Receiver, Mesuring devices, and Storage tank as shown in Fig.1

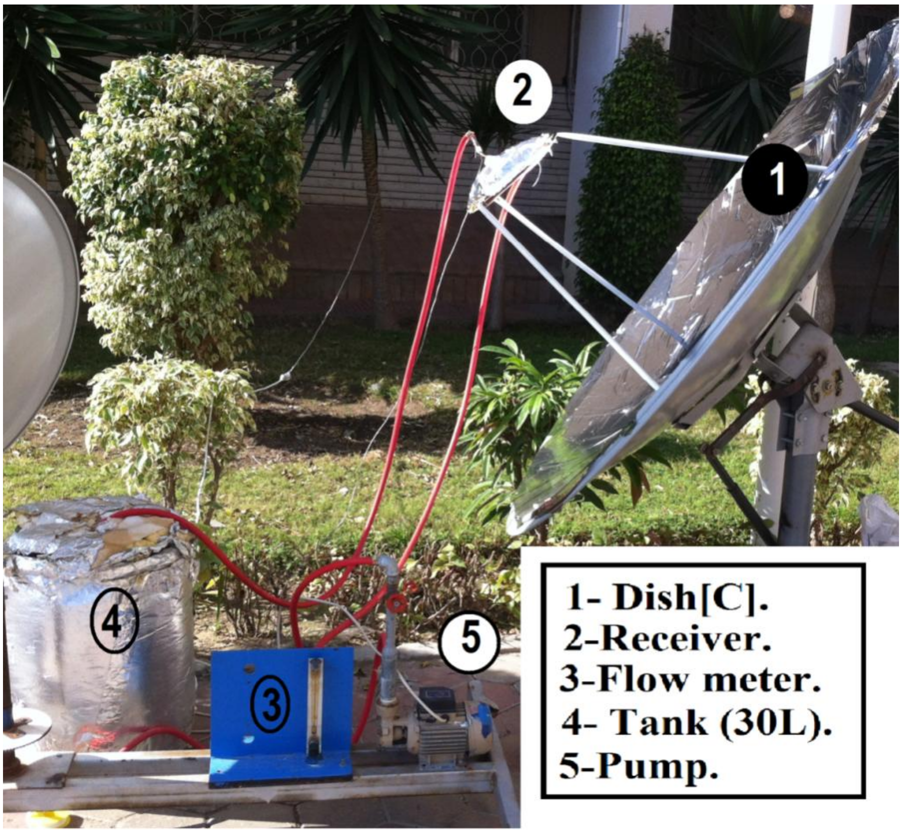

Fig.1: Experimental system (Dish[C])

Three parabolic dishes of (0.7 , 1.0 , 1.8) m opening diameter have been used in the experiments. They were made of the same material, the difference was their dimensions (table1). they have been coated by solar film and Aluminum foil as the reflective materials. The materials has been choosen based on three factors: high reflectivity, avalibilty, low coast.

Dish	A	B	C
Diameter of the parabola (D)	0.7 m	1 m	1.8 m
Depth of the parabola (d)	0.05 m	0.08 m	0.14 m
Focal distance (f)	0.6125 m	0.78125 m	1.446 m

Table1: dimensions of the three Parabolic Dishes.

The receiver is the part of the system that converts solar radiation to heat energy in a working fluid. The receiver is placed at the focal area of the parabola. The receiver consists of an absorber, heat exchanger and heat storage. Two types of absorber were investigated.The absorber is the surface for reflected solar radiation to strike. A receiver is completely insulated except for the absorber.

Fig.2 : External Absorber (Receiver after isolation with rubber)

Fig.3: Cavity Absorber (cupper case surrounding the tubes)

External absorbers (Fig.2) are flat plat absorbers. They are very cheap and simple. The cavity absorber, as shown in Fig.3, is recessed inside the receiver. Solar radiation is reflected by the concentrator through an opening, and is collected on the absorber surface. They are more expensive and complicated than external absorber.

Most heat transfer in a concentrating collector system occurs at the receiver. Energy from insolation is reflected onto the absorber and leaves the system via the working fluid and thermal losses. Heat is lost through all three modes of heat transfer: Radiation, Conduction, and Convection.

As the application of the system is to be used as a solar water heater, it was a must to measure the tempreture of the fluid in the system. Three thermocouples have been used. The first was placed in the inlet of the reciver and the second was placed in the outlet of the reciver. These two thermocouples have been used to show the change in tempreture between the inlet and outlet. The third thermocouple have been placed in the tank to show the tank's tempreture. A flow meter has been used to find out the output flow rate of the pump.

Two tanks of capacities (15, 30) liters have been used. The tanks have been isolated inorder to keep the tempreture high and prevent heat losses. Both tanks have been isolated by a glass wool.

The heat is stored in the tank to prevent heat losses to the surounding enviroment. CSP (parabolic dish) as a SWH has an advantage over the other kinds of SWH , because heat is stored in an isolated tank, and loses occure only in the reciver and during night the system is switched off. So a small amount of losses will occure. While other kinds of SWH do not have an isolated storage place where heat can be stored. So a great amount of losses occure because the water tubes exposed to light during the sun rise are exposed to wind during night.

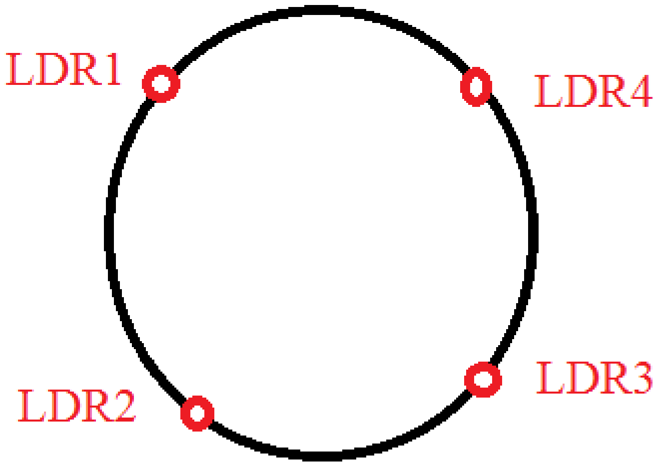

Fig.4: position of the 4 LDR sensors on the parabolic dish.

Fig.5:D.C. motors.

A sun tracking system has been designed to reflect the solar radiation on the parabolic dish to the absorber. Four LDR sensors (Fig.4) and two D.C. motors (Fig.5) has connected to a microcontroller.at the begining the average value of (LDR1 and LDR4) is compared to the average value of (LDR2 and LDR3) to controle the vertical motion then, the average value of (LDR1 and LDR2) is compared to the that of (LDR3 and LDR4) to provide the horizontal motion.

Results and disscution

Three dishes were used through the experimental work. The specification of the dishes are as follow:

Dish[A]: Parabolic dish with an outer diameter of 0.7 m.

Dish[B]: Parabolic dish with an outer diameter of 1.0 m.

Dish[C]: Parabolic dish with an outer diameter of 1.8 m.

The resultes of Dish[B] under different conditions such as changing the reflecting surface, tank size and kind of absorber are shown in Figures 6 and 7. Fig.6 shows the relations between time and the tank tempreture. The results show that Dish[A] reached a maximum tempreture of 40 C. Fig,7 shows relation between the time and the outlet tempreture. Based on figure(6,7) it was found that the defference between the tank and outlet tempreture range from 1 to 2 °C.

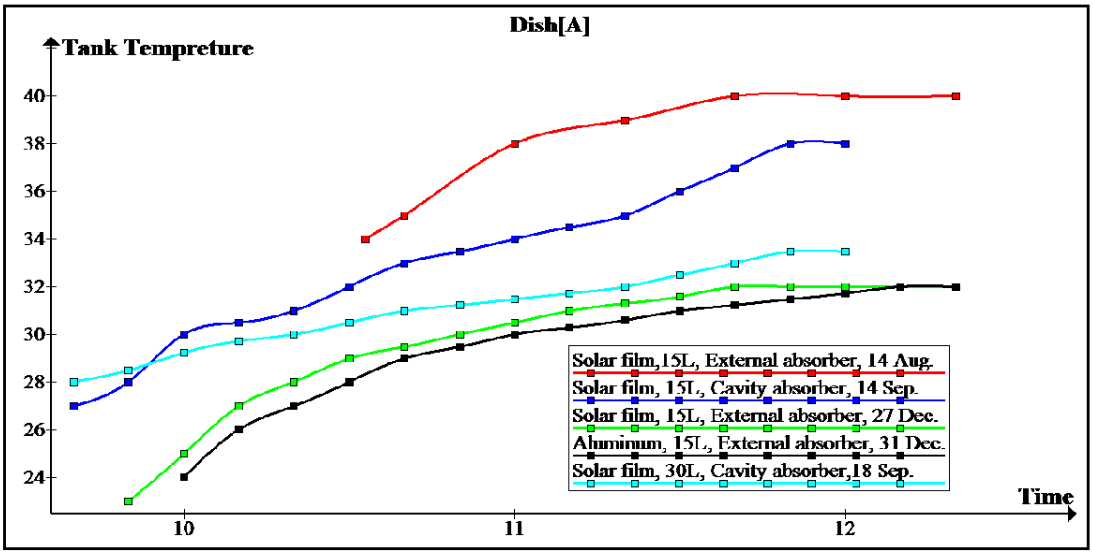

Fig.6: Relation between the time and tank tempreture (°C) for Dish[A]

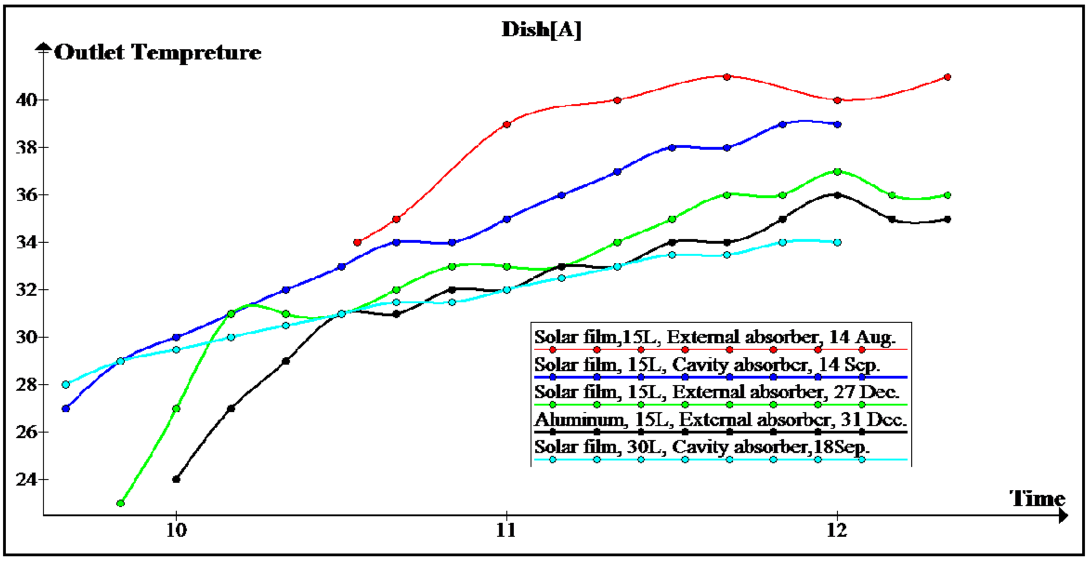

Fig.7: Relation between the time and outlet temperature (°C) for Dish[A]

The results of Dish [B] under different conditions such as changing the reflecting surface, tank size and kind of absorber are shown in Figures 8 and 9. Fig.8 shows the relations between time and the tank temperature. The results show that Dish[B] reached a maximum temperature of 45 C. Fig,9 shows relation between the time and the outlet temperature. Based on figure(8,9) it was found that the difference between the tank and outlet temperature is 3 °C in average.

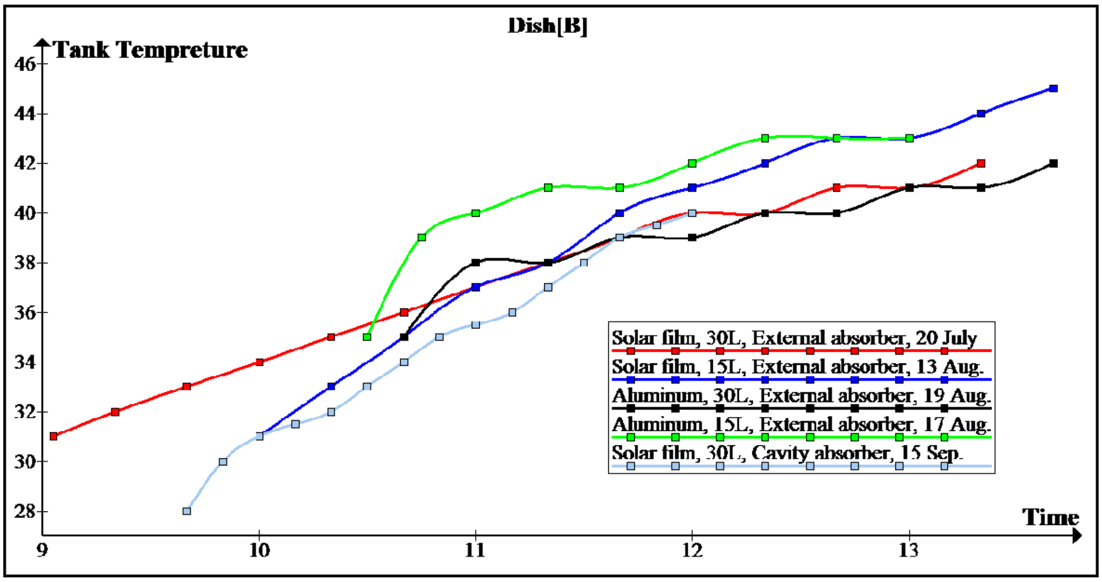

Fig.8: Relation between the time and tank temperature (°C) for Dish[B]

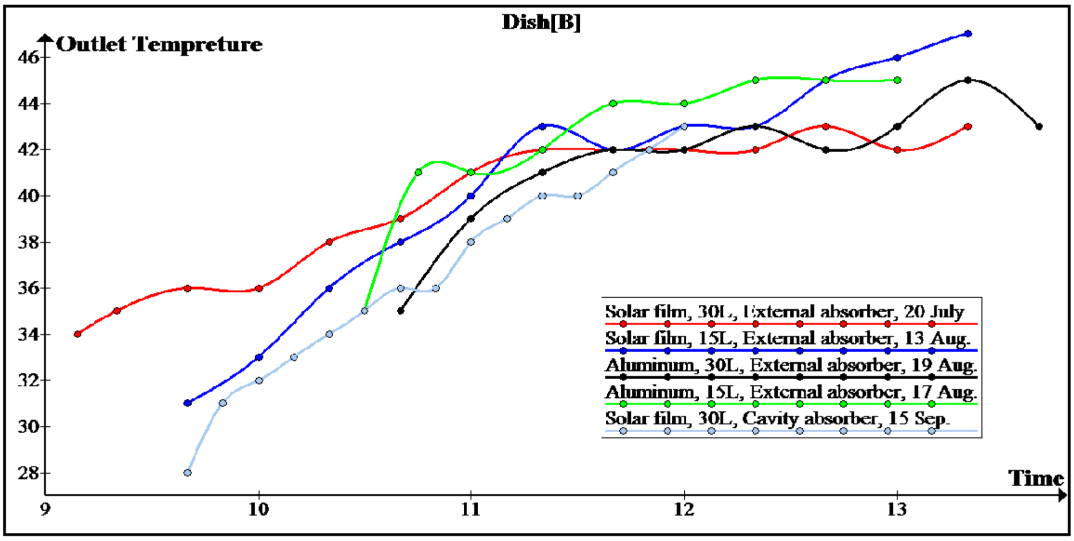

Fig.9: Relation between the time and outlet tempreture (°C) for Dish[B]

The results of Dish[C] under different conditions such as changing the reflecting surface, tank size and kind of absorber are shown in Figures 10 and 11. Fig.10 shows the relations between time and the tank temperature. The results show that Dish[C] reached a maximum temperature of 51 °C at December. Fig,11 shows relation between the time and the outlet temperature. Based on figures (10,11) it was found that the difference between the tank and outlet temperature range from 6 to 7 °C.

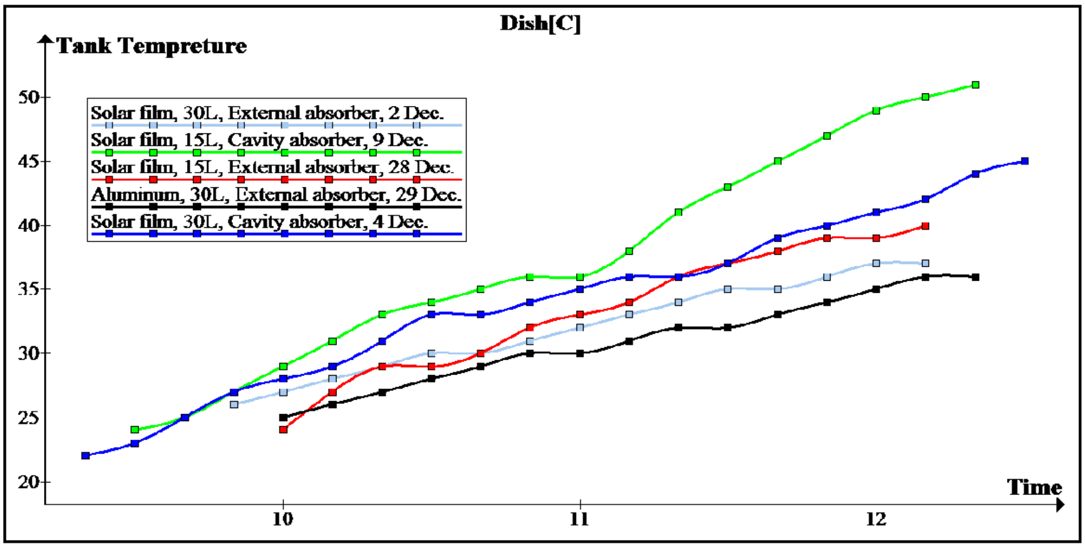

Fig.10: Relation between the time and tank temperature (°C) for Dish[C]

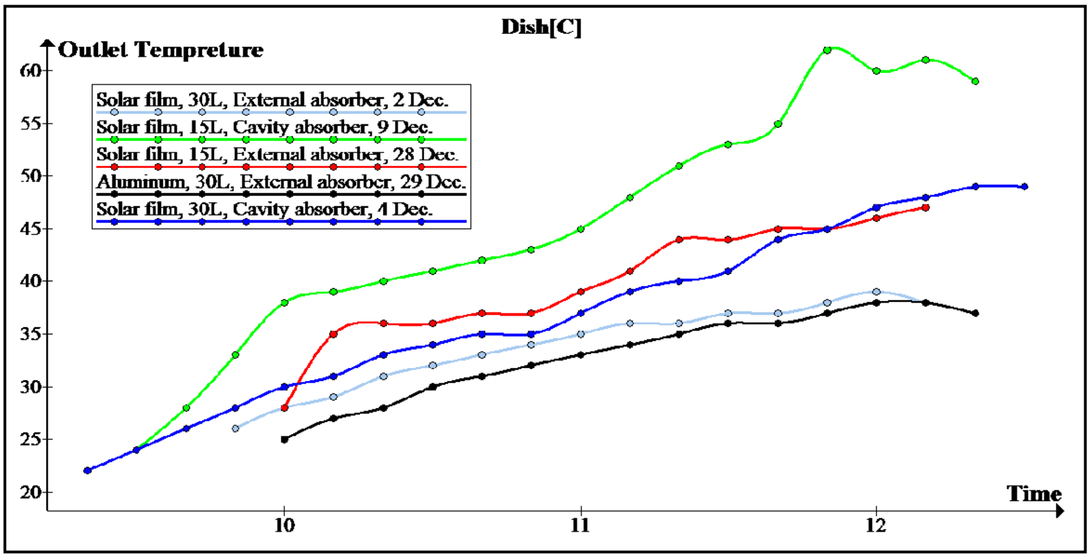

Fig.11: Relation between the time and outlet temperature (°C) for Dish[C]

Based on figures (6,8,10) it was found that Dish[C] reached a maximum tank temperature of 51 C in, while the Dish[A] and Dish[B] reached a maximum tank temperature of 40 C and 45 C respectively. Therefore the dish outer diameter has a direct relation with the amount of energy produced.

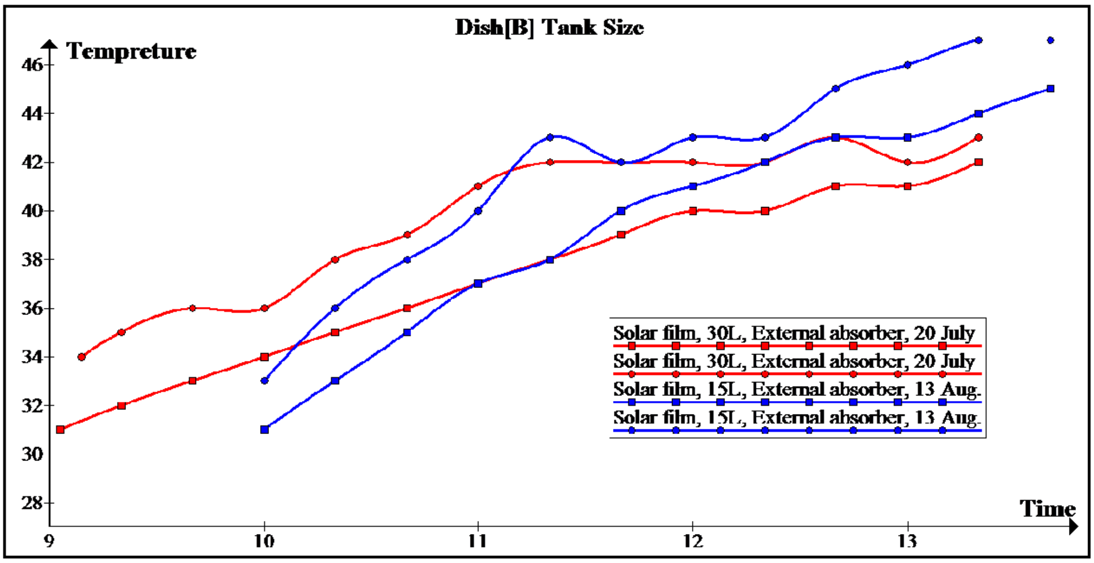

Fig.12: relation between time and both tank and outlet tempretures.

Fig.12 shows the effect of changing the tank size from 30L to 15L. It was found that the system with a tank size of 15L reached 45 C, while the other system with tank size of 30L reached 42 C. Therefore, there is an inversely relation between the tank temperature and tank size

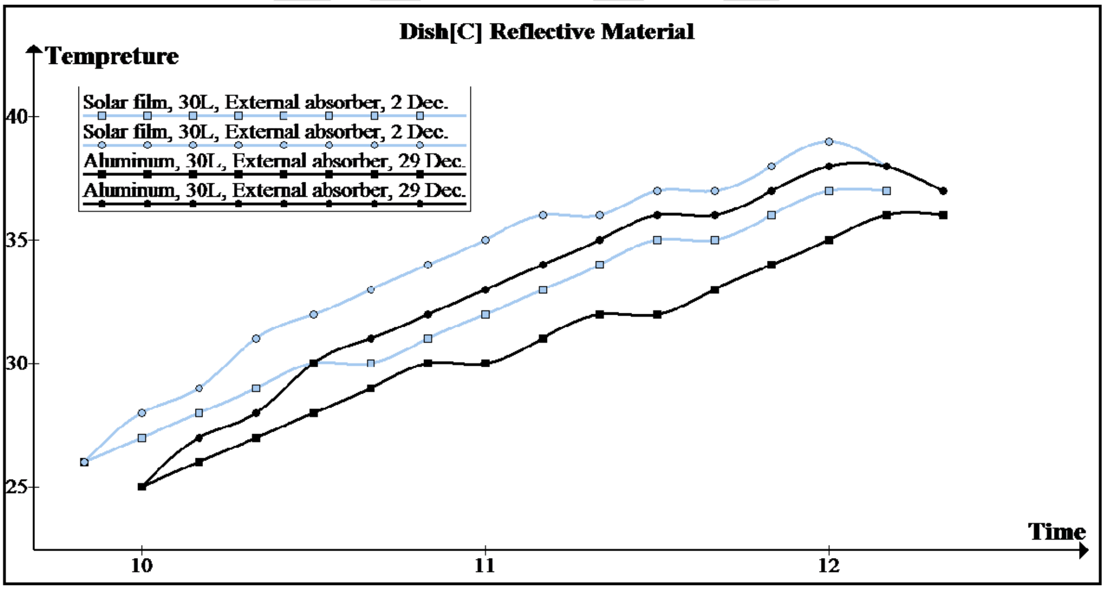

Fig.13: relation between time and both tank and outlet tempretures.

Fig.13 shows the results of Dish[C] under the same conditions except the reflective material. Solar film and Aluminum has been used. It was found that they have very close reflectivity, but dust covered Aluminum in a shorter period of time than that which covered the Solar film.

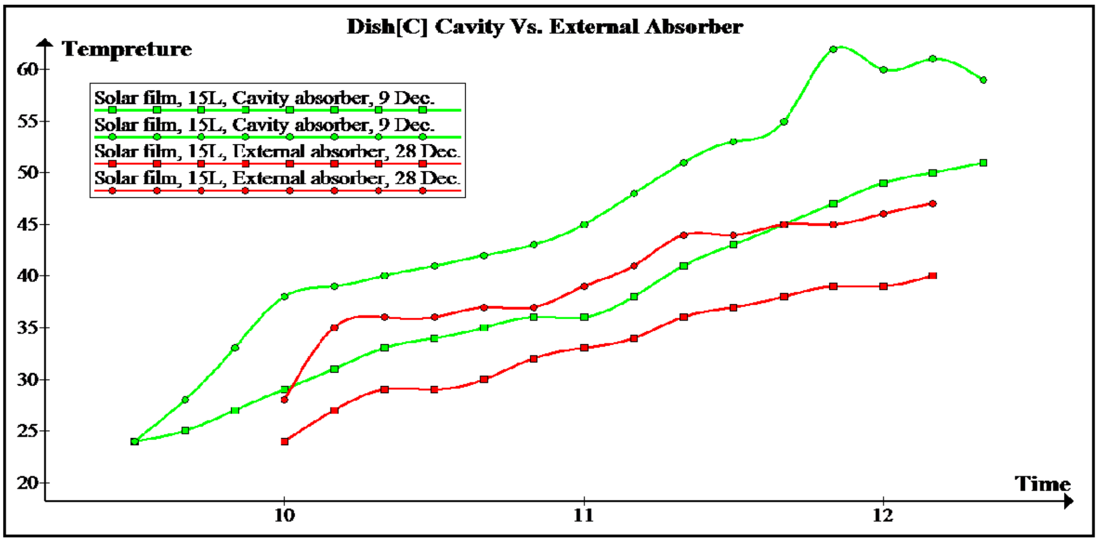

Fig.14:relation between time and both tank and outlet tempretures.

The kind of absorber used in the system has a great effect on the performance of the system as shown in Fig.14. It was found that the difference between the tank temperature and outlet temperature while using the external absorber was 7 °C and while using the cavity absorber was 9 °C. The tank temperature while using the external absorber reached 40 °C while the cavity absorber reached 51 °C.

External absorber has low efficiency due to convection losses between the ambient air and high temperature of the absorber. The cavity absorber, is recessed inside the receiver. Solar radiation is reflected by the concentrator through an opening, and is collected on the absorber surface. The chance of absorbing radiation is higher in the external absorber than that absorbed by the external absorber.

$Q_{act} = m\ C_p\ \Delta(T)$**equ.(1)**

Where $\Delta(T) = T_{T2} - T_{T1}$

The previous experiments show that the maxium output energy was produced using solar film as a reflective material, tank size of 30 L, and a cavity absorber. Using equ.(1) to calculate the output energy, Dish[A], Dish[B] and Dish[C] were able to produce 693 KJ, 1386 KJ and 2898 KJ respectivly.

For calculation the effeicincy of each dish it was a must to calculate the hourly extraterrestrial radiation received by a horizontal surface as follow:

The value of Angle of declination and Solar hour angle are given by:

$\delta^{\circ} = 23.45\, Sin\, [360\, \frac{n+284}{365}]$ equ.(2)

$\omega = \frac{360}{24}\, (t - 12)$ equ.(3)

The value of the normal extreterrestrial solar irradiance G_{on} is given by:

$G_{on} = G_{sc} \left(1 + 0.033\, cos \frac{360\, n}{365}\right)$ equ.(4)

θ_z is calculated using:

$\cos\theta_z = (sin\phi\, sin\delta + cos\phi\, cos\delta \cos\omega)$ equ.(5)

The extraterrestrial solar irradiance on a horizontal surface $G_{\circ}$ thus becomes:

$G_{\circ} = G_{on} \cos\theta_z$ equ.(6)

The hourly extraterrestrial radiation received by a horizontal surface $I_{\circ}$ is given as follow:

$I_{\circ} = \frac{180 \times 3600}{\pi \times 15} \int_{\omega_1}^{\omega_2} G_{sc} \left(1 + 0.033\, cos \frac{360\, n}{365}\right) (sin\phi\, sin\delta + cos\phi\, cos\delta \cos\omega)\, d\omega$ equ.(7)

Then the total energy recivied on a specific area is as follow:

$Q_{th} = I_{\circ} \times A$ equ.(8)

The effeiciency of the system is calculated as follow:

$\zeta = \frac{Q_{act}}{Q_{th}}$ equ.(9)

The overall effieciency of Dish[C] was able to reach 18.3% , Dish[B] was able to reach 19.6%, and Dish[A] was able to reach 18.34%. Fig.15 shows the relation between the time and the efficiency of the three dishes. The figure shows that at the begining of the of each experiments the losses were very small and the efficiency were very high while at the end of each experiments the efficiency were decreased due to high loses in the recevier. The difference between the ambient tempreture and the fluid tempreture inside the recevier was small at the begining, therefore the losses were very small and the efficiency was very high, while after one hour the tempreture of the fluid inside the receier became high, therefore the losses became higher than that losses at the begining.

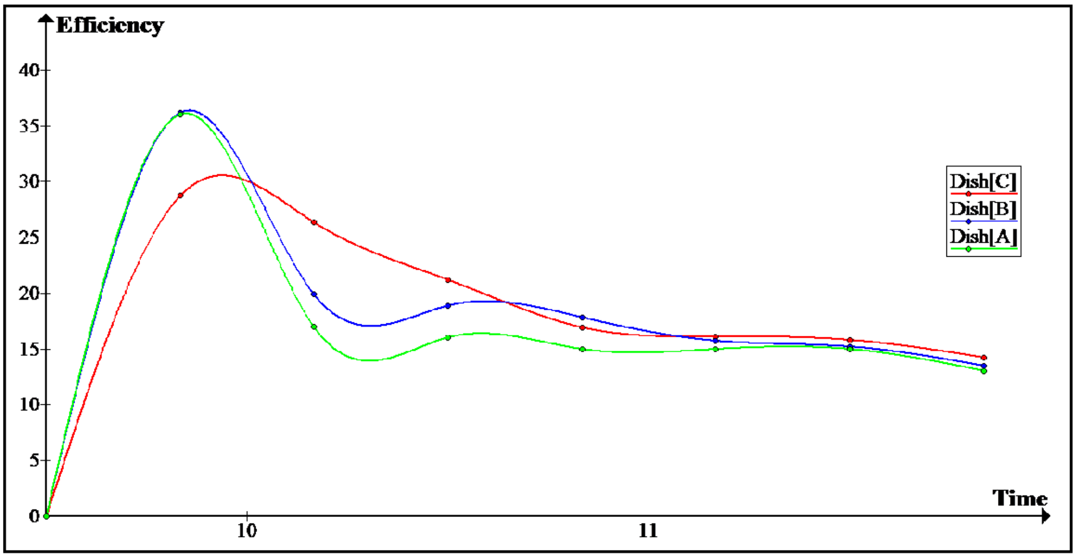

Fig.15:relation between time and efficiency

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Economical analysis

Based on the international prices of energy on December 2014, it was found that the cost of 42000 KJ is equal to 0.60 $ and the cost of the three systems was calculated. The initial costs of Dish[A], Dish[B] and Dish[C] are 68.01$, 73.56, and 156.25$ respectivly.

As Dish[A] produced 693 KJ, Dish[B] produced 1512 KJ, and Dish[C] produced 2898 KJ. The experiments of Dish[C] were in decamber, which means that the system average avarege output energy throughout the year will be 4347 KJ. Therfore; Dish[A], Dish[B], and Dish[C] were able to cover thier cost after 18.82, 9.33 , and 6.89 years respectivly.

Conculusion

The production of energy by parabolic dish has been achieved. It has been concluded that i) the opening diameter of the dish has a direct relationship with the amount of energy produced. ii) the Solar Film as a reflective material has higher reflectivity than that of the Aluminum. iii) When the tank size was 15 L water was able to reach higher tempreture than that when the tank size was 30 L . iv)The Cavity Absorber has a great effect on the improvment of the system compared to External Asorber. It is recomended to build the system with a parabolic dish of 1.8 m opening diameter covered with a Solar Film as a reflective material, conected to a tank of 15 L capacity and to use a reciever with a cavity absorber.

The results showed that the range of the efficiency was about 30% at the beging and after about one hour the range of the efficiency decreaced to 15% due to high losses.

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