International Journal of Recent Research and Review, Vol. III, September 2012
ISSN 2277 – 8322

Design and Study of Portable Solar Dish Concentrator

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Abstract — **The fixed focus concentrator are successfully used for medium temperature application in different parts of the world. There are few procedures reported in literatures for test and evaluating solar concentrator performance which are base on sensible heating of few working fluids. One of limitation of these procedures is requirement of precise operation condition during test. In this research the design and fabrication of solar dish concentration with diameters (1.6) meters for water heating application and solar steam was achieved .The dish was fabricated using metal of galvanized steel, and its interior surface is covered by a reflecting layer with reflectivity up to (76 %), and equipped with a receiver (boiler) located in the focal position. The dish equipped with tracking system and measurement of the temperature and solar power .Water temperature increased up to 80 C^o, and the system efficiency increased by30% at midnoon time.**

Keyword — **Solar Dish, Solar Concentrator, Focus concentration, Parabolic Reflector, Thermal Performance, Tracking System.**

I. INTRODUCTION

The basic principle of solar thermal collection is that when solar radiation is incident on a surface (such as black body) a part of this radiation is absorbed and causes to increase the temperature of the surface [1]**.** The typical solar flux concentration ratio typically obtained is at the level of 30–100, 100–1000, and 1000–10000 for trough tower and dish systems, respectively [2]. The Australian National University has re-engineered its 500 m^2 dish design for commercialization and mass production, the big parabolic solar concentrator dish was designed for solar-thermal to electric energy conversion using direct-steam generator. The SG4 dish implements two-axis tracking and may be incorporated into a dish-array for large-scale power production[3-7].The parabolic dish system use a parabolic mirror-shaped dish, or a modular mirror system that similar to parabola, and incorporates two-axis of tracking to focus the sunlight onto receivers which is located at the focal point of the dish[8,9]. The receiver can absorb the energy and converts it into thermal energy. This can be either used directly in thermal applications or for power generation purposes. The operation of any solar thermal energy collector can be described as an energy balance between the solar energy absorbed by the collector and the thermal energy removed or lost from the collector [10, 11].

A. Parabolic Geometry

A parabola is the locus of points that moves equal distance from a fixed line and a fixed point. As shown in Fig.1, the fixed line is called the directory and the fixed point is the focus F. The line perpendicular to the directory and passing through the focus F is called the axis of the parabola. The parabola intersects its axis at a point V which called the vertex, which is exactly midway between the focus and the directory.

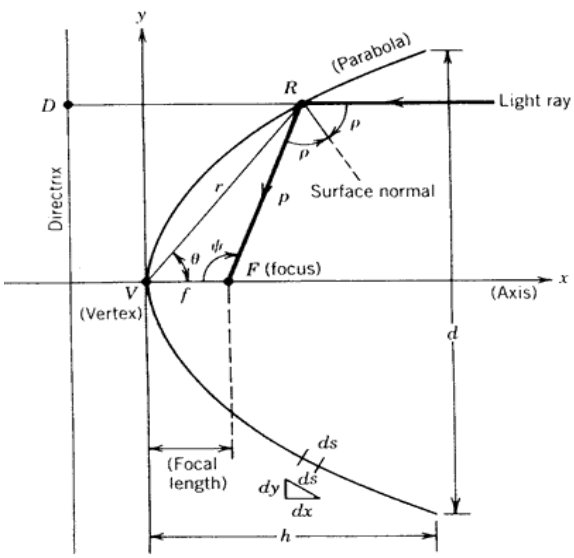

Fig.1 The parabola intersection

B. Concentration Ratio

The "concentration ratio" is used to describe the amount of light energy concentration achieved by a given collector. Two different definitions of concentration ratio are in general use. The Optical Concentration Ratio (C R_o) can be calculated using equation 1 as follow [4]

$$\mathrm{CR_o} = \frac{1/A_r \int I_r dA_r}{I_o} \tag{1}$$

Where (I_r) represent integration over the receiver area (A_r) and (I_o) the insulation incident on the collector aperture [4].The Geometric Concentration Ratio can be defined as the area of the collector aperture A_a divided by the surface area of the receiver A_r and can be calculated by Eq.2

$$CR_g = A_a/A_r \tag{2}$$

Where A_a is the area of collector and A_r is the area of receiver . Optical concentration ratio relates directly to lens or reflector quality; however, in many collectors the surface area of the receiver is larger than the concentrated solar image directory. If the origin is taken at the vertex V and the x-axis along the axis of the parabola, the equation of the parabola is

$$y^2 = 4fx \tag{3}$$

where f, the focal length, is the distance from the vertex to the focus. When the coordinates origin is shifted to point F as is often done in optical studies, with the vertex to the left of the origin, the equation of a parabola becomes

$$y^2 = 4f(x + f) \tag{4}$$

In polar coordinates, using the usual definition of r as the distance from the origin and θ the angle from the x-axis to r, we have for a parabola with its vertex at the origin and symmetrical about the x-axis

$$\frac{sin^2\theta}{\cos\theta} = \frac{4f}{r} \tag{5}$$

Usually, in solar studies, it is more useful to define the parabolic curve with the origin at F and in terms of the angle (ψ) in polar coordinates with the origin at F. The angle ψ is measured from the line VF and the parabolic radius p, is the distance from the focus F to the curve. Shifting the origin to the focus F, we have

$$p = \frac{2f}{1+cos\omega} \tag{6}$$

The parabolic shape is widely used as the reflecting surface for concentrating solar collectors because it has the property that, for any line parallel to the axis of the parabola, the angle p between it and the surface normal is equal to the angle between the normal and a line to the focal point. Since solar radiation arrives at the earth in essentially parallel rays and by Snell's law the angle of reflection equals the angle of incidence, all radiation parallel to the axis of the parabola will be reflected to a single point F, which is the focus. Careful inspection of the geometry described in Fig.3 will show that the following is true:

$$\psi = 2\text{p} \tag{7}$$

ψ is the angle of reflection and P is distance RF from figure 1. The general expressions given so far for the parabola define a curve infinite in extent. Solar concentrators use a truncated portion of this curve. The extent of this truncation is usually defined in terms of the rim angle (ψ_{rim}) or f/d which represents the ratio of the focal length (f) to diameter of dish (d) . The scale (size) of the curve is then specified in terms of a linear dimension such as the aperture diameter d or the focal length f. This is readily apparent in Fig. 2 which shows various finite parabola having a common focus and the same aperture diameter.

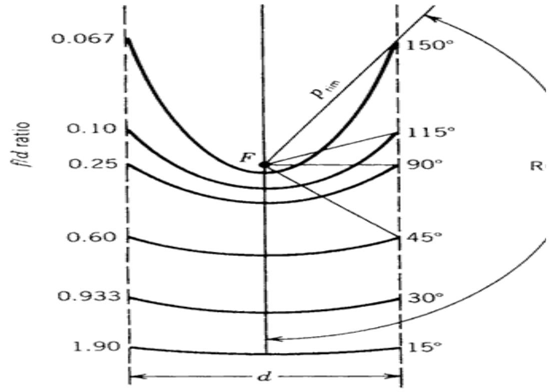

Fig. 2 Segments of a parabola having a common focus F and the same aperture diameter

$$h = \frac{d^2}{16f} \tag{8}$$

In a like manner, the rim angle (ψ_{rim}) may be found in terms of the parabola dimensions:

$$tan\psi_{rim} = 1/(d/8\text{h}) - (2\text{h/d}) \tag{9}$$

Another property of the parabola that may be of use in understanding solar concentrator design is the arc lengths. This may be found for a particular parabola from Equation (3) by integrating a differential segment of this curve and applying the limits x = h and y = d/2 as shown in Fig.2. The result is

$$s = \left[\frac{d}{2}\sqrt{\left(\frac{4h}{d}\right)^2 + 1}\right] + 2f\ 1n\left[\frac{4h}{d}\sqrt{\left(\frac{4h}{d}\right)^2 + 1}\right] \tag{10}$$

where d is the distance across the aperture (or opening) of the parabola as shown in Figure (2) and h is the distance from the vertex to the aperture. The cross sectional area of the space enclosed between a parabola and a line across its aperture and normal to the axis is given by

$$A_x = \frac{2}{3}d.h \tag{11}$$

This area should not be confused with the reflecting surface area of a parabolic trough or dish or their aperture areas [10]

$$tan\psi_{rim} = (\text{f/d})/2(\text{f/d})^2 - 1/8 \tag{12}$$

$$\tan\left(\frac{\psi_{rim}}{2}\right) = 1/4\left(\frac{f}{d}\right) \tag{13}$$

$$\frac{f}{d} = \frac{1 + cos\psi_{rim}}{4sin\psi_{rim}} \tag{14}$$

$$\frac{f}{d} = 1/\{4\tan\left(\frac{\psi_{rim}}{2}\right)\} \tag{15}$$

C. *Optical Energy Absorbed by the Receiver*

The Optical Energy of receiver (Q_{opt}) and heat transfer can be calculated using Eq.(16) as follow,

$$Q_{opt} = A_a \, p_{s.m} \, . \tau_g . a_r . S . I_a \qquad (16)$$

Where $p_{s.m}$ is Specular reflectance of concentrator, τ_g is Transmittance of glass envelope covering the receiver, A_a is Aperture of the collector, S receiver shading factor (fraction of collector aperture not shielded by receiver), I_a light intensity incident on the collector aperture, and a_r is the absorbance of the receiver. S,a_r,$p_{s.m}$ and τ_g are constants dependent on the materials used and the structure accuracy of the collector. These constants are nominally lumped into single constant term.

Thus, the thermal energy produced by the solar collector is described by,

$$Q_{out} = Q_{opt} - Q_{Loss} = w \qquad (17)$$

Where Q_{Loss} is the losses in thermal energy

D. *Collector Efficiency*

Collector Efficiency can be found by using equations (17) and other parameter [11], and described by,

$$\square_{\text{collector}}(v) = \frac{Q_{out}(v)}{Aa.Ia}$$

(18)

$$T_{receiver} = T_{sun}[1- \square . \tau . \; \frac{a}{\varepsilon} \frac{CRgeometric}{CRidial}]^{\frac{1}{4}}$$

(19)

II.EXPERIMENTAL WORK

A. *Parabolic dish*

A solar concentrator was homemade fabricated using galvanized steel sheets concave dish. Method of a given focus and directory was employed in the construction. A Miller paper was stacked on the interior side of the parabolic dish. High light reflection (76%) was obtained from this solar dish.

The dimensions of the designed dish are given in table I.

Table I : Dimensions of the solar concentrator

Diameter of opening of the parabola	**1.6 m**
Surface collecting of the parabola	**2.0 m^2**
Depth of the parabola	**0.018 m**
Focal distance f	**0.84 m**
Rim angle	**45°**
f/d	**0.677**

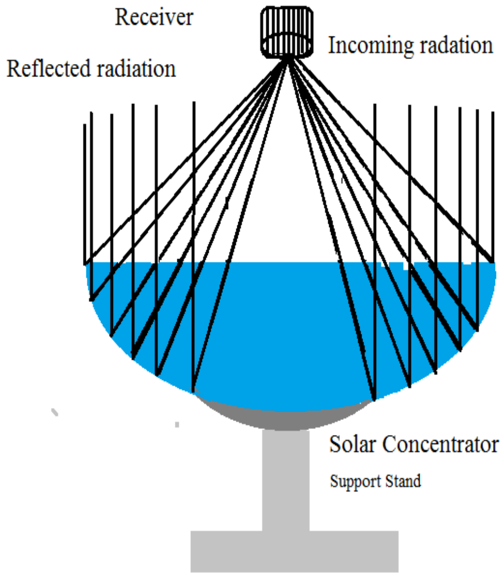

Fig. 3 Design of parabolic dish

B. *Receiver*

The heat receiver was made of stainless steel cylindrical tube, coated with a thin layer of black paint as antireflection coating and it was located in the focal zone of the solar dish of (1.6 m) diameter. Water pass through helical – wrapped cupper tubes inside receiver cavity. The geometrical dimensions was applied according to Eq.(2) for better performance and higher efficiency of radiation absorption and thermal energy inside receiver cavity.

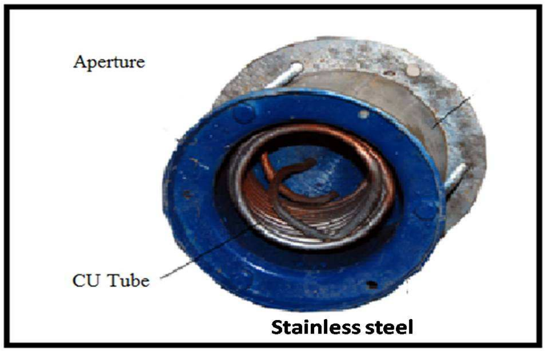

Fig. 4 Cylindrical receiver

C. Tracking system

To increase the efficiency of system, a sun light tracking circuit was used [12]. As shown in figure 5, the actuator circuit consist of two CDS detector were used for light sensing, the outputted signal of these detectors is amplified by operation amplifier U1 and U2. The driving transistors Q1, Q2, Q3 and Q4 are operating the motor for (24V DC, 0.5A) which is moving the solar dish in tracking way of incident sun light.

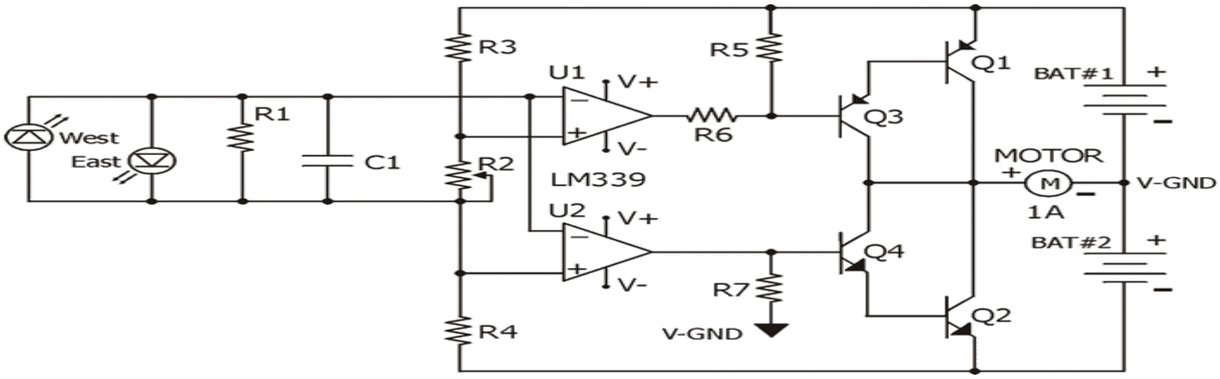

Fig. 5 circuit diagram of tracking system

Table II Tracking circuit components

U1/U2 – LM339 quad comparator	**Q4 – 2N3904 Transistor**	**R1 – 1M.ohm**
R2 – 1K.ohm trim pot	**R3 – 10K.ohm**	**R4 – 10K.ohm**
R5 – 10K.ohm	**R6 – 4.7K.ohm**	**R7 – 2.7K.ohm**
C1 – 10n ceramic capacitor	**Q1–TIP42Cpower transistor**	**Q2 –TIP41C power transistor**
	Q3 – 2N3906 transistor	

The sensor is divided into one by one east and west sensor, and separated by a vane which cast a shadow. When LEDs are exposed to direct sunlight within their focus angle they produce a small current (micro-amps) and associated voltage which is compatible with TTL inputs. Tracking the shadow vane and first row of west detector are used for tracking. The shadow alternately covers then exposes the first row of west detector, when the first row is exposed to the sun it outputs a small voltage which turns on a DC motor via a TTL circuit which drives the tracker and sensor in a west direction casting a shadow over the first row of west detector causing the voltage to drop and turning off the DC motor. This process repeats about every 60 seconds.

D. Receiver Calculations

By using Eq's. 16,17 ,18, and19 the system parameters can be calculated as shown in Table III.

Q_{opt} =Aa.P_{s-m}. τ_g.ar.S.Ia

Table III The receiver optical parameters

Ia = 700 $\frac{w}{m^2}$	**Q_{Loss}= 73 W**
Q_{opt} = 831.4 W	**□$_{collector}$= 0.54**
$T_{receiver}$ = 761^{O}K	**Q_{out}= 758.4 W**

III. RESULTS AND DISCUSSIONS

The relation between solar radiation and time has been studied in Iraq- Tikrit city with altitude (34.59) and longitude (43.68), the time of observation was in April-2011 as described in Figure 6. In this geographic zone, the maximum energy of solar radiation found between 9:00 AM to 1:00 PM, after this time the solar radiation begin decreasing between 1:00AM to sun set that because Iraq lies within moderate levels of solar radiation.

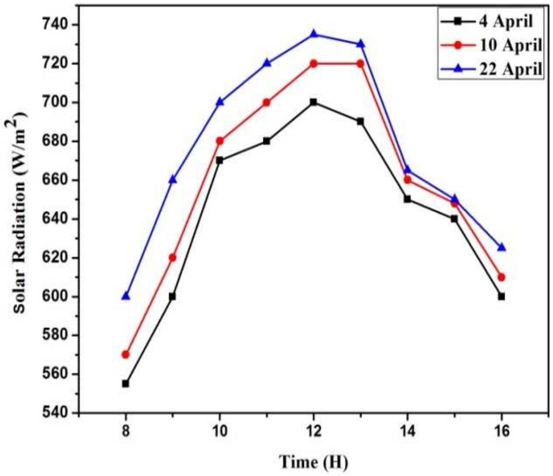

Fig. 6 Solar radiation distributions during April-2011 in Iraq zone

Fig.7 shows the dependence of water temperature in receiver on solar radiation during day time. It is clearly observed that the inlet and outlet water temperature increased during day time between 9:30 to 1:30 because of higher flux of solar radiation [11]. Then water temperature decreased after 1:30 simultaneously with time of lower flux of solar radiation.

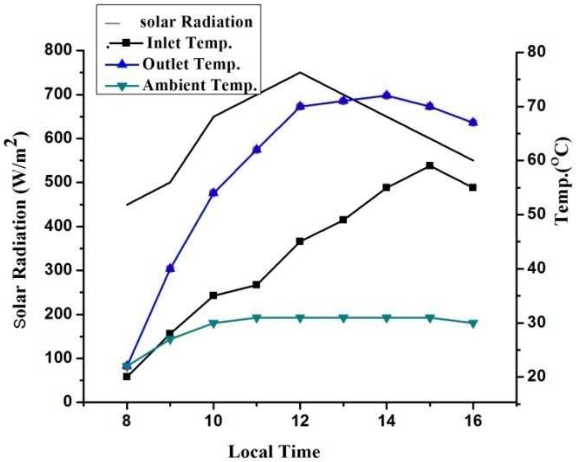

Fig. 7 Water Temp. in receiver correlated to working time and solar radiation

The ambient temperature contributes in quantity of heat loss of the receiver. This experimental fact is demonstrated in Figures (8), This figure shows an increasing in heat loss coefficient by convection with increasing of receiver temperature, this is justified by Steven-Boltzmann law in which the radiation emission from a hot source is proportional with the fourth power of source temperature The effect of ambient temperature is represented by the degradation in heat loss coefficient by radiation of receiver at any specific temperature. This fact is very well observed when the winter season approach months of summer season.

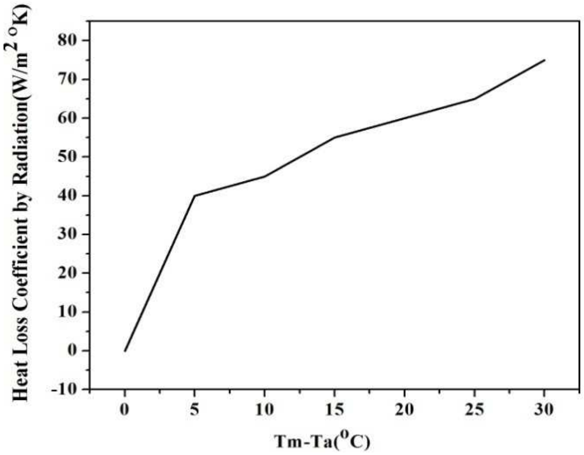

Fig. 8 Variation of heat loss coefficient by radiation with operating temperature of receiver

Fig. 9 shows the variation of instantaneous efficiency with operating temperature(T_m-T_a) for receiver. It was clearly observed that the system efficiency decreased related to receiver temperature. The reason beyond that is the losing of radiated energy is proportional to the fourth power of receiver temperature as mentioned before. Also, the results indicate the efficiency of conical receiver is decreasing related to higher temperature difference. The amount of optical and thermal loses energy is part of the total solar energy that incident on the concentrator. The others are called Q_{useful} energy. It is absorbed by employed fluid and stored in storage tank. The temperature of the stored fluid limits the type of thermal application, while the amount of this stored energy with respect to the total incident energy limits the efficiency of the thermal solar system as described in Eq. (18).

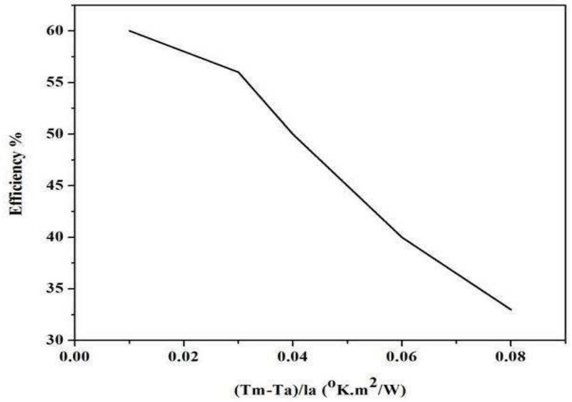

Fig. 9 Relation of efficiency with operation temperature for receiver

Fig. 10 described the relation of solar radiation with time. Figure shows increasing the solar radiation during day time with using tracking system and increasing the system efficiency about 30%.

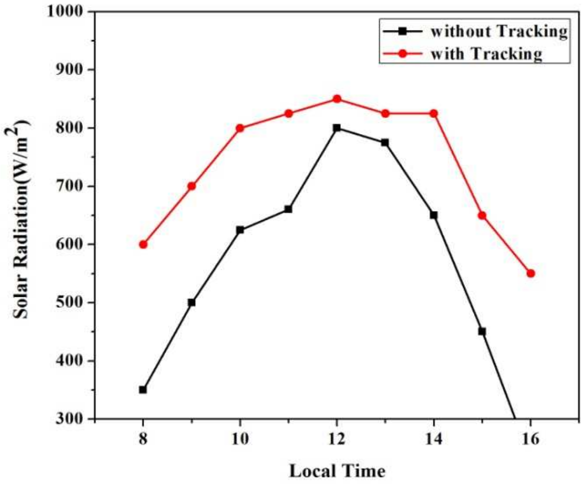

Fig. 10 Solar radiation correlated to working time

IV. CONCLUSIONS

In this work a solar dish concentrator has been designed and fabricated according to corresponding theoretical data. The parabolic concentrator has high sun light reflectivity (up to 76%). The high reflectivity of solar radiation increased outlet water temperature in receiver cavity, and consequently arising system operational efficiency. Furthermore using designed-sun light tracking system increased the operational efficiency to 30%.

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