Design and Operation of Solar Parabolic Dish for Water Heating

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Abstract

Design and operation of (2m) parabolic solar dish, water heater for hot water application was described. The heater was designed to provide hot water up to 100 ^{o}C using the clean solar energy. The system includes the design and construction of solar tracking unit in order to increase system performance. Experimental test results, which obtained from clear and sunny day refer to highly energy-conversion efficiency and promising a well performed water heating system.

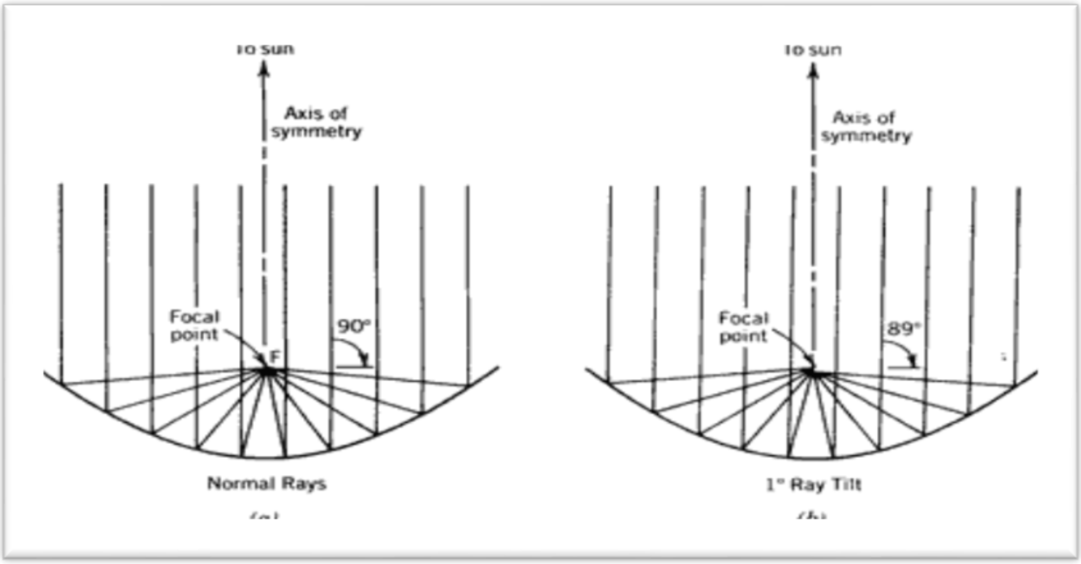
Keyword: Solar Dish, Heat Transfer, Solar Boiler, Water Heater, Parabolic Reflector, Thermal Performance, Solar Tracking System.

Introduction

The solar dish is the most important component in a solar thermal power plant. As such it is important to study and research about solar dish collectors in order to understands the characteristic performance of a concentrating solar thermal power system in a better way .Many researches related to parabolic concentrators are found , In solar thermal application design, construction and testing of of a parabolic dish solar steam generator. Using concentrating collector, heat from the sun is concentrated on a black absorber located at the focus point of the reflector in which water is heated to a very high temperature to form steam. It also describes the sun tracking system [1].parabolic solar concentrator has been experimentally studied. The experimental devise consists of a dish of 2.2 m opening diameter. Its interior surface is covered with a reflecting layer and equipped with a disc receiver in its focal position. The orientation of the parabola is assured by two semi-automatic jacks [2]. A parabolic dish solar thermal cooker having aperture diameter 1.8 m, depth 29.0 cm and focal length 69.8 cm was designed and constructed. The cooker was designed to cook food equivalent of 12 kg of dry rice per day, for a relatively medium size family. For effective performance, the design required that the solar cooker track the sun frequently, and a linear actuator (superjack) was adopted for this purpose [3]. Solar concentrator is a widely used and popular domestic solar cooker in parabolic dish cooker category. If the bowl of solar concentrator is fabricated then concentrators become bulky and transportability is a problem. If the bowl is not fabricated and only reflector sheets are stitched together with screws and bolts then transportability improves but bowl is weak and gets damaged even with high wind or strike of a ball or a stone [4]. Stirling cycle engine, a hot gas engine or an external combustion engine, offers potential advantages over conventional engines in fuel choices, noise and emissions. Multi-fuel such as agricultural by-product, biomass, biodiesel, solar energy and etc. can be employed as the heat source for a Stirling engine [5] .The study is helpful for the development of the membrane facet concentrator approximates a parabolic surface supported by a deployable truss structure, which originates from a large aperture space antenna. For optimizing the number of facets rows and focal-diameter ratio of the concentrator. Monte Carlo ray-tracing method is utilized to determine optical performance of the concentrator [6].This research work focuses on the development of an electronic control circuit for the tracking mechanism of a solar water heater, and assessing the effectiveness of this control circuit by assessing the thermal performance of the heater. A 10-litre capacity parabolic dish solar water heater was designed and constructed for use in Kaduna. The heater was designed to heat water from ambient temperature up to 100 ^{o}C. For effective performance the heater had to track the sun, and an electronic control circuit using two light-dependent resistors was designed and developed for this purpose [7]. Heat losses from receivers for a dish-type solar energy collecting system of Korea Institute of Energy Research (KIER) are numerically investigated. It is assumed that a number of flat square mirrors are arranged on the parabolic dish structure as a reflector. Two different types of receivers, which have conical and dome shapes, are considered for the system, and several modes of heat losses from the receivers are thoroughly studied. Using the Stine and McDonald model convective heat loss from the receivers is estimated [8]. Experimental plat form based on the design, development and performance characteristics of direct steam generation by non-tracking solar paraboloidal dish concentrating system. The performance of the concentrator is experimentally investigated with the water circulated as heat transfer fluid. The system system is fabricated with highly reflective aluminum foil sheet (0.8 reflectance factor). The experimental setup is placed in open, and the tests were carried out. The collector's efficiency was noted [9].This study carried out the design analysis of solar bi-focal collectors with the basic units comprising the paraboloid concentrators, receivers and support/connectors. The design of the receivers is such that it works on thermo-siphon principle while the heat energy requirement for each receiver is 650 kJ. Solar energy required to provide the needed power input in the collector's receiver is amounted to 0.967 kJ/s. The results of the analysis revealed that each collector has diameter of the receiver of 0.3 m, aperture diameter of 1.4 m and internal surface area of 1.53 m2 [10]. Four energy based parameters are proposed for solar cookers of different topological design, as their thermal performance indicators. To this end, graphs between energy output power and temperature difference are plotted, and they resemble a parabolic curve for each design. The peak energy (vertex of the parabola), can be accepted as a measure of devices' fuel ratings. The ratio of the peak energy power gained to the energy power lost at that instant of time can be considered as the quality factor of the solar cooker [11]. The ANU 500 m^2 dish is the first prototype of a new design geared towards mass production and low levelized cost of energy. The dish has high quality optics, with a geometric concentration ratio above 2200 and can be used for a variety of energy conversion technologies. The SG4 concentrator is currently being operated in direct steam generation mode with a monotube steam receiver [12].

Theoretical part

An optical concentration ratio (CR_o) is defined as the ratio of the solar flux (I_r) on the receiver to the flux on the aperture (I_a) and is most often referred to as the flux concentration ratio fig(1)



Fig(1) solar dish concentration .[13]

$$CR_o = \frac{I_r}{I_a} \qquad (1)$$

The higher concentration of solar radiation is achieved by refracting the flux incident on an aperture area (A_a), into a smaller receiver-absorber area (A_r)[14]

$$CR = \frac{A_a}{A_r} \qquad (2)$$

The optical concentration ratio gives a true concentration ratio because it takes in account the optical losses from reflecting and refracting elements. However, it has no relationship to the receiver area, thus it does not give insight into thermal losses. These thermal losses are proportional to the receiver area, and since the thermal aspects is most interested in the system, the geometric concentration ratio will be used here. The amount of solar radiation reaching the receiver is dependent on the amount of radiation available (sky conditions), the size of the concentrator, and several other parameters describing the loss of this radiation on its way to being absorbed. Heat loss from the receiver is separated into convection-conduction heat loss and radiation heat loss. The rate of heat loss increases as the area of the receiver and/or its temperature increases. This is why concentrators are more efficient at a given temperature than flat plate collectors, because the area in which heat is lost is smaller than the aperture area.The useful energy delivered by the collector (q_u) is given by the energy balance

$$q_u = \eta_o I_c\, Aa - U_c\,(T_c - T_a)\, A_r \qquad (3)$$

where η_o is the optical efficiency, U_c is the collector heat-loss conductance, T_c and T_a are the temperatures of the collector and the ambient air respectively, and I_c is the insulation incident on the aperture. The instantaneous collector efficiency, η_c is thus given by

$$\eta_c = \eta_o - \frac{U_c(T_c - T_a)}{I_c}\frac{1}{CR} \qquad (4)$$

Neglecting the optical efficiency, the instantaneous efficiency η_{inst} of the solar thermal collector can also be simplified and defined as the ratio of the useful heat, Q and delivered per aperture area, A_a, and the insulation, I_c which is incident on the aperture.

$$\eta_{inst} = \frac{\dot{Q}}{A_a I_c} = \frac{\dot{q}}{I_c} \qquad (5)$$

The useful heat Q is related to water flow rate m and specific heat at a constant pressure and the inlet and outlet temperatures T_{in} and T_{out} [13].

$$\dot{Q} = mC_p(T_{out} - T_{in}) \qquad (6)$$

Where C_p is heat capacity at constant pressure

Experimental Work

A-Parabolic dish A concave dish was made of galvanized steel and lined with a sheet steel. A method of a given focus and directory was employed in the construction of the parabolic dish. The reflector plain mirror cut into shapes and fixed by screw, this structure or the sheet painted by steel paint and used miller paper stick with reflectance of (76%) as shown in Fig (2).

Fig (2) Diagram of fabricated solar dish.

The following table describes the main characteristics of the solar concentrator

Table 1: Characteristics of the solar concentrator

Diameter of opening of the parabola	2 m
Surface collecting of the parabola	3.14 m
Focal distance	0.8 m
Deep	0.35 m

B- **Receiver**: The experimental receiver was made of stainless and covered with a thin coat of black paint to decrease the reflection of the solar rays and it was located in the focal zone of the parabola dish. Heat losses of the receiver should be minimize to keep water temperature almost at constant degree. Since convection and radiation losses are normally significant compared to conduction loss, convection and radiation heat transfer from the receiver to the surrounding should be carefully investigated. The heat loss became higher in the case of wind parallel to the aperture plane than that of the case of the head–on wind. In this of work, cylindrical receiver was chosen, the receiver was designed in small area which facing the aperture window in order to minimize the reflection losses. Thus, this type of receiver design gave more chance to absorb the internal reflected photons. The receiver consists of a set copper windings coil house paint by black color .All these parts were made locally the dimensions of cavity are (150 mm) depth and (100 mm) thickness and (3mm) of an aperture diameter, the coil consist of (15) windings of (5 m) length of reduced diameter pipe. Two thermocouples of k-type were used for measuring temperature of inlet and outlet fluid (HTF).

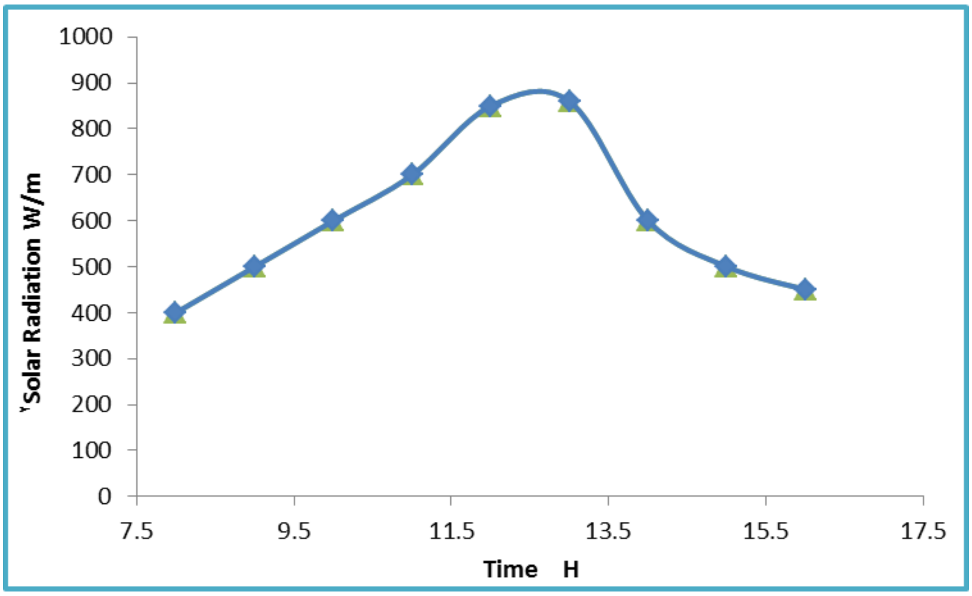
C-**Storage tank**: A 20 liters steel tanks was used to storage cooling refrigerant. The tank have two holes for water inlet and outlet. A k-type thermocouple placed to measure water temperature.

D-**Tracking system**: A DC- motor with light sensor consist of two cds- photo resistor were used for solar light tracking system.

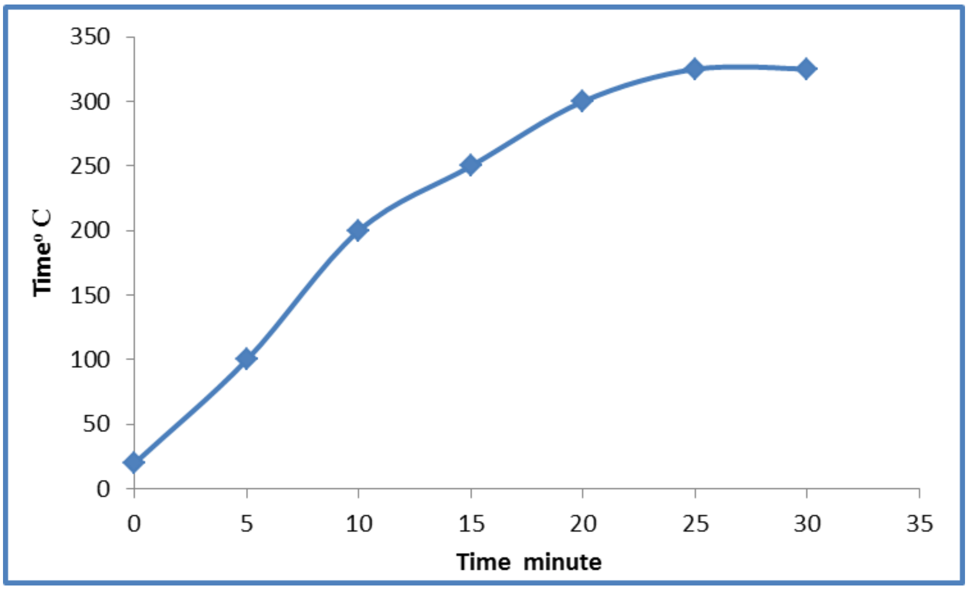
E- **System Operation**: system was assembled and operated in clear, sunny weather. The solar radiation focused to water boiler for about (10) minutes, the boiler temperature rose to about 300°C (without water). A low power water pump was run for water circulation between the boiler and the tank. This process was repeated for 5 times. The temperature of inlet and outlet water was recorded.

Result and discussion:-

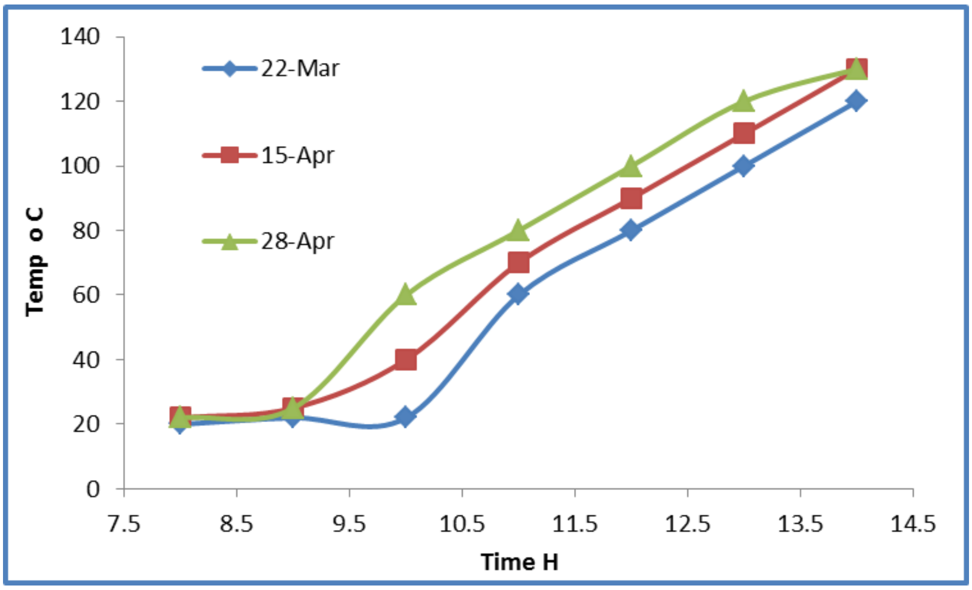
We have done this work in Iraq-Tikrit. A parabolic solar concentrator prototype was built by using available and cheap materials. Through a clear day, with a temperatures over (350ºC). In this work, the qualitative evaluation of the operation of parabolic solar concentrator has been achieved, the data indicates in general that the incident solar radiation is increased with time and reach it maximum at mid-noon and it decrease until the sunset time, that's because Iraq is in a suitable place for solar thermal application as shown in fig (4) [1][12]. Also increasing the temperature of boiler to 300 ^{o}C faster during months of the year and with end of summer because the solar radiation direction is perpendicular to earth surface [13] as shown in fig(6).



Fig(4) Relation between solar radiation and time.



Fig(5) Show boiler temperature without water with time.



Fig(6) Relation between temperature and time within two months.

Fig's (7) and fig. (8) Shows the useful energy increasing with time until mid-noon this because increasing temperature and solar radiation and decreasing until sun-set [14].

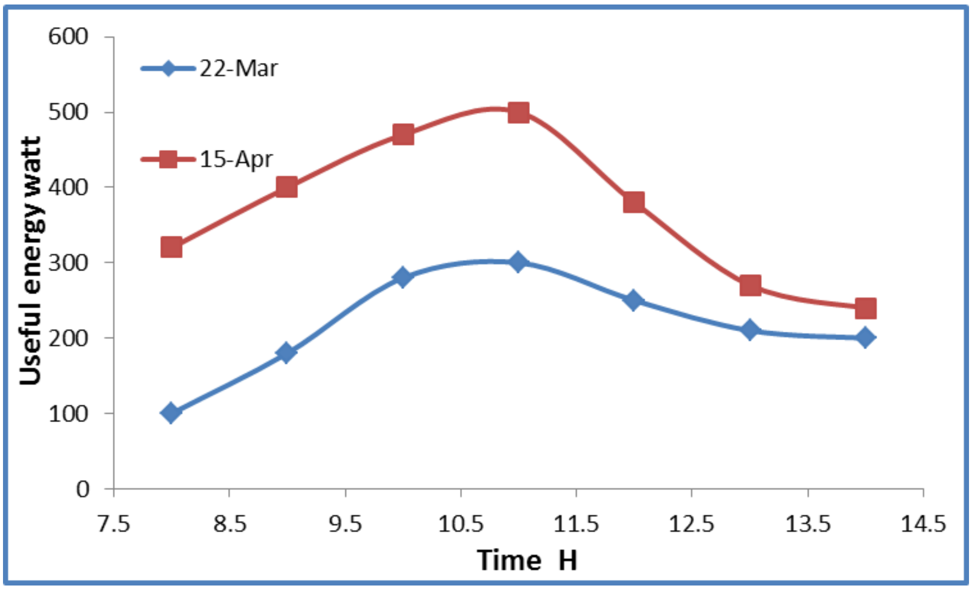
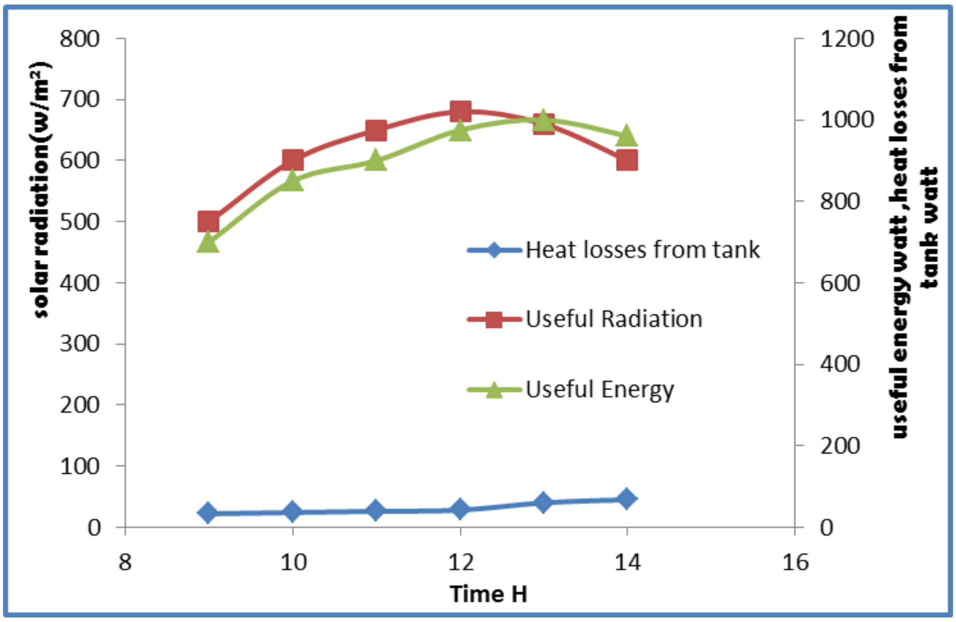


Fig (7) Useful energy for two month.



Fig(8) Relation of solar radiation with useful energy and heat lose

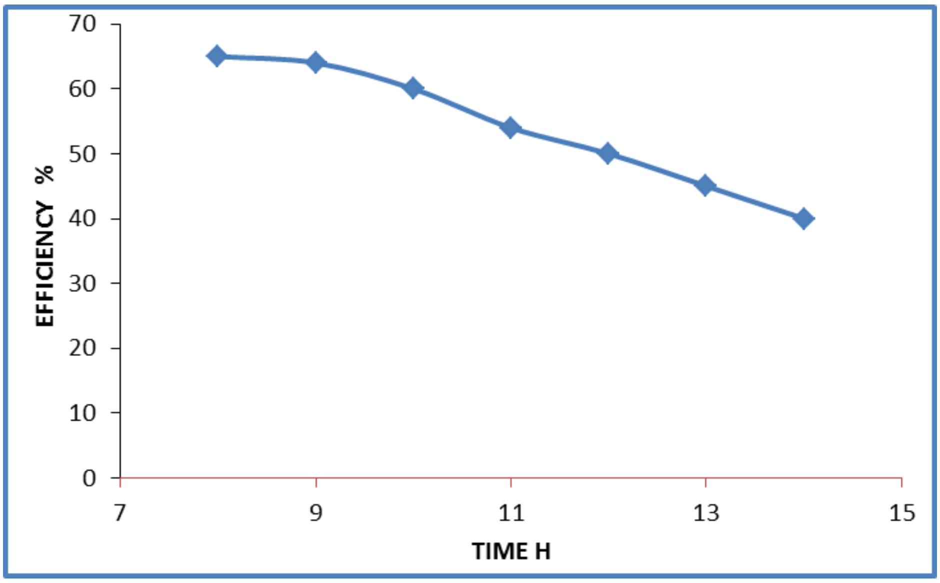


Fig (9)Variation of efficiency with time for receiver.

Fig's (9) and fig.(10) describes the efficiency of the system related to time of operation. The efficiency have high value in initial time of operation and decreased along with time. This behavior belong to losing energy by radiation process which is proportional to fourth power of receiver temperature, this value indicates to perfect performance of the cylindrical receiver [12].

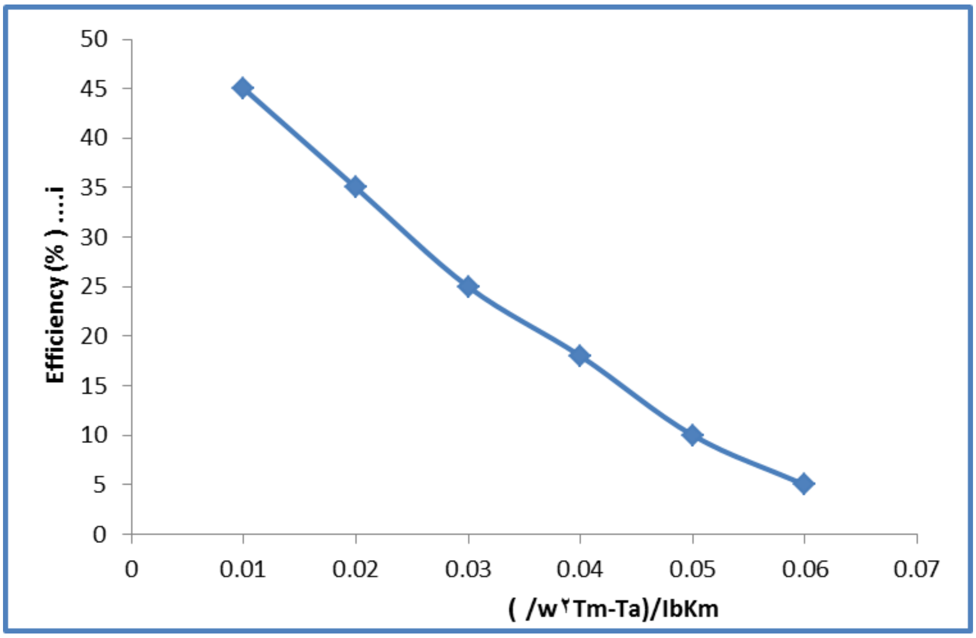


Fig (10) Variation of efficiency with operation temperature.

Finally, in order to conserve the hot water temperature a thermal isolating layer has been wrapped and covered the hot tank, this process can help to keep the water temperature for longer time.

Conclusions

The results obtained from present study indicates that the parabolic solar concentrator can be used successfully for desalination of water to provide potable water for domestic usage. The parabolic solar concentrator operates with temperatures higher than different types of the solar radiation conversion systems. Water temperature increased with low flow rate and reply the water cycle between cold tank, receiver and the hot tank. The amount of the potable water was much dependent on the accurate focusing of the system and increased when the preheating method was applied and increasing the time of water storage by insolated the hot tank and piping.

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تصميم وتشغيل الصحن الشمسي ذو القطع المكافئ لأغراض تسخين الماء

الملخص:

في هذا البحث جرى تصميم وبناء وتشغيل الصحن الشمسي ذو القطع المكافئ بقطر(2m)لأغراض تسخين الماء. وقد تم تصميم الصحن لتجهيز ماء بدرجة حرارة تصل الى (100 C)باستخدام الطاقة الشمسية. وتتضمن المنظومة كذلك تصميم وبناء وتشغيل وحدة التتبع الشمسي لغرض زيادة كفاءة المنظومة. لقد اظهرت نتائج الفحوصات العملية والتي اجريت في الاجواء المشمسة والصحوة كفاءة عالية في تحويل الطاقة الشمسية الى طاقة حرارية ، مما يفسح المجال للحصول على منظومة تسخين الماء بكفاءة عالية.