Thi_Qar University Journal for Engineering Sciences
http://www.doi.org/10.31663/tqujes.9.2.328(2018)
Vol.9 No.2 (September 2018)
ISSN 2075 – 9764
Available at http://jeng.utq.edu.iq
engjrnal@jeng.utq.edu.iq

Solar Water Desalination by Using Parabolic Dish in Hot Climate Weather Conditions

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Abstract

The solar energy development is one of the modern sciences that used the new experiments ideas to reach the benefit. This paper demonstrated the idea of concentrating the solar energy by using two practical models (Model 1 and 2) of parabolic dish with cross sectional area of (1.13 m^2) and (2.545m^2) respectively for accumulation of solar energy in one focus at Nasiriya city, southern of Iraq (31.036˚N,46.21˚E). The controlled closed pan was placed at the centre situation of this focus of dish. That used the concentrated solar array heat to raise the focal temperature to many hundreds degrees. So, this small pool used to minimize the heat transfer losses by the convection and radiation way. Also, this small volume increased the concentration ratio to reach the boiling and vaporizing temperature of water which found inside the closed pool. The generated steam leaved the pool to pass throughout the small diameter pipes of condenser that help the steam to decrease its enthalpy to convert the state to liquid. The maximum distillated water for both rigs (model 1 and 2) was 2.5 and 5.25 L/day respectively in 20th of June while the average efficiency was 77.6 % and 76.6 % respectively.
Keywords: distillation, solar energy, parabolic dish, parabolic trough.

1. Introduction

The investigators have long provided studies and search theory and practical experiences on the topics of how to improve the efficiency of solar stills to produce potable water for use as a result to importance of an influential and large role in public life and the urgent need for desalinated and clean water. There are many techniques used in different applications such as desalination of salty or waste water using solar desalination technology to meet the grow in drinking water demand or for agricultural purposes.

There are many researchers conducted for the improvement of solar still to increase the productivity. The distillation by solar energy is old has begun since M.A.S. Malik (1872) [1]who constructed the first solar still plant with productivity 4.255 L / m^2day and collector area of 4700 m^2, and continued in development of solar technique by many papers conducted in this field. Soliman S.H.(1972) [2], H.P.Hanson (1973) [3], Howe E.D.(1974) [4] depicted the studies of ambient effects for various productivity of solar radiation, wind speed, slope angle of cover transparent thermal insulation dripped factors and air temperature in different operation such as the depth of solar pond and the feeding method on the performance of desalinated water. Satcunanathan (1973) demonstrated that there is the highest productivity of distilled with an perfect temperature for the condensation surface depends on the variables and the surroundings which were not mentioned for the increase in productivity. Suleiman (1973) presented the condensation surface and the effect of cooling on it with accurate temperature inside water still, and concluded when the wind velocity increases upper the transparent cover surface or increasing the exposure area to the wind, an increase in the distilled water productivity. The researcher Hanson (1973) searched the effect of vacuum displacement between the transparent cover and distilled basin, and Milan lid on the distilled water performance, has been found to decrease the size into the pelvis which suitable for performance improvement as well as making distilled Milan cover vertical to the path of the sun fall to decrease the solar radiation falling reflection on distilled water [5]. G. Kamaraj (1978) [6] investigated the linking reflector effects on the sun as large as the distilled of basin area at an angle and is unlike additional rays to the inside of the still base basin increased the productivity by 50 – 60% while using the reflective mirror and increase of 25 %at using a reflector of aluminum, but the efficiency will be decreased. Bastors (1979) [7] made a new distilled included two complex parts of solar thermal water heating only used intensify in this type to cover the condenser cooling and temperature control condensation while water of another basin with glass lid isolated from sunlight. Abdul-Jabbar in 1982 [9] claimed the partial discharge basin distilled effects to its performance, designed two devices, one is the condensation in another separated basin isolated from its pelvic vacuum and the other is cooled with the discharged basin. He linked simple monoclinic SOLAR STILL with a simple solar water heater to investigate the effect of the hot water preheated introduction. At the California scientific exhibition in 2003 Bornemenn [8] conducted several five types tests of glass changes with other fixed and different four degrees in air temperature for two days concluded that the glass windows were very well for distillates to pass the sunlight throughout. Ahmed and Ibrahim (2006) [10] presented a study of the solar water still production and performance by studying a single effect solar water still and the effect of preheating inlet water supplied on it and also the effect of air and water flow on glass cover cooling. Chahoud and Leila (2013) [11] designed and characterized solar desalination unit with a five parabolic collectors connected in series, the collector efficiency was 69% while the maximal unit efficiency was 50.2 %. Al-Qedra (2014) [12] studied a practical water desalination unit by solar parabolic trough collector system and found 38-48 % collector efficiency. Hannun et al. (2015) [13] depicted the effect of collector area and forced circulation on the solar still system at Nasiriya city, they found the increase of collector area would increase output distillated water and efficiency (was 31 %). Mahmood et al. (2015) [14] modeled a 2 m in diameter solar parabolic dish to produce boiling water with average efficiency of day 64.5 %, so, they found the accurate centering of dish increase the water heating.

The aim of this paper is the comparison between two different area parabolic dishes for solar arrays accumulation techniques. The water shortage may be solved by this technique due to its being an economic sources of salty water purification. The technique is based on the evaporation of salty or waste water to separate salts and suspended solids and then intensify water vapor to get the fresh drinkable water wherever required needs in the houses, small offices, agricultural or industrial areas.

2. Practical fabrication

The center of the saucer type (Dish) which is the focus of direct sunlight for many times, leading to rapid evaporation of the water with a time and a record proportion to other concentrates. This device is heated to evaporate water without the use of any pressure steam and then intensify this natural and not forced and thus the production of distilled water. The solar cooker or a water desalination efficient devices, where the temperature reaches in normal conditions to high temperature and this qualifies it to be a source of heat for many industries. This device is in the collection of solar radiation falling using pot concave (dish) coated with a reflecting material. The boiler is placed in focus position and is painted black to increase the efficiency of absorption. It contains valves, one to enter the water that is sideways in the middle of the boiler and must regulate the entry of water so that the boiler is filled with water so as to increase the rate of evaporation. The second way is to the exit of steam and is always open to the highest extent possible so as to increase the amount of steam passes-intensive to be positioned at the top of the boiler and transmits steam to the condenser through plastic pipes. The user is like a condenser located in any refrigerator that it is a winding tube contains a large number of fins that allow leaking heat. They are cooled by the atmosphere, because the steam generated was not subjected to great pressure so any drop in temperature in the condenser will lead to condensation and generate steam that collects water droplets on the wall and hurtling towards intensive pot assembly by vapor pressure.
If the pressurized basin used in this experiment, the production of desalinated water will increase. The two rigs are shown by Figs. 1 and 2 respectively.

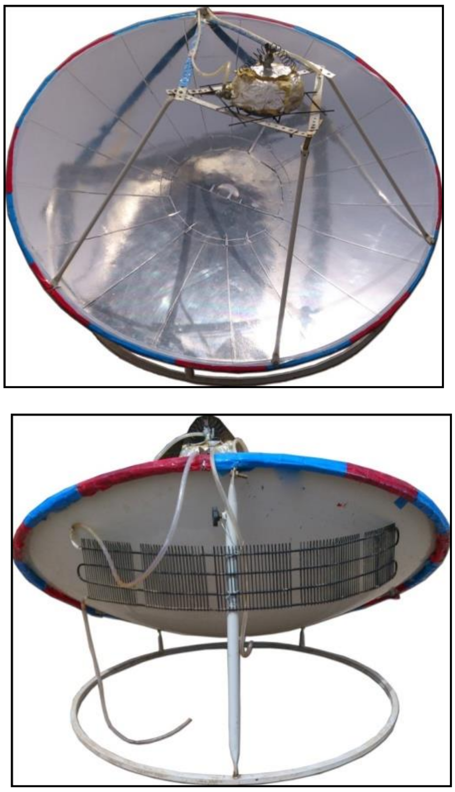


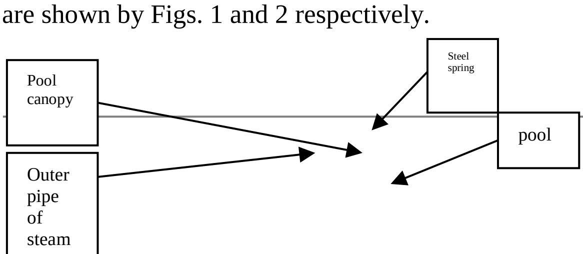
Fig. 1 Rig 1 demonstration of parabolic concentrated dish with behind side of condenser pipes

Fig. 2 Rig2 demonstration of parabolic concentrated dish

3. Theoretical Analysis

Fig. 3 presents the drawing and angles used by solar parabolic dish for calculating the different parameters of design.
The dotting angle is

$$W_a = 4f \tan\left(\frac{\varphi_r}{2}\right) \tag{1}$$



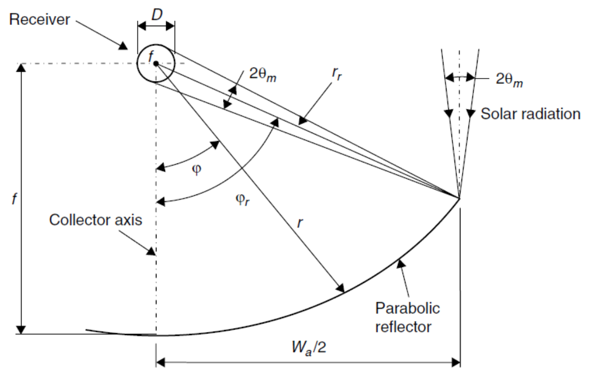


Fig. 3 Demonstration of parabolic dish angles and solar dimensions [15]

The concentration ratio is

$$C = \frac{W_a}{\pi D} \tag{2}$$

The length of the surface of the reflector is curved to the bowl when taking the cross section

$$S = \frac{H_p}{2}\{\sec\left(\frac{\varphi_r}{2}\right) \quad \tan\left(\frac{\varphi_r}{2}\right) + \ln\left[\sec\left(\frac{\varphi_r}{2}\right) + \tan\left(\frac{\varphi_r}{2}\right)\right] \tag{3}$$

Transmitted solar radiation from the sun to earth distance ($5*10^{11}$) m and almost reach the surface temperature of the sun is about ($6 *10^{6}$°C) according to the base of radiation, enters the solar radiation into the glass box and different quantities of all aspects, but that the bulk of the entry of radiation surface is oblique, and be the amount of heat gained within distilled, which cause evaporation process resulting from the heat gained by solar radiation minus losses by distilled completely. It was extracted the amount of heat generated by the radiation from the following equation:

$$Q_{r_1} = F_{12} * \sigma * A * \alpha * (T_1^4 - T_2^4) \tag{4}$$

The losses composite or distilled part of the energy absorbed by radiation or convection. The solar arrays reflected by dish surface to reach the pool of water to the focus. Some of heat is lost by convection and radiation.

$$Q_{r_2} = \sigma * A * \in * (T_2^4 - T_3^4) \tag{5}$$

$$Q_c = h * A(T_2 - T_3) \tag{6}$$

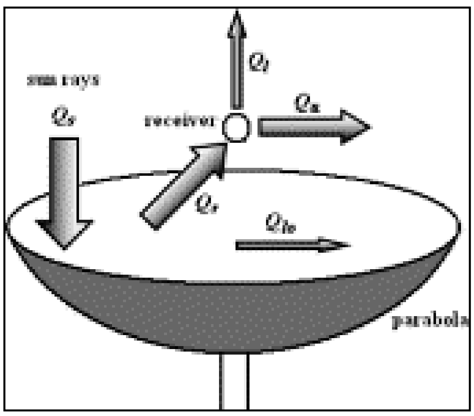


Fig. 4 Heat and array flux transfer analysis [15]

Where F_{12} is the shape factor of dish which may be assumed to be 0.9 (because the total solar arrays transferred to focus approximately [10, 11]) and α is the absorption factor assumed is 0.8 [10, 11, 13], ε is the emissivity of pool assumed 0.1. (h) is the heat transfer convection factor. (σ) stephan- Boltzman factor ($5.67* 10^{-8}$). A is the cross sectional area of dish (1.13 m^2) and (2.545m^2) respectively. It is concluded that:

Energy falling on the collector = energy gained + energy lost

$$Q_3=Q_1+Q_2 \tag{4}$$

Thus, it is seen that the solar complex does not change energy from nothingness, nor does it excrete it,3 but rather transforms it, and since the thermal energy acquired is the amount of heat obtained by the fluid in which heat is transferred.

It can be calculated from the following law:

Energy gained= Liquid mass ×Specific heat× Temperature rise

$$Q_1=mcp\Delta T \tag{5}$$

The amount of heat lost from the complex depends on the coefficient of heat transfer from the surface of the complex to the surrounding environment and on the area of the complex surface and the difference in temperature between the surface of the complex and the ambient atmosphere.

According to the following relationship:

Lost heat = Surface area × Overall heat transfer coefficient × Temperature difference

$$Q_2=AU\Delta T \tag{6}$$

And that the total heat obtained and lost is equal to the amount of energy falling on the collector, which is equal to the amount of solar radiation on the unit area multiplied by the surface area of the system, ie:

Falling energy on the collector = Solar radiation on the unit of area × surface area of the dish

$$Q_3=S.A \tag{7}$$

$$(Q_3=Q_1+Q_2)/Q_3 \tag{8}$$

$$1=Q_1/Q_3+Q_2/Q_3 \tag{9}$$

(Q_1 / Q_3) is the ratio of energy acquired to energy falling on the surface of the compound

I.e. they represent the efficiency of the system.

Q_2 / Q_3 represents the relationship between lost energy and energy falling on the surface of the complex.

$$\frac{Q_2}{Q_3} = \frac{\Delta TUA}{AS} = \frac{U\Delta T}{S} \tag{10}$$

If it consider that the heat transfer coefficient (U) is constant, we see that Q_2 / Q_3 is directly proportional to the temperature difference between the surface temperature of the collector and the ambient atmosphere and vice versa with the intensity of solar radiation and after compensation in Equation (10) for Q_1 / Q_3,

$$\frac{U\,\Delta T}{S} + \eta = 1 \tag{11}$$

$$\eta = 1 - \frac{U\,\Delta T}{S} \tag{12}$$

But as a result of the absorption factors and the reflection of solar radiation from the absorbent plate inside the compound, the efficiency of the system takes the following form:

$$\eta = 0.8 - \frac{U\,\Delta T}{S} \quad (13)$$

The graph of this relationship is shown as a straight line with a value less than $\frac{U\,\Delta T}{S}$.

For both transformation from liquid state in basin to vapour and then this vapour will change to liquid by condenser, the latent heat must be absorbed in the first case to rejected to out in the second as mentioned in equation 14.

$$Q_{latent} = m\,h_{fg}(T_2 - T_1) \quad (14)$$

In order to increase the efficiency of the solar system, it requires increasing the amount of energy gained and reduce the amount of energy lost, and even increase the amount of energy gained must consider the following aspects:

a- Reduce barriers to solar radiation access to those parts of the compound that absorb solar radiation, using materials that allow sunlight to reach the absorbent surfaces very efficiently.

b- Increasing the efficiency of absorbent surfaces for solar radiation, using some coatings that increase the absorption of sunlight and reduce the thermal radiation of these surfaces.

c- Raise the efficiency of the transfer of solar energy absorbed on the absorbent surface to the fluid (gas or liquid) that passes through the solar collector, usually by the use of well-conductive metals.

To reduce the amount of energy lost, the following aspects should be considered:

i- Reduce the heat lost by means of convection, conduction and radiation. This is usually done by reducing the heat transfer from the absorbent surface to the surrounding environment by using more than one glass cover over the absorbent surface or discharging the solar collectors from the air (vacuum process) to prevent heat transfer. It is known that the heat does not move in the vacuum, but requires a physical medium for transmission (except in radiation).

ii- Reduce the absorbent surface area to reduce the amount of heat lost. This is done by collecting and concentrating the sun's rays and then on a low surface. This method is used in concentrating solar collectors [2].

After outgoing the water from the water pool at the focal area of dish it passed to condenser to reduce the enthalpy and temperature. Condenser is made from 3 tubes with 50 cm length and 0.625 cm (1/4 inches) diameter metallic tubes, it coupling with fins to increase area of heat transferred to surroundings.

4. Results and Discussion

The process of desalination water accumulation requires increasing the temperature of water at a constant or different static pressure. This temperature and pressure depends the thermodynamic properties of water type. Therefore, this idea of paper depends increasing the temperature of entering water with pressure enforcement by applying steel spring over the canopy of water pool where the concentrating focus lies.

This experiment is placed at Nasiriya city (31.036˚N,46.21˚E) of Iraq. The solar arrays density is very high at this city as shown by fig. 5 for most seasons of year[16, 17]. The outside temperature of solar pool with different hour days (three different months) is measured in fig. 6 for Rig 1. The highest focus temperature of the parabolic dish is recorded at 20thJune because it is the most hot month from others with high intensity of solar arrays and solar flux (the period of study is in different seasons for three different days) to be 350^{o}C at 1 p.m. (afternoon) but the minimum was at 8 a.m. morning of 17thMarch to be 110^{o}C since it is the coldest day from the other two days. When the area of reflector (dish) is increased the solar density increased directly. This matter is seen in Fig. 7 for model 2. The focus temperature is increased by 380^{o}C for the same day and hour of 20thJune but the increase is 120^{o}C for17thMarch which is the coldest for model 2. These increments are due to the increase of reflecting area of dish with staying the same area of focus, which doubled the temperature range as the concentration ratio of area. When the focus area is 1 cm the concentration ratio is 113 for first model of area (1.13m), but it will be 169.7 for the second model as assuming the focus area is 1.5 cm while it will be 254.5 for the same focus area of the first model. This is the cause of increasing the focus temperature more than the doubled value between the two figures (6 and 7).

Fig.8 clarifies the desalinated water output from the condenser that connected to pool of dish for three sunshine clear days of the year. All experimental curves slopes at morning (before solar noon) have low inclination with small angle to horizon. This means the water production is little in comparison to afternoon hours that is because of low solar energy accumulated by solar dish at early time of day. But the higher liters of condensed water are gathered at the first hour afternoon (12 am – 1 pm) when the sun is at perpendicular view by absorber on the earth and incident angle is approach to zero. Afternoon, the heat dissipated from absorber is low because the surrounding surfaces on the ground have high temperature and energy, therefore that make low heat transferred by convection and radiation from the absorber is low with high arrays flux from the sun arrive to water inside the absorber pool. In addition, after this time, the slopes of curves begin to be small while advancing to sunset time. To compare the curves, the range and domain of 20th July curve is the higher as a result to high solar flux incident throughout the day and long day (hours) and hot day. The same trend of curves in Fig. 8 is found for curves in Fig.9 for water distillation by Rig2 which is increased by dish area. It is seen that the water production by this model is doubled here since the collecting area is doubled. The maximum water accumulation is in 20th July to be 5250 milliliter at 5 pm (the end of solar day) approach to sunset time, but is 2500 milliliter for Rig1. The thermocouple sensor is placed between the outlet of absorber pool and the condenser inlet to measure the water temperature in Rig1 and 2 that depicted in Fig. 10 and Fig.11 respectively. Generally, it is shown that the temperature is low at morning to reach its maximal at 1 pm (13) midday (noon) because of high solar energy absorbed at this time and the losses to the surrounding are low. Therefore, the temperature is high but it decreases when the day advanced to sunset and high losses, and they are lower than that at morning. So, the temperature of 20th June has larger value that for 17th March at 5 pm as a result to short day of March approach to sunset time make the temperature is low because of high losses but long days of June and 5 pm is not closed to sunset and the losses from water are low. As it is known before, the temperatures of Model2 in Fig. 11 are larger than in Model1 (Fig. 10) since the absorber area for Model1 is less than the area of Model2.

Fig. 12 demonstrates the temperature of water out from condenser for three days 17 March, 15 April, and 20 June of the year. By this condenser, the water ensures low temperature with low enthalpy to be used by storage tank. The temperature of water decreases depending the effectiveness of condenser directly. The hottest water needs high effectiveness or more time for cooling according on its amount and temperature. From Fig.11 it is seen maximum temperature is 45 ℃ at 12 am of 20th June but the maximum temperature for lower curve is 31℃ in 17th March (1pm). The same trend of curves is found for Fig. 13 but with higher temperatures reach to 51℃ at 12 am of 20th June and the minimum at morning 8 am, 19℃ in 17th March.

The water production percentage along the day is introduced in Fig. 14 which shows maximal percentage for Rig 1 to be at 1 pm for all days. But the 20th June curve is more smoothly than others because the ambient temperature is high along the day due to the high solar flux especially afternoon. The same manner and trend of curves in Fig. 14 is in Fig. 15 for Rig 2 since the same reason.

Fig. 16 showed hourly solar flux evolution at 15th of the respective months in Chuquicamata (Chile) (22.3167˚ S, 68.9333˚W) [18] which is the same curve trend as paper position of Nasiriya city (31.036˚N,46.21˚E) of Iraqshown in Fig. 5 with inverse amounts between the summer and winter as a result to south and north position from equator (solar perihelion and apogee).

Fig. 17 presented the solar evolution of the average monthly direct (beam) irradiation in eight locations [18] on the world from south and north equator that is the cause of curves reversal.

5. Validity of Study

The validity of present study in comparison with Mahmood et al. [14] for efficiency of the Model 1 and Model 2. They used solar parabolic dish made of galvanized steel sheet. Their reflecting plain made of mirror pieces (3 cm ×3 cm), 2 m diameter of parabola, 3.14 m^2 collecting area. The comparison between the two studies by efficiency curves as shown in Fig. 18 and Fig. 19 by using the equation (13) and the previous equations. It is depicted that the present work is higher than the compared study but with the same manner of curve because the present study is fabricated from smooth lustrous reflecting surface but previous study was done by collecting small mirrors pieces (3 cm ×3 cm) left some lines of losses. In addition to decrease the efficiency at noon since the losses are high for both studies. The average efficiency of previous system was 64.5%, while the current 78.53111% for the first rig, 76.67556 % for the second rig because the second has high losses.

6. Conclusions

The system consisted of a high-efficiency unit to collect and concentrate sunlight to feed the initial evaporation process and heat energy to waste water by big diameter dish. The hot vapor condensed by series continuous small bore pipe to be suitable for human need.

This design will profit the small offices, houses and agricultural desert places for production of distilled water. This idea may be improved by designing a controlled, governed closed basin since the utilizing from increasing the pressure inside the boiler with increasing the temperature by solar arrays to produce high velocity of vapor outgoing the pool. So, the another method of increasing the production of condensed water by increasing the diameter of dish designed for accumulation of solar rays heat with tracking the sun by threeangles (declination, latitude and incident angles) throughout the day so as to ensure high quantity and quality of produced water. So, the effectiveness of condenser to be with range (0.5-0.85) by using the readings of present study which is suitable for decreasing the water temperature and enthalpy.

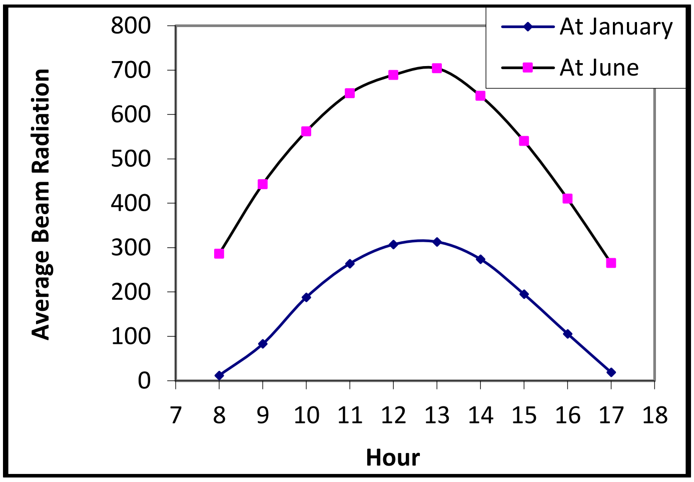


Fig. 5 Average beam radiation (W/m^2) for days on January & June at Nassiriya city [16, 17]

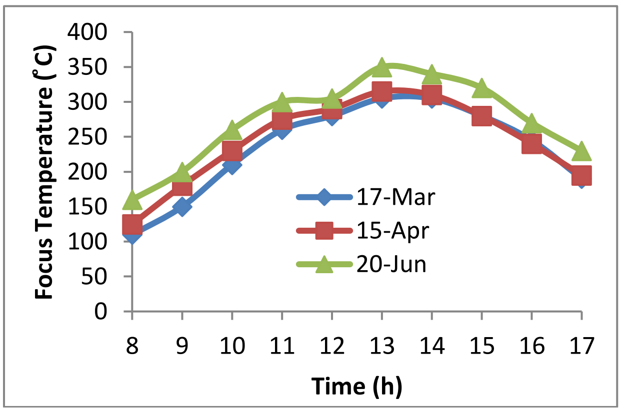


Fig. 6 Focus temperature of model 1 through one day hours

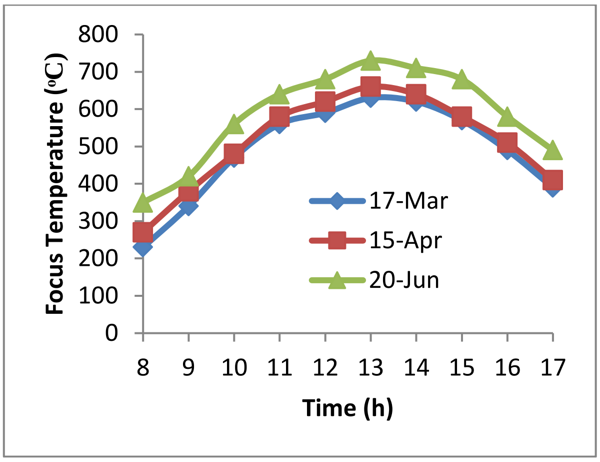


Fig. 7 Focus temperature of model 2 through one day hours

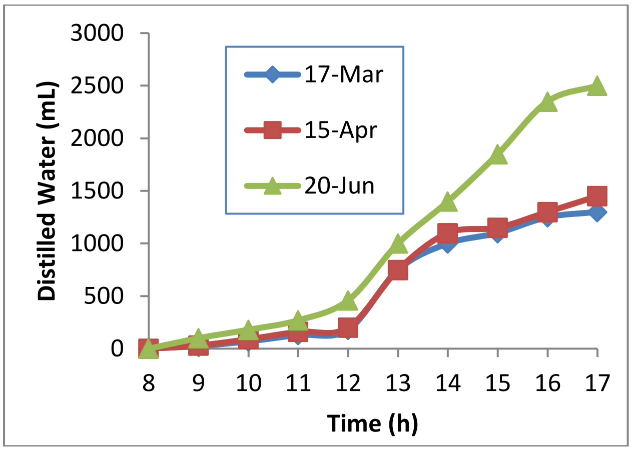


Fig. 8 Distilled water production (milli liter) at different day hours (Rig 1)

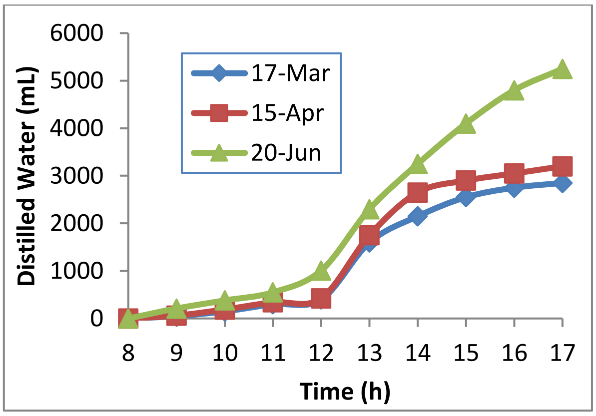


Fig. 9 Distilled water production (milli liter) at different day hours (Rig 2)

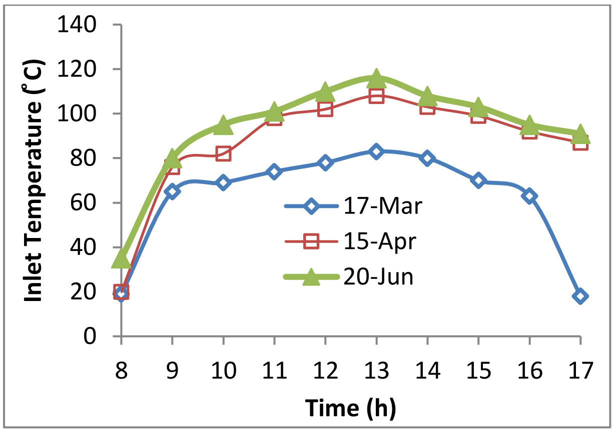


Fig. 10 Inlet water temperature to condenser along the day hours (Rig 2)

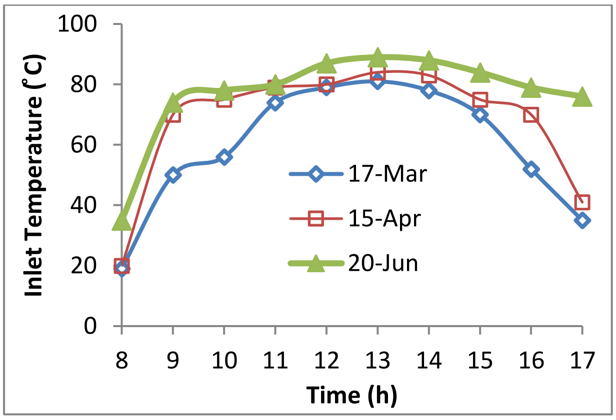


Fig. 11 Inlet water temperature to condenser along the day hours (Rig 2)

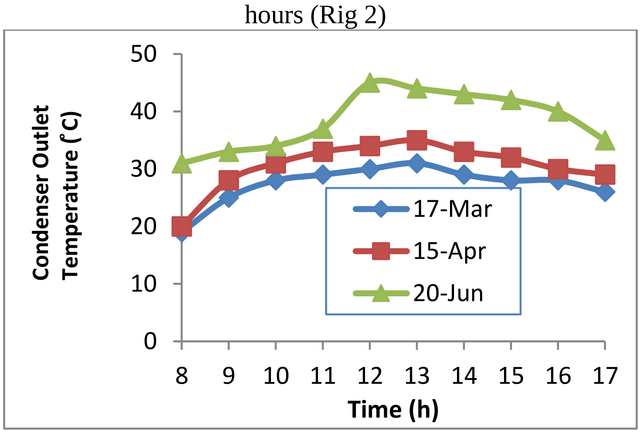


Fig. 12 Condenser Outlet water temperature along the day hours (Rig 1)

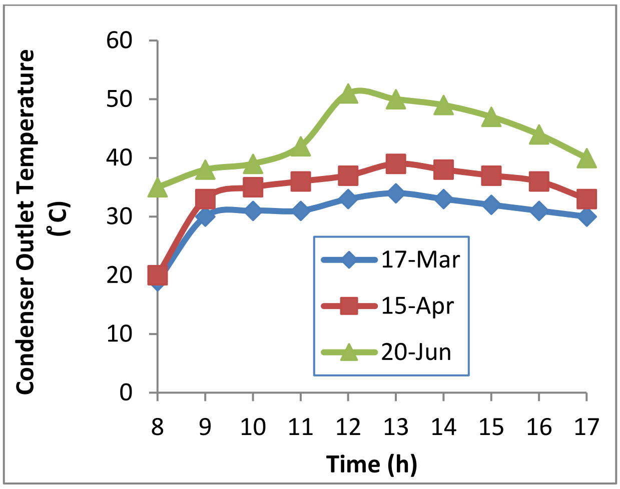


Fig. 13 Condenser Outlet water temperature along the day hours (Rig 2)

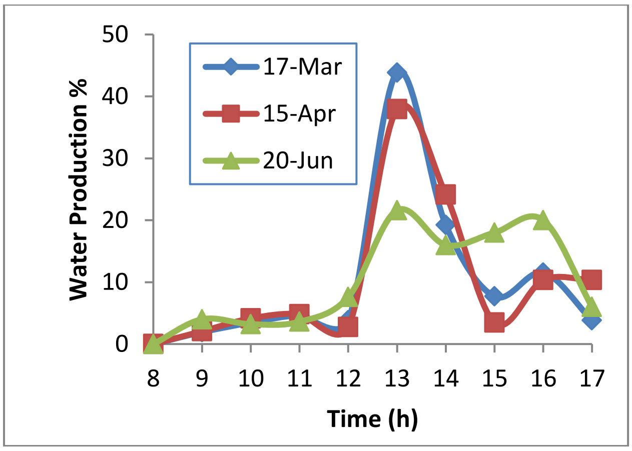


Fig. 14 Water Production percentage along the day (Rig 1)

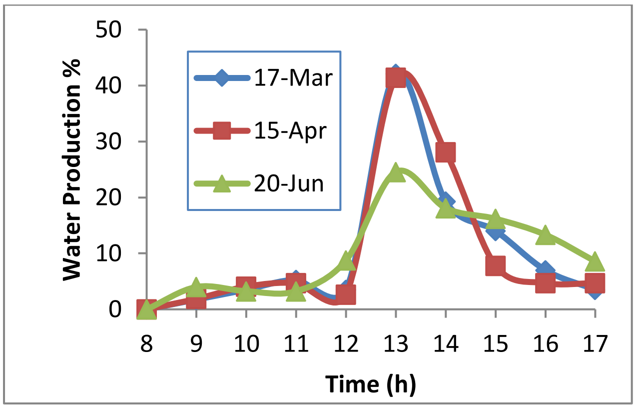


Fig. 15 Water Production percentage along the day (Rig 2)

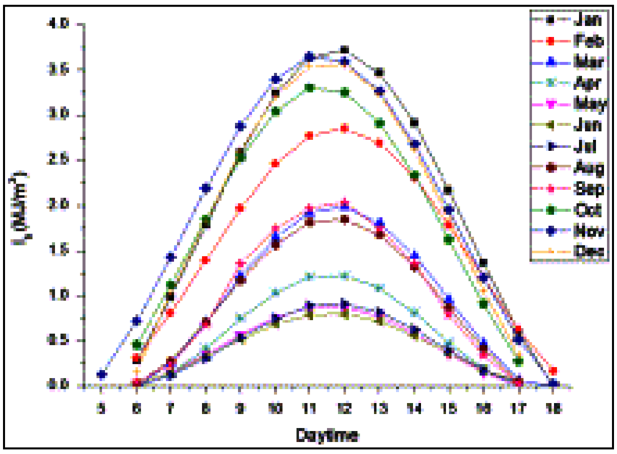


Fig. 16 Hourly evolution at the 15th of the respective months, in Chuquicamata (Chile) [18]

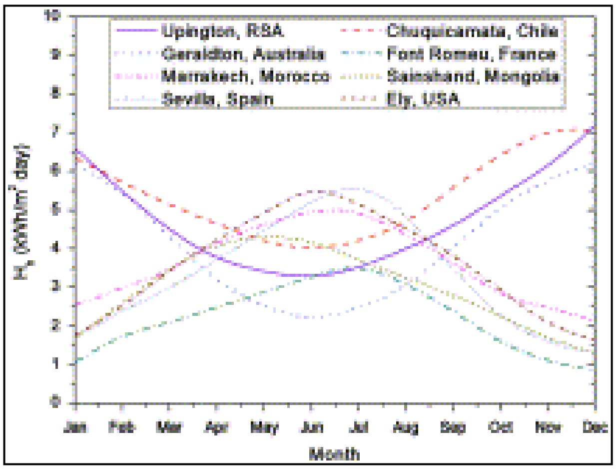


Fig. 17 Evolution of the average monthly direct (beam) irradiation in 8 locations [18]

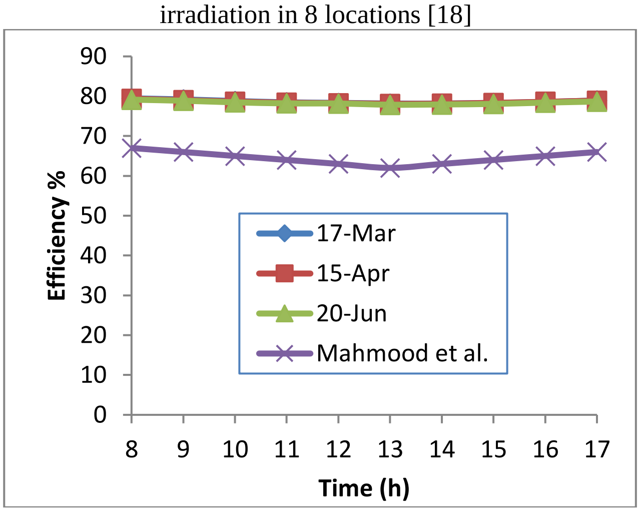


Fig. 18 Daily Solar Dish Efficiency in comparison with Mahmood et al. (Rig 1)

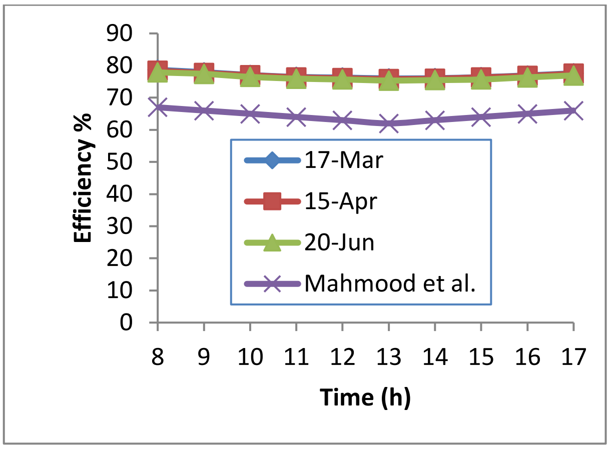


Fig. 19 Daily Solar Dish Efficiency in comparison with Mahmood et al. (Rig 2)

Nomenclature

Symbol	**Meaning**
r	Focal length
r_r	Focal length at the edge of the dish
f	Focal length at the center of the dish
φ_r	Half the angle of the dish
θ_m	Half the angle of inclination
D	Diameter of the area of the asterisk
W_a	Dotting angle
H_p	Length of the imaginary line passing through the focal point known as latus rectum.
F_{12}	Shape factor of dish
α	Absorption facor
ε	Emissivity of pool
h	Heat transfer convection coefficient
σ	Stephan- Boltzman factor ($5.67*10^{-8}$).
A	Cross sectional area of dish
S	Intensity of solar radiation on the unit area

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