Effect of Design Variation on Saved Energy of Concentrating Solar Power Prototype

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***Abstract*— the sun is a huge emission of energy. Mainly of the energy is in the form of heat and light, which can be collected and used for generating electricity, as well as for heating, cooling and lighting building. Electric utility companies are using mirrors to concentrate heat from the sun to produce environmentally friendly electricity for cities. This abundance of solar energy makes Concentrating Solar Power (CSP) plants an attractive alternative to traditional power plants, which burn polluting fossil fuels such as oil and coal. Unlike traditional power plants, CSP systems provide an environmentally kind source of energy, produce virtually no emissions, and consume no fuel other than sunlight.**

This study is focused on the feasibility of improving CSP planet efficiency, by design and investigates a diminished prototype. Three cases studies have been investigated these are, coloring the central receiver with selective black color, enclose the receiver by a glass box and color the glass enclosed by specific black color. Investigations have been conducted in Baghdad-Iraq summertime weathers 2011. The results showed a good improvement in thermal storage when using the glass enclosed comparison with other two cases. Also, it is found that this improvement varied and depends on month and reaches the peak in summer.

***Keywords*—** Design, Solar Power, Manufacturing, CSP systems and Thermal Storage

I. INTRODUCTION

The sun is an excellent source of radiant energy, and is the world's most abundant source of energy. It emits electromagnetic radiation with an average irradiance of 1353 W/m^2 on the earth's surface [1-2]. To put this into perspective, if the energy produced by 25 acres of the surface of the sun were harvested, there would be enough energy to supply the current energy demand of the world [3]. When dealing with solar energy, there are two basic choices. The first is photovoltaics, which is direct energy conversion that converts solar radiation to electricity. The second is solar thermal, in which the solar radiation is used to provide heat to a thermodynamic system, thus creating mechanical energy that can be converted to electricity. In commercially available photovoltaic systems, efficiencies are on the order of 10 to 20 percent, where in a solar thermal system, efficiencies as high as 30 percent are achievable [4-5].

Central receivers (or "power towers") are types of solar thermal systems that use mirrors to focus sunlight to a focal spot (in this case a tower) [6]. But instead of using a dish to harvest solar power, central receivers rely on a stationary tower and nearly flat, tracking mirrors (heliostats) arrayed around the tower [7]. Each heliostat in the array is free-standing, and is able to independently track the sun [8]. Inside the receiving tower, a heat transfer fluid (usually water or molten salt) absorbs the sun's thermal energy and is used to generate steam for a turbine [9].

Because so much sunlight is concentrated in a small area, the tower fluid becomes superheated, reaching 650° Celsius [10]. These higher temperatures help to reduce the cost of thermal storage. Also, the heliostats used in central receivers are nearly flat, rather than curved, reducing their manufacturing cost [11]. These features combine to give central receivers the potential to be produced inexpensively [12]. A major benefit of a CSP plant is that its fuel comes directly from the sun. This is a renewable energy source that has the added benefit of being completely free to harvest [13]. The generation of electricity through CSP produces few, if any, harmful atmospheric emissions. Since the energy source comes directly from the sun, there is no destructive extraction process [14]. There is also no combustion process when generating power with CSP, which eliminates the issue of hazardous emissions [15]. In most electric generation systems, the fuel must be combusted to release heat for use in generation [16]. With CSP, energy from the sun is directly utilized for the heat used in the electricity generation process. This lack of a conversion step is a key component of what makes CSP such a clean energy source [17]. CSP has been under investigation for several decades, and is based on a simple general scheme: using mirrors, sunlight can be redirected, focused and collected as heat, which can in turn be used to power a turbine or a heat engine to generate electricity [18]. Despite being relatively uncomplicated, this method involves several steps that can each be implemented in a plethora of different ways. The chosen execution method of every stage in solar thermal power production must be optimally matched to various technical, economic and environmental factors that may favor one approach over another [19]. Extensive

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explorations of various solar collector types, materials and structures have been carried out, and a multitude of heat transport, storage and electricity conversion systems have been tested. The progress made in every aspect of CSP, especially in the last decade, was geared towards expanding the efficiency of solar-to-electric power production, while making it affordable in comparison with near-future fossil fuel derived power [20].

II. EXPERIMENTAL WORK

A small prototype was designed with 4 rows of reflectors arranged in an arc form; the inner and outer diameters are 0.25 m and 1 m, respectively. The rows were distributed as arcs with an angle 150° at its centre facing south. The heliostats made up from 2.0×2.0 cm^2 mirrors. The first row heliostats were fixed 3 cm height from the ground. The second heliostats row was fixed 4 cm height from the ground and departed from first row 25 cm. The third heliostats row was fixed 6 cm height from the ground and departed from second row 25 cm. The forth heliostats row was fixed 8 cm height from the ground and departed from third row 25 cm. These arrangements were taken to enhance reflected radiation aiming to receiver by mirrors.

The receiver was made of a cylindrical wrought iron rod with 6 cm diameter, 10 cm height and 2.8 kg weight. Receiver specific heat is (*Cp= 0.46 kJ/kg °C*) and its thermal conductivity is (*k= 59 W/m °C*), [26]. The receiver was put at a height of 30 cm above ground level. A glass cover box (25cm × 25cm × 25cm) was prepared to preserve all the incident radiation, and to prevent heat transfer by convection with ambient air, also to utilize the greenhouse effect. Another glass cover was prepared but it was colored with specific black color to increase the heat absorptivity. The used glass was 2 mm thickness and its transitivity about 92%. Three calibrated thermocouples were used to measure the receiver temperature at any time. One thermocouple was fixed at the top of the receiver, while the second one was fixed at its bottom and the last one was fixed in the middle.

A calibrated mercury thermometer was used to read the ambient air temperature every hour. It was fixed in shadow. The thermal efficiency of the system from incoming solar beam was calculated using the following equations:

The saved energy in the receiver at each hour Q_{act} (kJ/hr) is

$$Q_{act} = m\, Cp\, \Delta T \qquad (1)$$

Where: *m* (receiver mass) = 2.8 kg

Cp (receiver specific heat (*Cp*)) = 0.46 kJ/kg °C

ΔT (temperature differences between every two hours from sun rise to sunset) = °C

While the theoretical energy supposed to reach receiver every hour from sun rise until sunset Q_{theo} is calculated by the equation:

$$Q_{theo} = I_h \times \eta_r \times \epsilon_g \times \eta_{ab} \times A_p \times N \qquad (2)$$

Where, I_h - solar intensity for every hour of the day, these data were taken from the Iraqi Metallurgy Organization.

η_r - mirrors reflection efficiency (%)

ϵ_g - Transmissivity of the glass surrounding the receiver

η_{ab} - Receiver absorptive

A_p - single mirror area

N - Mirrors numbers

The hourly efficiency η_h was calculated by the equation:

$$\eta_h = \frac{Q_{act}}{Q_{theo}} \qquad (3)$$

III. EXPERIMENTAL PROCEDURE

The field was divided into three groups of mirrors. The first group was aimed to the receiver every half an hour, starting from the first day light up to eleven o'clock at morning. The second group was aimed to receiver every half an hour starting from 11 o'clock until 14 o'clock. The last group (which is on the right hand side of the receiver) was aimed to the receiver every half an hour starting from 14 o'clock until sunset time. This procedure was used to get reading of the critical angles of solar radiations.

Fig. 1, the used receiver in experiments photo (case 1)

The prototype was examined for four cases:

1. Case 1: The solar radiation was aimed to receiver (Fig. 1).
2. Case 2: The solar radiation were aimed to receiver covered by glass enclosure (Fig. 2).
3. Case 3: The solar radiation were aimed to receiver covered by black glass enclosure (Fig. 3).

The tests were conducted in Al Shaab city north of Baghdad, Iraq. The tests were conducted starting from June 2011 till the end of August 2011. Every test was conducted in one shiny day starting from daybreak till sunset.

The various solar energy applications/technologies are influenced by the character of the resource, such as its directional nature (whether the sunlight is direct of diffuse (by clouds for example), and its angle of incidence on the

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collector surface). Also, its spectral nature (what specific wavelengths of sunlight the collector technology responds to most effectively), and its variability. The variability characteristic can be in the span of a few minutes (how clouds will affect power production), seasonal (how climate patterns will affect the solar resource), inter-annual (how the resource will vary year to year), or even decadal (how climate change could affect the resource). Exhibit relates the various solar conversion technologies to the fundamental solar parameters on which they depend.

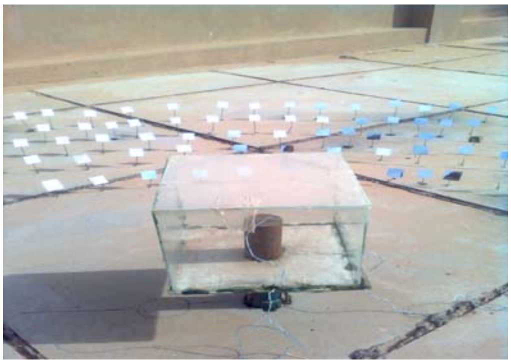

Fig. 2, the used receiver with glass cover photo (case 2)

Fig. 3, the used receiver with black colored glass cover photo (case 3)

The Iraqi summertime at 2011 was characterized by its dusty weather for few days in this season. For research purposes shiny and clear days were chosen to conduct tests.

Fig. 4 represents the temperatures of the three cases compared to air temperature. The figure shows good thermal gain for receiver but the maximum thermal gain was glass enclosure quotient. The black colored enclosure gain was limited partially. The specified black color enclosure absorbed solar energy and raised its temperature instead of heating the receiver. This result means incompetence of this method for CSP systems.

Figures 5 and 6 show the same former trend except the cases temperatures became higher. For comparison purposes on June receiver temperature increased by 83.83, 97.52 and 167.85 for receiver, black color glass and glass enclosure, respectively compared with air temperature. The maximum air temperature achieved was 43°C, for receiver it was 73°C, for black colored glass enclosure was 87°C and for glass enclosure the receiver maximum temperature was 111°C.

On July the increment in air temperature was about 19.7% compared with June. The increment in receiver temperature was 7.23% compared with June temperature. The increment in (case 2) temperature was 49.74% compared to June temperature. Finally, the increment for case 3 was 35.06% compared to June temperature. Also the maximum air temperature on August was 51°C in shadow, which gives a good idea about the greatness of solar energy in Iraq. The maximum temperatures achieved on August were 96°C for case 1, 179°C for case 2, and 139°C for case 3. These results insure the idea of the effectiveness of using this type of systems in power generation in Iraq, putting in mind that these temperatures achieved in very small prototype.

Figures 7, 8 and 9 represent the stored energy in the receiver. The curves resemble each other but differ in its values. Stored energy increased starting from first morning to reach its maximum values between 11 AM to 1 PM then it fall down. If August is taken for comparison purposes, it might be seen that glass enclosure energy exceeded case 1 by 39.79% and case 2 by 28.22%.

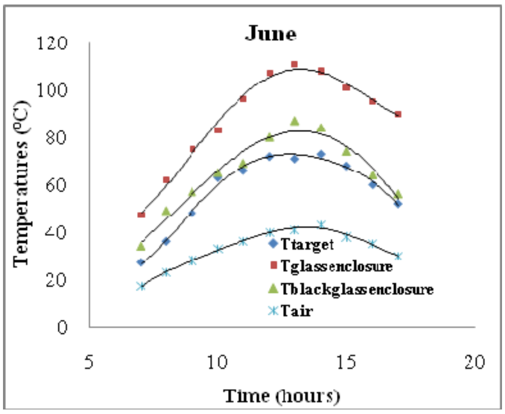

Fig 4, Receiver temperatures at daylight for the tested variables on June

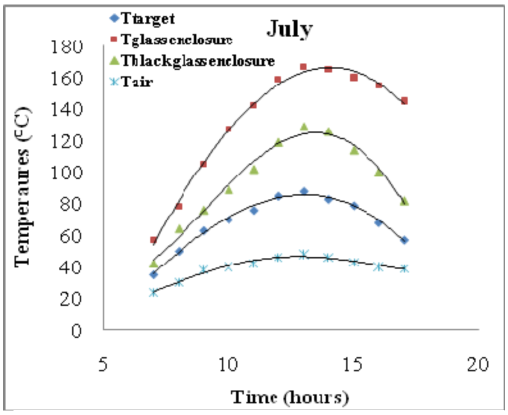

Fig 5, Receiver temperatures at daylight for the tested variables on July

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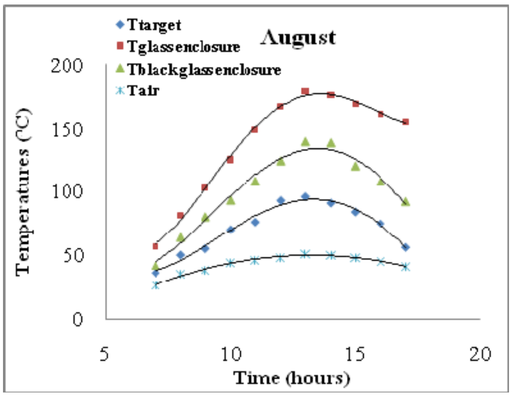

Fig 6, Receiver temperatures at daylight for the tested variables on August

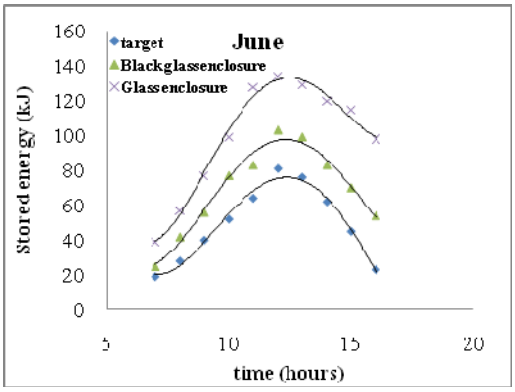

Fig 7, Receiver stored energies for the tested variables on June

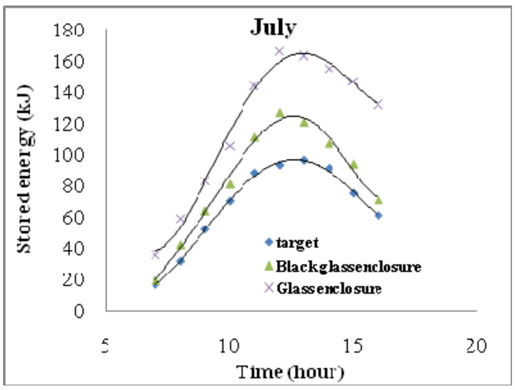

Fig 8, Receiver stored energies for the tested variables on July

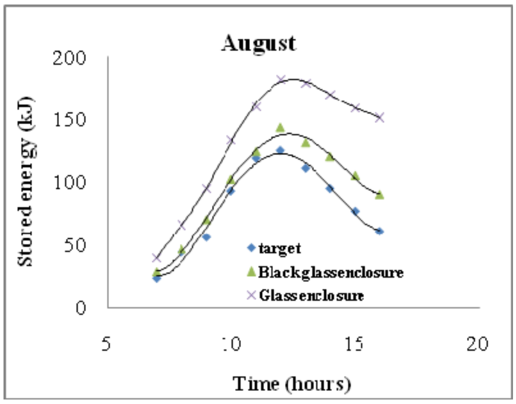

Fig 9, Receiver stored energies for the tested variables on August

V.CONCLUSIONS

In this paper CSP prototype system has been investigated. Investigations have been conducted in Iraqi summertime to measure the temperature, stored energy and hourly efficiency for three cases. The case studies used to find the best assembly for CSP station prototype designed and manufactured for this purpose. The following points were the main conclusions:

1. For these case studies solar thermal electricity – and more precisely CSP – holds great possibilities with relatively little realities to date - a perfect example for renewable energies.
2. CSP technologies concentrating solar radiation several times to reach higher energy densities. Type of receiver material is crucial element specify the amount of received energy.
3. Higher temperatures can lead to a lower-cost storage system. However, heliostats for tower systems must each have their own automatic control to track the solar radiation by an array of mirrors in the linear concentrator systems.
4. The investigations showed a good improvement in thermal storage when using the glass enclosed comparison with other two cases. Also, it is found that this improvement varied and depends on months of the year and reaches the peak in summer.

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