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Practical Investigation for Improving Concentrating Solar Power Stations Efficiency in Iraqi Weathers

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ABSTRACT

Better understanding the innovative process of renewable energy technologies is important for tackling climate change. Concentrated solar power (CSP) is a method of electric generation fueled by the heat of the sun, an endless source of clean, free energy. Commercially viable and quickly expanding, this type of solar technology requires strong, direct solar radiation and is primarily used as a large, centralized source of power for utilities.

This study has focused on the feasibility of improving concentrating solar power (CSP) plant efficiency, by manufacturing a diminished prototype. Three states were studied, coloring the central target with a selective black color, fixing a reflector with arc form behind the target, and using these two changes together. The results showed an improvement in the thermal storage varied form month to month. The maximum stored energy was gained at August with increments about 56.1%, 58.63%, 62.23 and 64.69% for ordinary target, black painting, using reflector alone and black target with reflector together, respectively compared with stored energy for March.

Key words: Concentrated solar power, target, reflectors, stored energy, glass transmissivity.

1. INTRODUCTION

Mitigating climate change and achieving stabilization of greenhouse gas atmospheric concentrations are the most important objectives of mankind. It will require deep reductions in global emissions of energy-related carbon dioxide emissions. Developing and disseminating new, low-carbon energy technology will thus be needed [1]. Renewable energy sources offer a great potential for satisfying mankind's energy needs with negligible atmospheric CO_2 emissions. They are also contrary to fossil fuels inexhaustible, and more widely spread over the earth's surface [2]. A wide number of technologies and sources such as: biomass, hydraulics, ocean thermal energy, ocean tides and waves, solar heating and cooling, solar photovoltaic, solar thermal electricity and wind are encompassing as renewable. Sources of renewable energy, such as solar and wind power can generate more energy than the immediate demand. Large-scale production of solar electricity is still technically and economically challenging. For solar energy, concentrating solar power (CSP) plants offer ways to store this energy on a large scale, either thermally or as chemical fuels [3 & 4].

Radiation reaching the Earth's surface is altered by a number of factors, namely the inclination of the earth's axis and the atmosphere that causes both absorption and reflection (albedo) of part of the incoming radiation [5, 6]. Accounting for absorption by the atmosphere, reflection from cloud tops, oceans, terrestrial surfaces, and rotation of the Earth (day/night cycles), the annual mean of the solar radiation reaching the surface is 170W/m^2 for the oceans and 180W/m^2 for the continents [7, 8]. Of this, about 75% is direct light, the balance of which is scattered by air molecules, water vapor, aerosols, and clouds [9].

This abundance of solar energy makes concentrating solar power plants an attractive alternative to traditional power plants, which burn polluting fossil fuels, such as oil and coal. Fossil fuels also must be continually purchased and refined to use. Unlike traditional power plants, concentrating solar power systems provide an environmentally benign source of energy, produce virtually no emissions, and consume no fuel other than sunlight. The only impact concentrating solar power plants have on the environment is land use. Although the amount of land a concentrating solar power plant occupies is larger than that of a fossil fuel plant, both types use approximately the same amount of land, because fossil fuel plants use additional land for mining and exploration as well as road building to reach the mines [10 & 11].

Unlike solar (photovoltaic) cells which use light to produce electricity, concentrating solar power systems generate electricity with heat. Concentrating solar collectors use mirrors and lenses to concentrate and focus sunlight onto a thermal receiver, similar to a boiler tube. The receiver absorbs and converts sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity [12].

There are three main types of concentrating solar power systems: parabolic troughs, dish/engine systems, and central-receiver systems. These technologies can be used to generate electricity for a variety of applications, ranging from remote power systems as small as a few kilowatts (kW) up to grid-connected applications of 200-350 megawatts (MW) or more. A concentrating solar power system that produces 350 MW of electricity displaces the energy equivalent of 2.3 million barrels of oil [13, 14 &15].

Central receiver (solar tower) systems use a circular array of large individually-tracking mirrors (heliostats) to concentrate the sunlight on a central receiver mounted on top of a tower, with heat transferred for power generation through a choice of transfer media. After an intermediate scaling up to 30 MW capacity, solar tower developers now feel confident that grid-connected tower power plants can be built up to a capacity of 200 MW solar-only units [16 & 17]. Use of thermal storages will increase their flexibility. Although central receiver plants are considered to be further from commercialization than parabolic trough systems, solar towers have good longer term prospects for high conversion efficiencies. Projects are in various stages of development (from assessment to implementation) in Spain, South Africa and United States. In the future, central receiver plant projects will benefit from similar cost reductions to those expected from parabolic trough plants. The anticipated evolution of total electricity costs is that they will drop to 5 cents/kWh in the mid to long term [17, 18 & 19].

Iraq can be considered retarded in solar electric technology, because of the 100% dependence on fossil fuels to produce electricity. Many valuables Iraqi researches [20, 21 & 22] clarified and confirmed the excellent activity of using sun in electrical power generation. Iraq posses about 3000 sunny hour per year, and the hourly solar intensity at (Baghdad city as an example) changes from 416 W/m^2 at Jan. to 833 W/m^2 at June [23]. The aim of this article is to study the effect of variable designs of the central receiver (target) to improve the solar tower efficiency in Iraqi weathers.

2. EXPERIMENTAL SETUP

The concentrated solar power plant is a solar optical concentration technology that uses a tower receivers and extremely closely spaced reflectors to allow a high delivered output from an area of roof or ground. It uses the annual solar beam radiation striking an area of ground or roof that can be captured and efficiently converted into useful electrical, thermal or cooling energy by using this technology.

The basic characteristics of CSP system are:

- A reflector field using a horizontal fixed axis and extremely closely spaced silvered glass reflectors of a novel design to allow high ground coverage and low cost. Row-like low structures for reflector support have the potential for low cost.
- A relatively wide field width compared to tower height, which allows high concentration.
- Supports allow the receivers to be placed above the reflector field. These may be small towers or posts, or else arch-like structures.
- A choice of receivers of radiation, including thermal, photovoltaic or chemical absorber technology.
- Conversion equipment to convert the solar energy collected into useful forms, including heat, electricity, cooling, or hydrogen fuel.

The aiming strategy in which successive rows of rays reflected from the mirrors are directed to the receiver at different day time. **Fig.(1)** illustrates the resultant appearance in a simple ray trace. **Fig.(2)** shows the photographic picture for the used assembly.

A small prototype was manufactured with 4 rows of reflectors arranged in an arc form, the inner diameter was 0.25 m, and the outer dia was 1 m. The rows were distributed as arcs with 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 target by mirrors.

The receiver was made of a cylindrical wrought iron rod with 6 cm dia, 10 cm height and 2.8 kg mass. Target specific heat is (C_p= 0.46kJ/kg °C), and its thermal conductivity is (k=59 W/m °C) [24]. The target was put at a height of 30 cm above ground level. It was covered by a glass cover box (25 cm×25 cm×25cm) to preserve all the incident radiation, to prevent heat transfer by convection with ambient air, and to utilize the greenhouse effect. 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. Another target sample was prepared with the same specifications, except it was painted with a selective black color, to study the effect of this painting on collecting efficiency. **Fig.(2)** represents the prototype assembly.

To collect the scattered radiations, an aluminum reflector was manufactured and prepared. It was fixed behind the target rod departed 17.67 cm from it. Ground coverage can be increased to high levels by using a reflector behind the receiver from the north side. This high ground coverage maximizes the collectable energy from a given available roof or ground space. This reflector was prepared by covering a piece of aluminum sheet with aluminum reflecting paper, and it was shaped as an arc. This reflecting arc was put (12 cm far from the target assembly) facing the heliostats in such a manner that it reflected the incident rays coming from the holists directly to the receiver. **Fig.(3)** depicts the prototype assembly in case of black target with reflector.

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 target at each hour, Q_{act}, is

$$Q_{act} = m\ Cp\ \Delta T \quad (kJ/hr) \tag{1}$$

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

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

The hourly efficiency η_h was calculated by the equation:

$$\eta_h = \frac{Q_{act}}{Q_{theo}} \tag{3}$$

3. TESTS PROCEDURE

The field was divided into three groups of mirrors. The first group was aimed to the target every half an hour, starting from the first morning up to eleven (11:00) o'clock. The second group was aimed to target every half an hour starting from 11:00 o'clock until 14:00 o'clock. The last group (which is on the right hand side of the target) was aimed to the target every half an hour starting from 14:00 o'clock until sunset. This procedure was used to get rid of the critical angles of sun radiations.

The prototype was examined for four cases:

1. The sun rays were aimed to target.
2. The sun rays were aimed to black colored target.
3. The sun rays were aimed to target with aluminum reflector behind it.
4. The sun rays were aimed to black target with aluminum reflector behind it.

The tests were conducted in AL Al-Shaab city north of Baghdad, Iraq. These tests were conducted starting from March 2011 till end of August 2011. Every test was conducted in one shiny day starting from day break till sunset.

4. RESULTS & DISCUSSIONS

Figs. (4, 5 & 6) reveal the measured temperature variation of the four cases compared to air temperature at Iraqi springtime (March, April and May). The air temperature rises during these months, the maximum temperature recorded for March was 20°C, for April was 27°C and for May was 33°C. The solar intensity increased in these days causing the target temperature to be higher with days advancing. These figures illustrate a fixed trend for measured temperatures variation. The lower measured temperature range was for the ordinary target. The maximum temperature range was for black target with reflector. Black target temperatures exceeded the ordinary target temperatures, but it delayed from the ordinary target with reflector.

These figures show that coloring the target with selective black color increased the collected energy due to black color absorption. Adding reflector to the assembly increased the collected energy. The reflector acted as a gathering element that collects the scattering radiation due to sun movement. Sometimes, the solar energy use causes instability in its readings due to the effect of clouds or dust. In April curves, it can be observed that black color temperatures reduced and approached to ordinary target temperatures.

The temperature variation for summertime (June, July and August) is represented in **Figs. (7, 8 & 9)**. The former observations can be repeated here except for higher temperatures were recorded. As a comparison, the maximum air temperatures recorded were: 43°C at June, 48°C at July and 51°C at August. Bearing in mind that these temperatures were recorded at shadow, these results show the largeness of solar energy in Iraq. To continue the comparison, the maximum target temperature recorded was 207°C at August using black target with reflector, while in springtime the maximum recorded temperature was 114°C at May.

The stored energy variation with day time for the four tested cases at Iraqi springtime (March, April & May, respectively) is demonstrated in **Figs. (10, 11 & 12)**. These figures illustrate the sequence of stored energy increments started by ordinary target, black target, target with reflector and the maximum values always for black target with reflector. This sequence is always correct, except for some variations. As an example in **Fig.(10)** at April tests, the black target curve comes near the target with reflector, also in May; the two curves approached each others before sunset.

Figs. (13, 14 & 15) manifest the stored energy variations at day time at Iraqi summertime (June, July & August respectively). These curves clarify the former sequence without any approaches between the curves. Also, these figures indicate that when the atmosphere is clear, then the black target with reflector will collect and store the maximum energy. The stability of solar intensity in Iraqi summertime made the stored energy curves taking this order, while the instability of solar intensity in Iraqi springtime caused the black target curve approaching to target with reflector some times. The hourly incident radiation varies through daytime (where it increases starting from daybreak till it reaches its maximum value at noon, then it falls down after that). As a result, the stored energy in the target took the same trend.

For comparison purposes, in March, the stored energy increased by 8.49, 18.2 & 28.6% for black target, target with reflector and black target with reflector, respectively. While in August, the increments were 13.14, 37.38 & 59.89%, respectively for the above mentioned cases also.

In view of the fact that the black target with reflector gains and stores the maximum energy compared to the other cases, the hourly efficiency for this case was studied, as illustrated in **Figs. (16 & 17)** for Iraqi spring and summertime. The hourly efficiency increased from month to month and approached its maximum values at August. These figures show that the maximum efficiencies will be reached at 12 AM and 1 PM, when the solar intensity reached its maximum values. These results clarify the possibility of improving the thermal storage of solar station by using any of the tested cases.

5.CONCLUSIONS

A prototype of concentrated solar energy station was designed and constructed. The variation of the target state was studied. Four cases were studied: using ordinary target, selective black colored target, ordinary target with reflector and black colored target with reflector. The tests were conducted at Iraqi weathers in springtime (March, April and May) and summertime (June, July and August). The results clarified the following conclusions:

1. The Iraqi weathers are suitable for this type of systems. It is possible to attain high target temperatures which can operate power station.
2. The maximum temperatures and stored energies reached were at July and August; this indicates the relationship between the solar intensity and resultant temperatures.
3. Coloring the target with a selective black color increased the target absorption which increases its temperatures and stored energy.
4. Using a reflector behind the target to collect the scattered rays and reaming it to the target increased the target temperature as well as it increased the stored energy.
5. The use of black colored target with reflector behind it gave the maximum temperatures and stored energy results, indicating its preference.

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7. NOMENCLATURE

m	(target mass) = 2.8 kg
Cp	(target specific heat (Cp) = 0.46 kJ/kg °C
ΔT	(temperature differences between every two hours from sun rise until sunset) = °C/hr
I_h	solar intensity for every hour of the day, these data were taken from the Iraqi Metallurgy Organization.
A_p	single mirror area (m^2)
N	Mirrors numbers
ϵ_g	The of transmissivity the glass surrounding the target =(90%)
η_r	Mirrors reflection efficiency = (75%)
η_{ab}	Target absorptive = (0.8)
η_h	The hourly efficiency

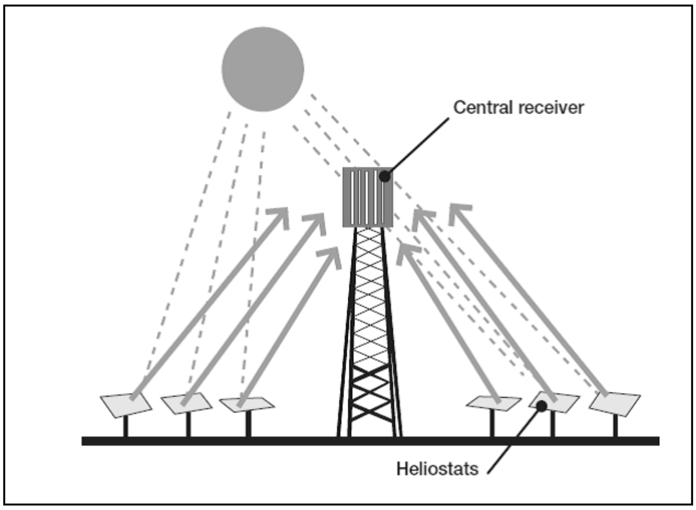

Figure (1): The appearance of a simple ray trace.

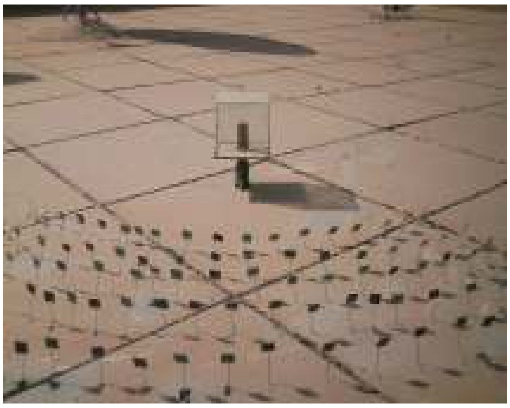

Figure (2): Photographic picture for the prototype assembly

Figure (3): Photographic picture for the prototype assembly with black target and reflector

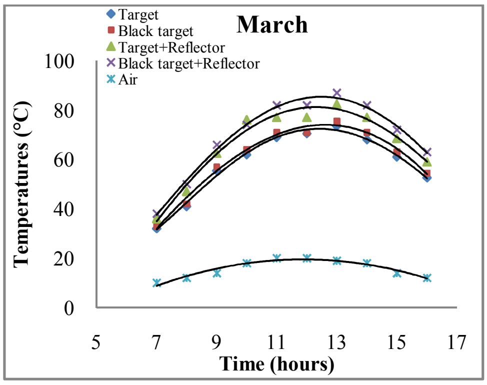

Figure (4): Various target temperatures variations with time at March.

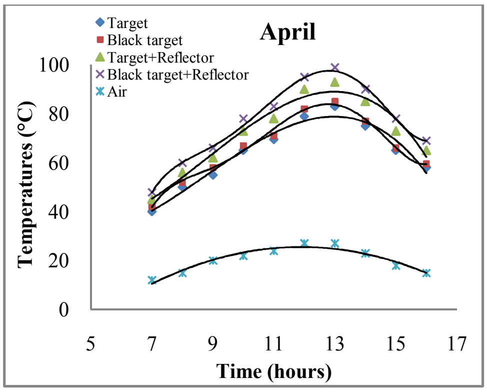

Figure (5): Various target temperatures variations with time at April.

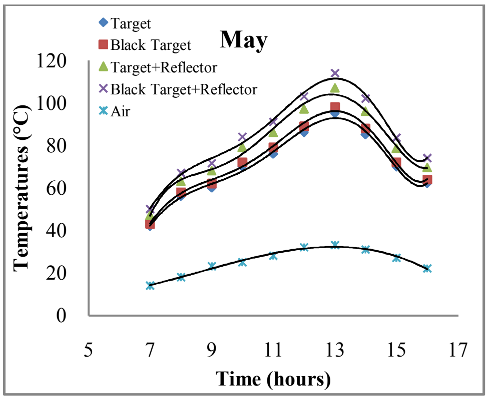

Figure (6): Various target temperatures variations with time at May

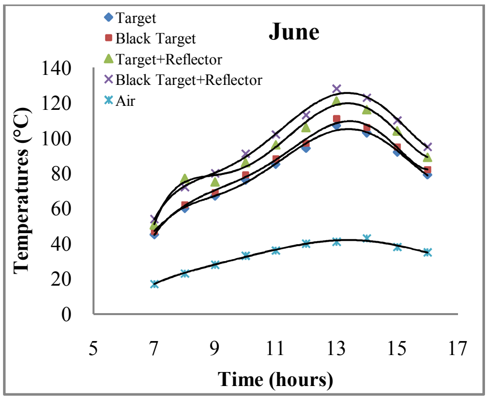

Figure (7): Various target temperatures variations with time at June

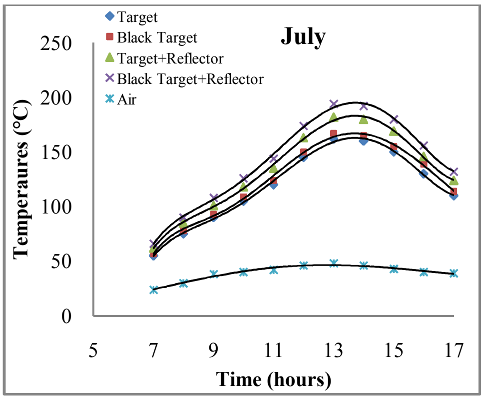

Figure (8): Various target temperatures variations with time at July

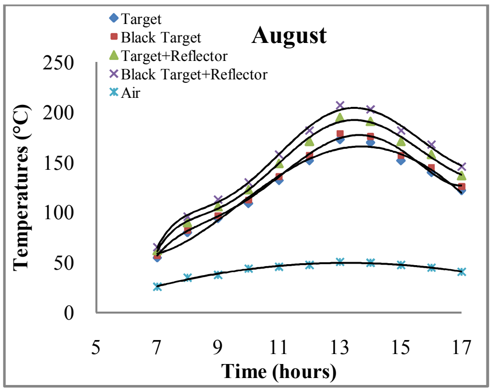

Figure (9): Various target temperatures variations with time at August

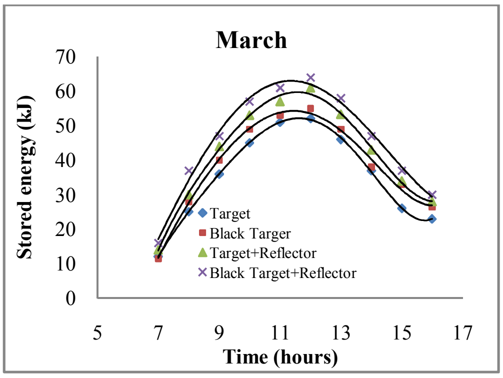

Figure (10): Various targets stored energies variations with time at March

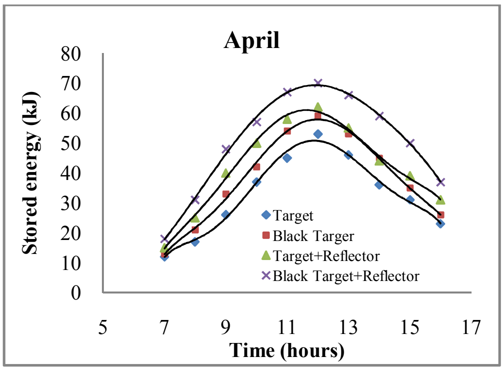

Figure (11): Various targets stored energies variations with time at April

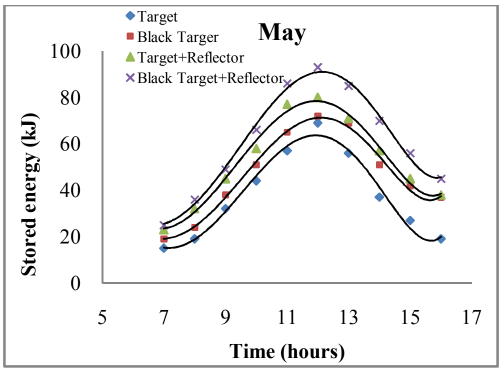

Figure (12): Various targets stored energies variations with time at May

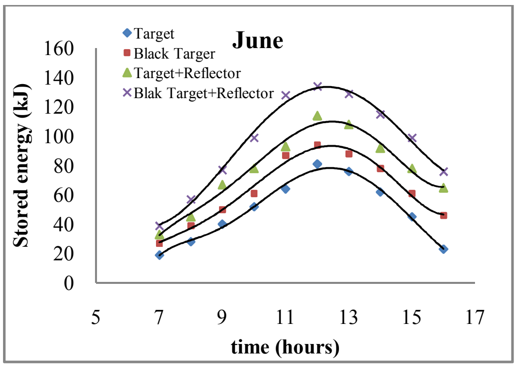

Figure (13): Various targets stored energies variations with time at June

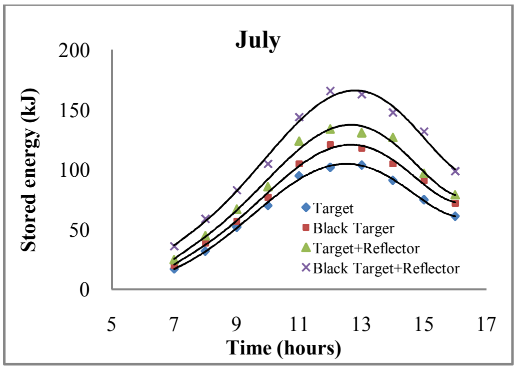

Figure (14): Various targets stored energies variations with time at July

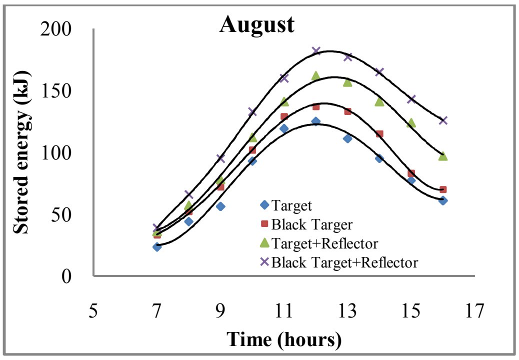

Figure (15): Various targets stored energies variations with time at August

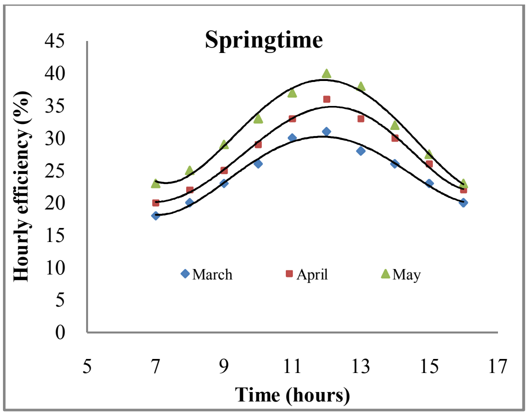

Figure (16): Various targets hourly efficiency variations with time at springtime

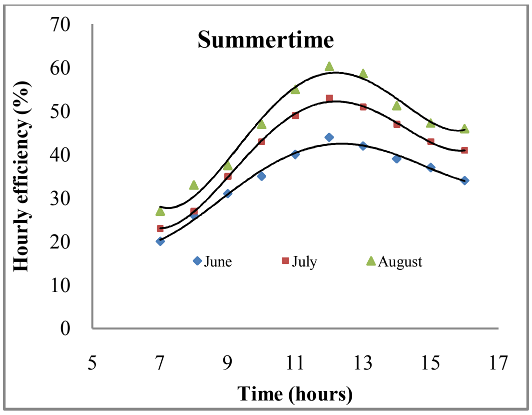

Figure (17): Various targets hourly efficiency variations with time at summertime

دراسة عملية لتحسين كفاءة محطات القدرة الشمسية المركزة في أجواء العراق

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الخلاصــة

إن الفهم الأفضل لعملية الأبداع في تقنيات الطاقة البديلة مهم لمعالجة التغير في الطقس، تعتبر القدرة الشمسية المركزة (CSP) اسلوب لتوليد الكهرباء بوقود هو حرارة الشمس، وهو مصدرغير ناضب من الطاقة النظيفة والمجانية، متوفرة تجاريا وتتوسع بسرعة، وهذا النوع من التقنيات الشمسية يحتاج الى اشعاع شمسي مباشر وقوي، ويستخدم في المقام الأول كمصدر مركزي وكبير من القدرة النافعة.

ركزت هذة الدراسة على امكانية تحسين كفاءة محطة قدرة شمسية بالتركيز (CSP) عن طريق تصنيع نموذج مصغر، ودراسة ثلاثة حالات، صبغ الهدف المركزي باللون الأسود، وضع عاكس خلف الهدف، واستخدام المتغيرين معا. بينت النتائج تحسن في كفاءة الخزن الحراري تتغير من شهر الى آخر. وكانت اعلى قيمة للخزن الحراري المكتسب في شهر آب، وكانت الزيادة بحدود 56.1%، 58.63%، 62.23% و 64.69% لحالات الهدف الأعتيادي، الهدف مصبوغ بالأسود، استخدام عاكس بمفرده، واستخدام عاكس وصبغ الخزان معا على التوالي مقارنة بشهر آذار.