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Modulating a Solar Parabolic Dish to Produce Boiled Water

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Abstract: A two-meter parabolic solar concentration dish has been modulated to produce boiled water over 100 ^{o}C for various purposes of central heating services. For an effective performance, the system required both continuous exposure of the dish to sunlight during the day time as well as to an electric control circuit (tracking system). The amount of the potable water was dependent particularly on the accurate centering of the system which could increase upon preheating. This system has therefore been possible to heat up water at home via increasing the temperature in hot tank by both covering the hot water tank and isolating it from the surroundings using insulators. Applications of a successful parabolic solar concentration has also been designed to provide desalinated water for domestic usage which operates with temperatures higher than other types of the solar radiation for the future.

Key words: Solar dish concentration, hot water; heat transferring, parabolic reflector.

1. Introduction

Solar water heaters could generally be categorized as either condensing or non-condensing type. Flat plate collectors and evacuated tube collectors are the two most widely used non-condensing (Non-concentrating) type of solar water heaters. The concentrating type of heaters usually employs parabolic-concave mirror reflectors to condense the total solar energy incident on the collector surface which usually becomes very wide and the temperature achieved could therefore be very high. Some of the collectors, in this category, are either parabolic trough, compound parabolic condenser, parabolic dish, or cylindrical parabolic concentrator. Parabolic dish, however, has the highest efficiency in terms of utilization the reflector area as in a fully steerable dish system where there would be no loss due to the aperture projection effects. The radiation losses could also be small because of the small area of the absorber at the focus [1]. A few relevant approaches to parabolic condensers have dealt with setting up a test facility for parabolic dish systems with power conversion unit in their focus [2]; simple solar tracking concentrator for university research applications [3] and a heat transfer in a conical cavity calorimeter for measuring thermal power of a point focus concentrator [4]. Most of the desalination processes are based on expensive fuels like electricity, coal and gas etc.. Thus, to provide fresh water at reasonable cost, it is necessary to convert fuel operated technology to solar operated technology [5].

In 2006, an alternative application has been suggested by Palavras and Bakos [6] to couple the sun concentrator with a starling engine. However, the cost of these systems remains expensive enough in the sense of both quality of material sand the dimensions. Cost reducing researches have also been proposed [7, 8]. A focusing point of the solar concentrator can also be made from two trough collectors by orienting their longitudinal axes in perpendicular directions. Meanwhile, separate them by different focal lengths

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along the optical axis Quincy [9]. Designation and modulation of solar dish concentration of 2 meters for water heating application has been proposed [10] and solar steam has been achieved [11].

1.1 Theoretical Part

Solar dish concentration: The solar collector is the key element in a solar thermal energy system which intercepts the incoming solar insolation and converts it into a useable form of energy that can be applied to meet a specific demand i.e. generation of steam from water. They are used to generate high temperatures to accomplish the concentration of the solar radiation by reflecting the flux incident on the aperture area (reflective surface, Aa) onto a smaller absorber (receiver) area (Ar).

Due to the smaller surface area of the receiver in comparison with that of the reflective surface capturing the energy, this would allow the same amount of radiation spread over a few square meters. It could, therefore, be collected and condensed over a much smaller area that enables generating higher temperature. The latter have the advantage of both higher concentrator and capability for much greater utilization of the solar intensity at off-noon hours than other types of solar concentrators. However, one of the major problems of using a "dish-type" parabolic collector is that a two-dimensional tracking is required. Most concentrating collectors can only condense the normal beam insolation (the parallel insolation comes directly from the sun), otherwise, the focal region becomes scattered out of focus (Fig. 1). Therefore, a concentrator becomes necessary to follow the sun throughout the day for efficient energy collection meanwhile continuous tracking is needed for the parabolic concentrator.

For any east-west orientation, the concentrator requires an approximate ± 30°/day motion while for north-south, an approximate 15°/hr motion become necessary. This tracking must also accommodate a ± 23.5°/yr excursion declination by refracting the flux

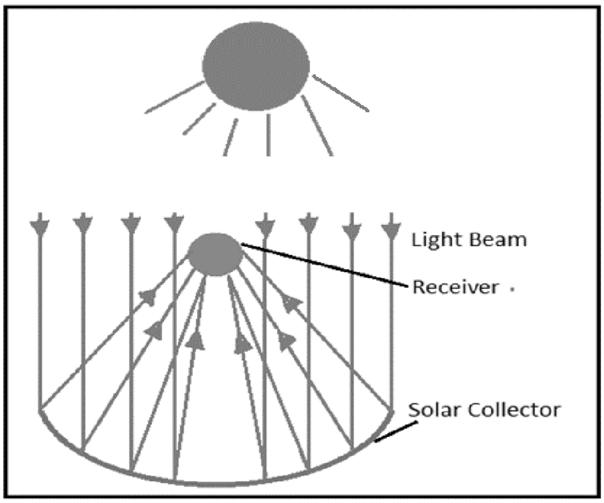

Fig. 1 A schematic diagram of a parabolic dish concentrator reflecting parallel light beams.

incident, the aperture area, Aa, onto a smaller receiver/absorber area, Ar. There are two ways of representing this ratio of concentrator either as an optical or as a geometric ratio. An optical concentrator ratio, CRo, is described as the ratio of the solar flux, Iron the receiver to the flux on the aperture while I_a is most often referred to as the flux concentrating ratio:

$$CR_o = \frac{I_r}{I_a} \tag{1}$$

Eq. (1): The geometric concentrating ratio, CR, is based on the ratio of the area of the aperture and the receiver.

$$CR = \frac{A_a}{A_r} \tag{2}$$

The optical concentrating ratio provides a true concentrating ratio because it takes into account the optical losses from reflecting and refracting elements while it is irrelevant to the receiver area giving an insight into thermal losses. These thermal losses are proportional to the receiver area. Since the authors are most interested in the thermal aspects of the system, the geometric concentrating 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 be 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, as 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.

$$qu = \eta o \cdot Ic \cdot Aa - Uc \cdot (Tc - Ta) \cdot Ar \quad (3)$$

Where, η_o is the optical efficiency, U_c is the collector heat-loss conductance, T_c and Ta are the temperatures of the collector and the ambient temperature respectively, and I_c is the insolation incident on the aperture. The instantaneous collector efficiency, ηc is thus given by Eq. (4):

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

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, Aa and the insolation, I_c, which is incident on the aperture:.

$$\eta_{inst} = \frac{\dot{Q}}{AI_c} = \frac{\dot{q}}{I_c} \quad (5)$$

The useful heat Q is related to the flow rate, m and specific heat at a constant pressure and the inlet and outlet temperatures, T_{in} and T_{out} by Eq. (6):

$$\dot{Q} = m \cdot C_p \cdot (\dot{T}_{out} - T_{in}) = inC_p \cdot \Delta T \quad (6)$$

$$h = \frac{d^2}{16f} \quad (7)$$

1.2 Experimental Equipment

1.2.1 The Parabolic Dish

The concave dish has been made of galvanized steel sheet. The method of a given focus and directory was employed in the construction of the parabolic dish. The reflecting plain mirror pieces (3 cm × 3 cm) have been cut into shapes, fixed by screw, painted by steel paint and stuck on the reflective surface of the parabolic dish to collect almost 90% of sun rays by a concentrator (Fig. 2 and Table 1).

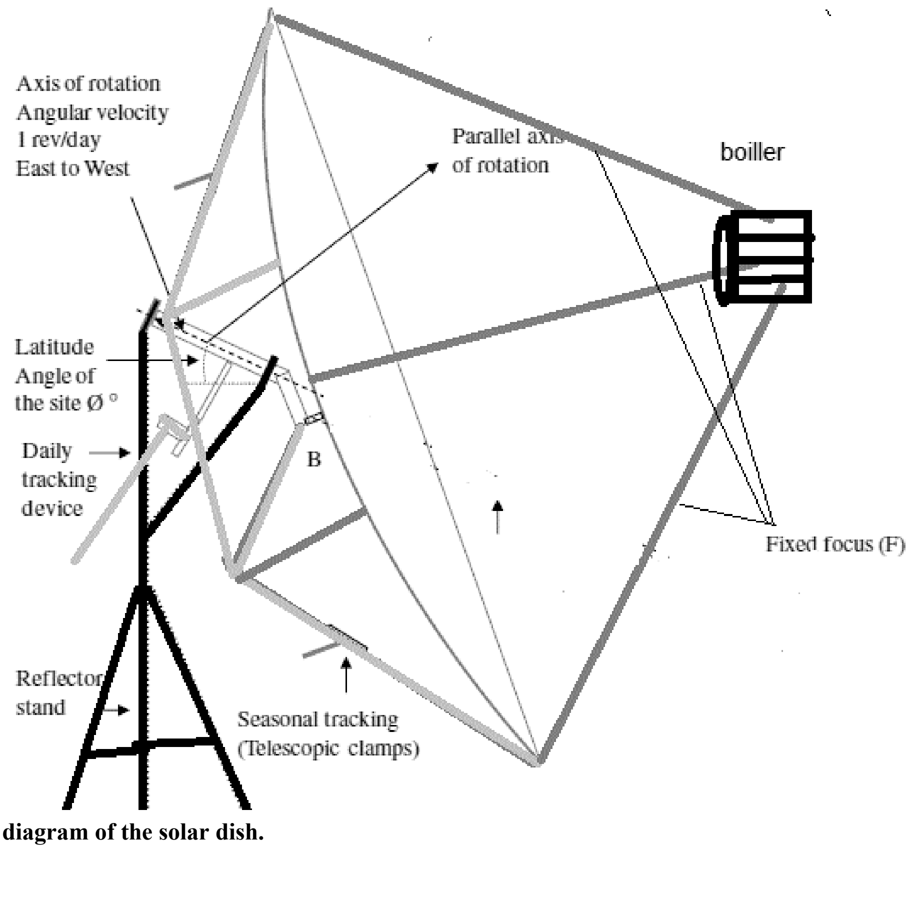

Fig. 2 Schematic diagram of the solar dish.

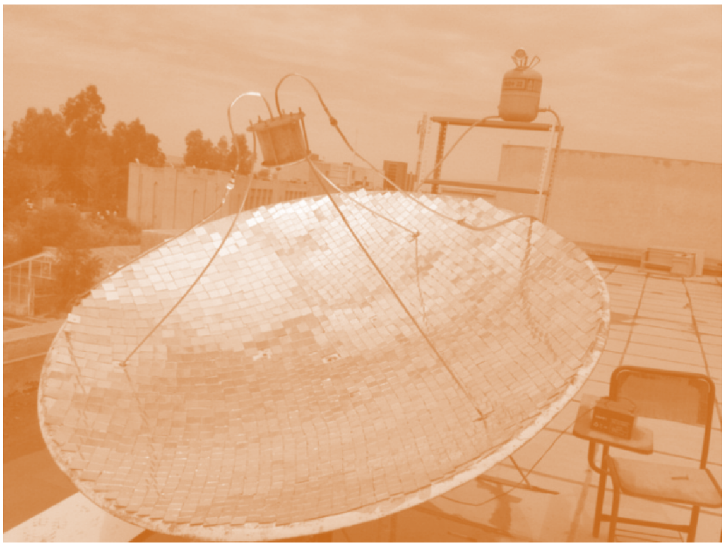

Fig. 3 A designed experimental solar condenser.

Table 1 Details of the solar condenser.

Parameters	Measurements/units
Diameter of opening of the parabola	2.0 m
Surface collecting of the parabola	3.14 m^2
Depth of the arabola	0.3 m
Focal distance	0.83 m

1.2.2 The Receiver

The experimental receiver was made of stainless steel, covered with a thin coat of a black paint to decrease the reflection of the solar rays and located in the focal zone of the parabola dish to study the radiation and temperature on a cavity of receiver. The geometrical concentration of this model is designed in a way to get the optimum design of the receiver. The heat loss of the receiver should be minimum, since convection and radiation losses are normally significant in comparison to conduction loss, convection. The radiation heat transfer from the receiver to the surrounding is to be carefully investigated. It also is difficult to find simple method to predicate the surrounding. The heat loss became higher in case of wind parallel to the aperture plane than that of head-on wind. In this of work, cylindrical receiver was chosen due to its small area facing the aperture window which leads to minimize the reflection losses. Such receiver design provides more chance to absorb the internal reflected photons. The receiver consists of a set copper windings coil house painted in black color, with the dimensions of cavity (150 mm depth × 100 mm × 3 mm thickness) aperture diameter while the coil has been (5.0 meters in length of 15 consecutive windings of reduced diameter). Two thermocouples of k-type were used to measure both in inlet and outlet temperature of the heat transfer fluid (HTF). All these parts were made locally.

1.2.3 Storage Tank

Two storage steel tanks filled with Freon gas and modifications of additional two holes for both water inlet and outlet were placed for installation thermocouple.

1.2.4 Tracking System

A DC motor similar to the motor of the satellite control was used with two sensor (CdS) photo resistor.

1.2.5 Operating System

After collecting the system, the center dish was directed towards the sun. Meanwhile, the solar radiation focused onto the boiler for about 10 minutes when the temperature is raised almost to 300 °C (without water). Low power water pump was used to raise the temperature of the water to the boiling point before transferring to other tanks while the operation was repeated for 5 times and both the inlet and outlet temperatures were recorded to calculate the heat transfer from receiver to the hot tank.

2. Results and Discussion

Apart from reflective film the present work involved building a parabolic solar concentrator prototype with locally available materials which was assessed to be of reasonable cost. On a clear day, a temperature above 100 °C makes it possible to achieve with the parabolic-shaped surface of the solar concentrator prototype. The results had confirmed the possibility of the direct increase in the solar radiation proportionally with time which could reach the maximum at mid-noon followed by gradual decrease towards the sunset. It has also been confirmed that the Iraqi climate would be a suitable place for solar thermal application (Fig. 4) [12, 13]. It has also been found that an increase in the temperature is proportional with time towards the maximum at summer season when the utmost solar radiation gets closer to perpendicular on earth (Fig. 5).

The useful energy increased steadily with the time until mid-noon. That is because that both temperature and solar radiation increased steadily up to the midday but decreased until sunset (Figs. 6 and 7) [14].

The efficiency has been the utmost at the beginning of the operation. However, it gradually decreased with the time. The temperature of the operation system was dropped to 10^4 to receiver's temperature of the cylindrical boiler as the radiation losing energy operates proportional. The latter confirms its suitability for operation (Figs. 8 and 9) [12].

3. Conclusion

The parabolic solar concentration had succeeded in operating with temperatures higher than any other different types of the solar radiation and in desalination of water for potable water and domestic usage pending on both accurate adjustment and increased at preheating method. An increase in low-flow rate of water temperature was achievable together with an alternative exchange in the water cycle between cold tank/receiver and the hot tanks. Fully insulating the system from the surrounding would be also useful for heating water services at home. Various other applications of this modulation could also be achievable i.e. generating boiled water, electricity, water pump for turbine and distillation water for medical uses.

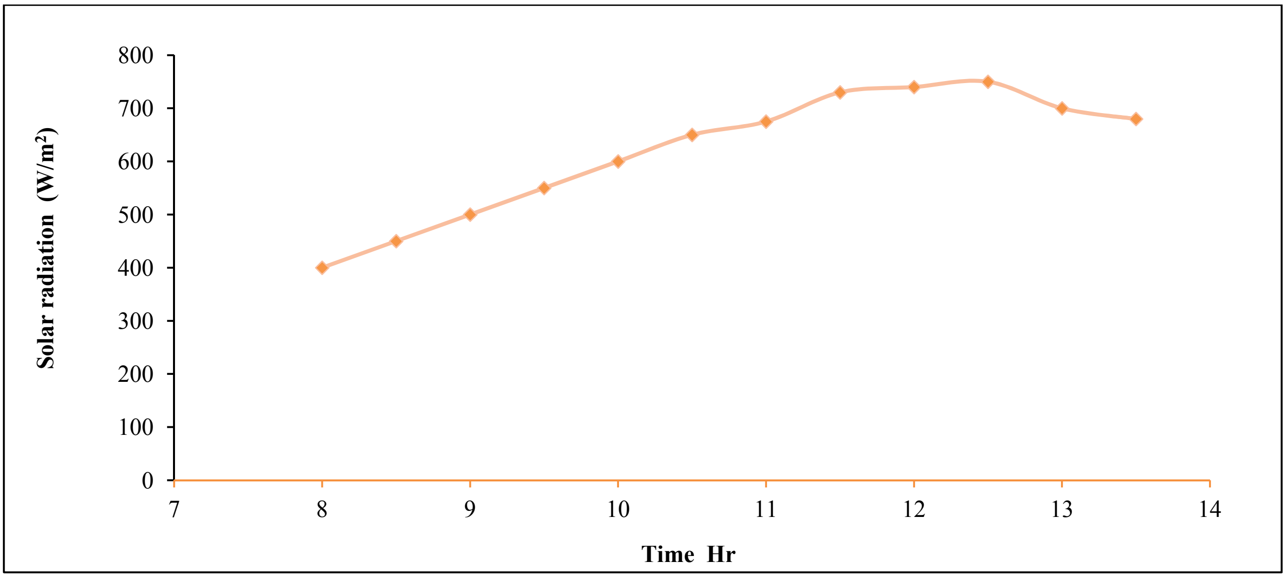

Fig. 4 The correlation between solar radiation and day hours, the gradual increase in solar radiation up to the mid-day.

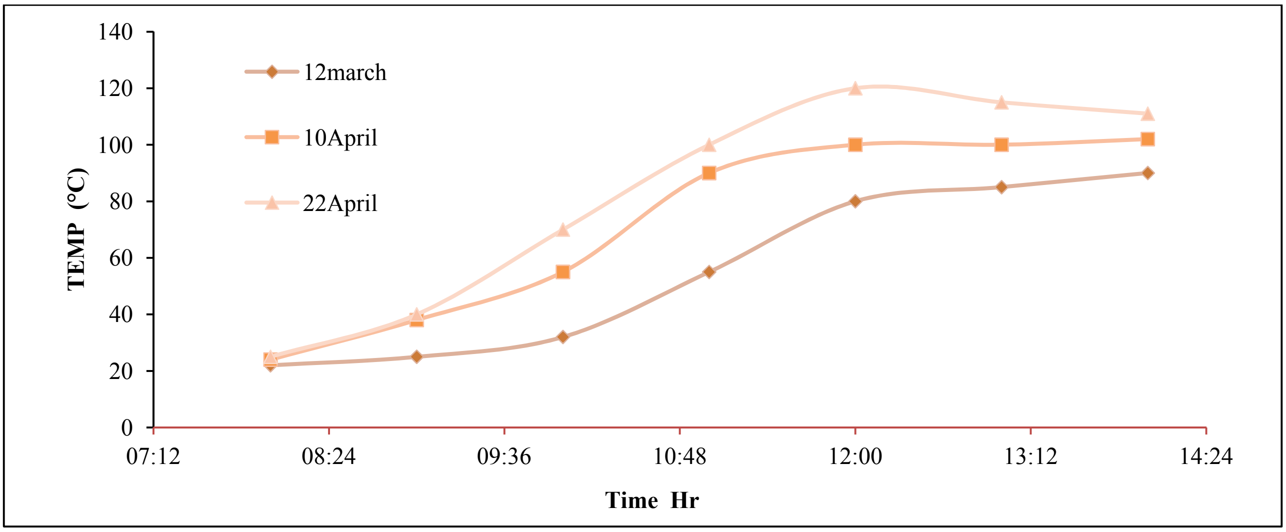

Fig. 5 The relation between temperature and time within two months.

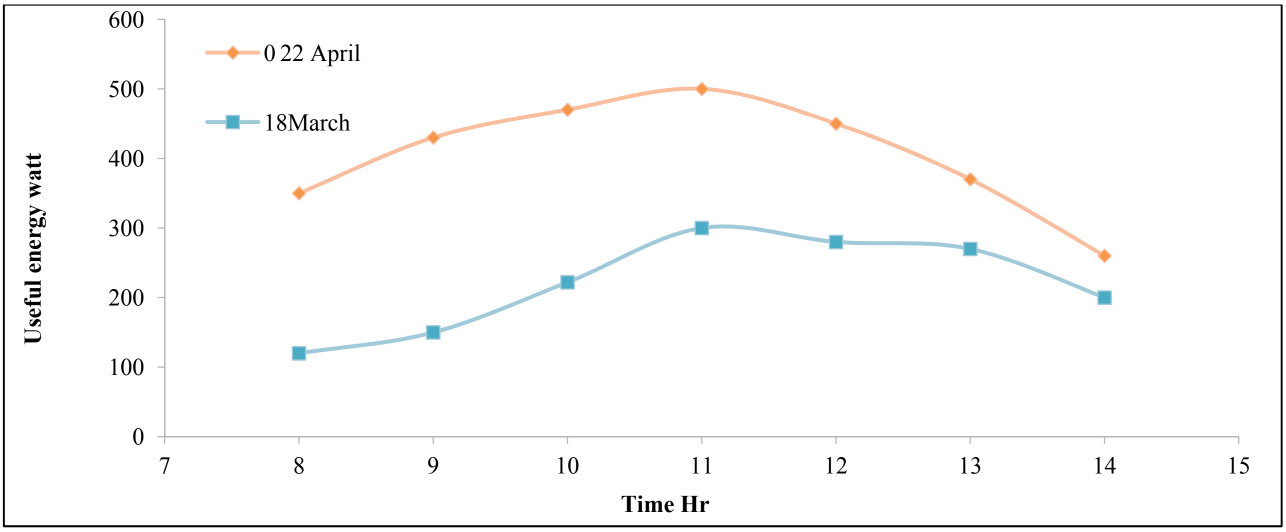

Fig. 6 The useful energy for two month.

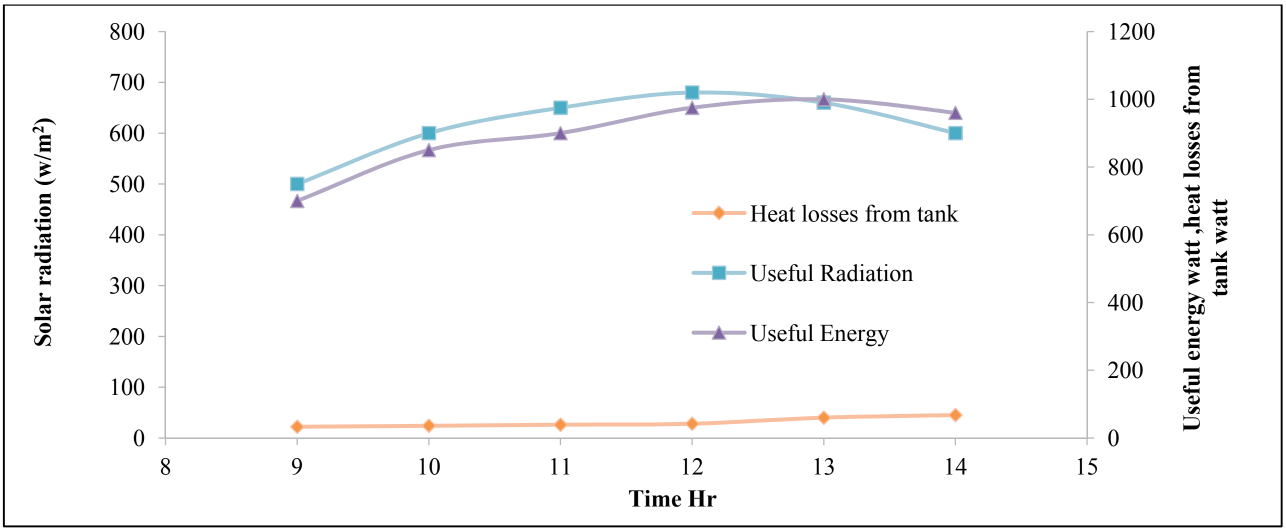

Fig. 7 The relation of solar radiation with useful energy and heat lose.

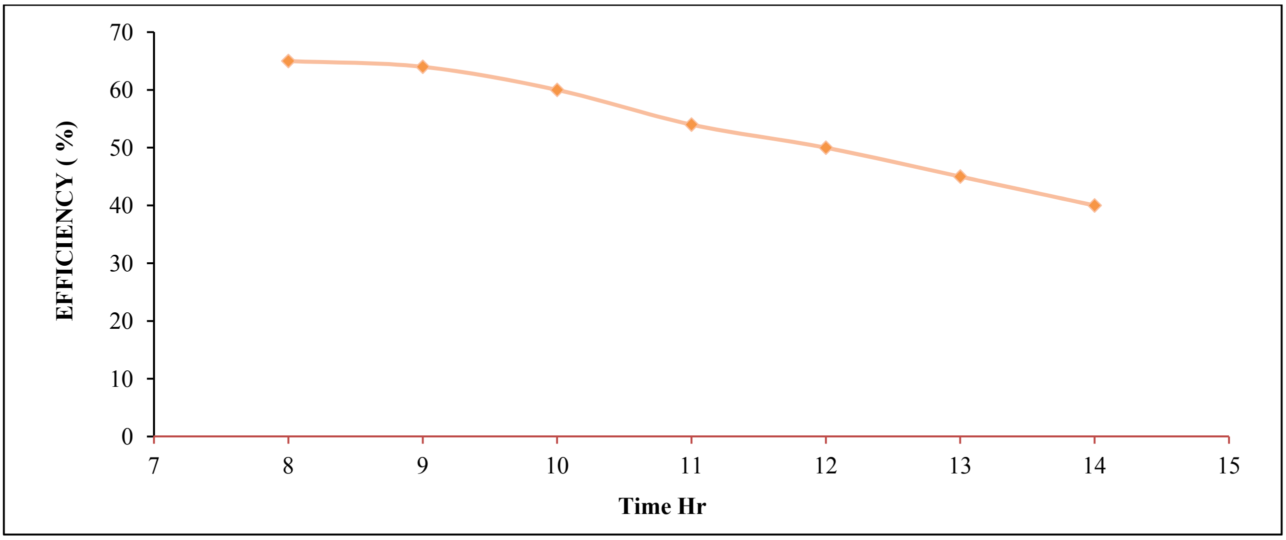

Fig. 8 Variation of efficiency with time for receiver.

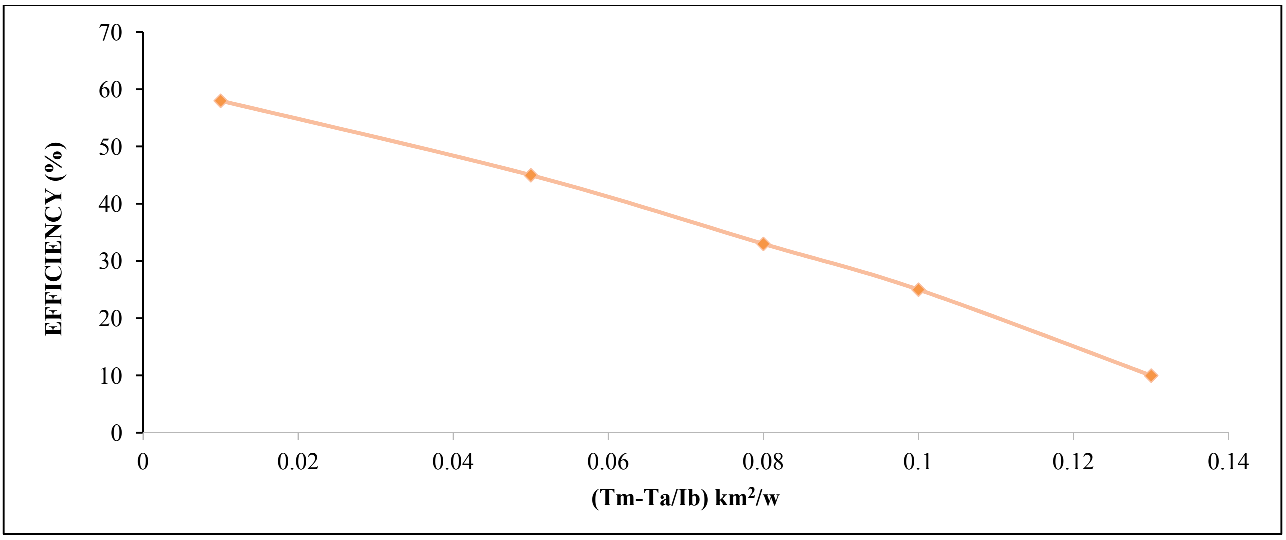

Fig. 9 The variation of efficiency with operation temperature.

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