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The effect of environmental conditions on concentrated solar system in desertic weathers

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Abstract— Concentrated Solar Power (CSP) is a technology that capturesand exploits solar thermal energy by concentration. It uses highly polished mirrors called heliostats to focus the sunlight onto a target. Inside the target, there is a transferring fluid that will be heated and then it transfers heat to heat exchangers to generate power. The possibility of installing a CSP plant at urban, rural or semi-urban locations makes it a desirable choice for electricity generation plants. Also, it has the possibility of installing in industrial areas as long as the array is not in a shaded area.

In the present study, the effect of desertic environmental conditions on CSP plant was evaluated by fabricating two heliostats fields. Some plant variables like target temperature, efficiency, and stored energy were measured and evaluated. The desert dust was the primarilyaffected factorthatits accumulation on heliostats causes high reduction of the studied variables. The average reductions measured were 24, 12, 15 and 4% for spring, summer, autumn and winter seasons respectively. Spring season ranked the highest reduction due to the high dust storm reiteration during it. At winter season, the rainfall limits the dust effect. The high solar intensity in Iraq, Baghdad city taken as case study, manifests the possibility of construct and operates CSP plants with high efficiency in spite of the desertic environmental conditions. The study results clarified the importance of washing and cleaning the heliostats from dust several times per month to reduce dust effects.

Index Terms— cleaning, concentrated solar power plant, destertic areas, dust, heliostats, plant effeciency.

1 Introduction

Concentrated solar plant (CSP) technology has improved greatly over the last decade and enhanced itself as a suitable scheme for high productive solar plants. The high capital investment necessary for the construction of these systems is one of the obstacles that designers strive to overcome [1]. Another obstacle is the dependence of CSP systems on meteorological conditions. Many meteorological parameters impact the performance of CSP plants such as direct normal irradiance (DNI), wind, ambient air temperature, humidity. Also, soil and dust as in Middle East countries and North Africa (in majority desertic areas) [2].

Iraq as many countries of the Middle East, until now, renewable energies did not comprise any percentage of the generated power [3], [4].Many studies were conducted to represent solar energy utilization in reducing the oil dependence, whether for heating or power generation [5], [6], [7], [8], [9], [10], [11], [12].CSP is a type of solar thermal energy that is used to generate electricity takes the attention in Iraqi studies in recent years. Also, CSP can provide hundreds of megawatts of electricity to the grid [13], [14]. Furthermore, CSP can provide a large-scale, sustainable alternative to fossil-fuel power plants [15].

Chaichan [16], [17] studied the feasibility of improving concentrating solar power plant (CSP) efficiency by varying many factors. The results presented an enhancement in the thermal storage differed from month to month. The maximum stored energy gained was in August with high increments rates. The measurements of solar receiver temperature, stored energy and efficiency of the solar receiver showed a promising improvement compared to other geometries.

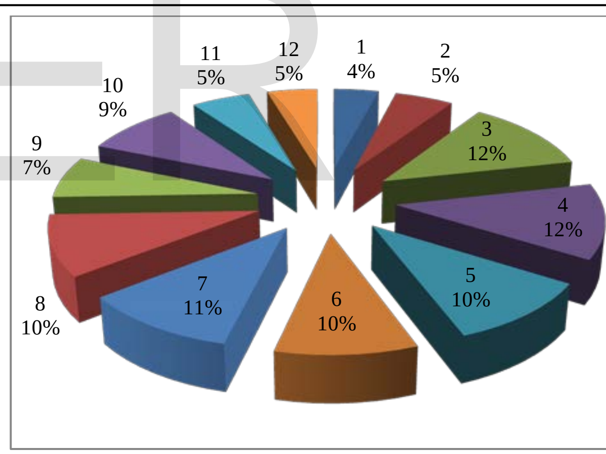

Fig. 1 Average suspended dust for the period from 1981-2013 for Baghdad Station/day (months 1-12)

Hunnen [18] used a central receiver constructed on a flat, smooth, rigid wooden board exploited as a base for the model. The prototype fixed on an inclined position at an angle of 20º. The field area situated in a figure look like quarter a circle to arrange the heliostats. At the circle center, the tower consisted ofa copper plate target was fixed. Two heliostat field sets [(540) and (1097) mirrors] tested experimentally. The achieved temperatures of the target were in the range of steam boilers operation temperatures (268- 578) ˚C. The study concluded that the heliostat's number has a primary impact on the power concentration factor, the target temperature, and the overall efficiency of the system.

Two decades of drought accompanied with inappropriate farming practices and mismanagement of water resources

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have increased the effects of desertification resulted in about 31% of Iraq's surface is desert [19]. Spring season in Iraq is the dust storms season. It covers half of the total frequency of dust storms. April has the highest dust storms frequency, followed by March, May and then June and July [20], [21]. Figures 1, 2 & 3 declare these trends.

Lateef [22] studied the dust storms phenomenon making use of the satellite images (Meteosat-9) and the sensor (SEVERI). The study chased dust storms in different dates in 2012. The researchers used the geographic information system programs (ERDAS-GIS) to distinct the regions responsible for this phenomena. The study introduced an Iraqi map describing these areas for year 2012 and performed a comparison with similar maps for previous years. Fig. 4 represents this plan that presents the spatial distribution of the regions that cause the occurrence of dust phenomenon in Iraq for year 2012.

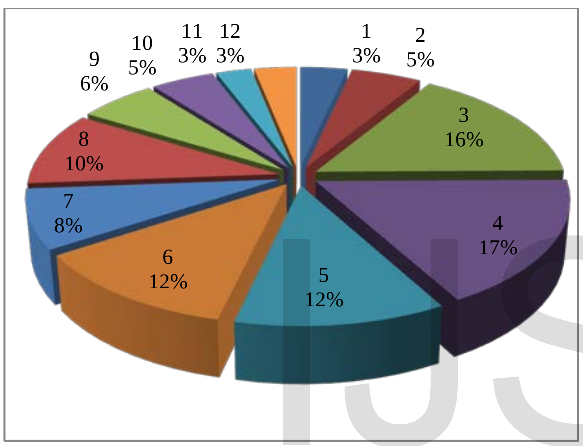

Fig. 1 Average ascending dust for the period from 1981-2013 for Baghdad Station/day (months 1-12)

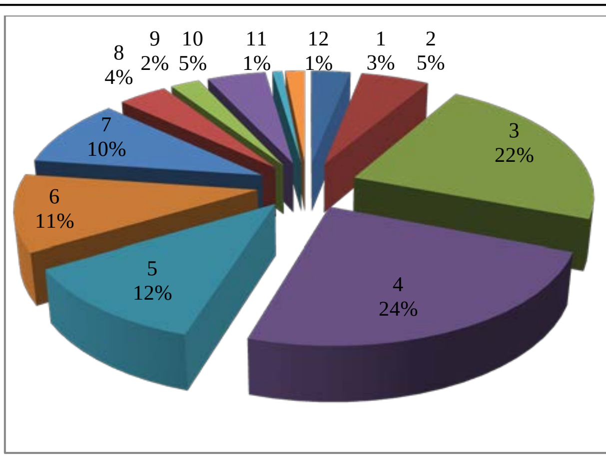

Fig. 3 Average dust storm for the period from 1981-2013 for Baghdad station (months 1-12)

Many studies of dust collected from different Iraqi regions concluded that the concentration salts and carbonates are high in all Iraqi dust and soil samples and extremely high in many regions [23]. Silica (quartz) is the primary component, and it is usually less than 80% of the sample mass. Three common clay minerals (muscovite, chlorite, and kaolinite) are common in Iraqi dust [24]. The average particle size of the sampled Iraqi dust is less than the particle size of bulk soil samples [25]. Soluble salt, carbonate, chlorides, and sulfates in addition to Halite (sodium chloride), gypsum (calcium sulfate), and calcium sulfate minerals were identified in the samples in Iraqi dust samples, also. The heavy metals concentration shows significant spatial variations than the seasonal variations. Pb and Cd percentages are stable all over the year except in spring where Pb concentrations increase compared to the rest seasons. The settlement of atmospheric dust onto the surface of the solar panels or mirrors considered as a serious problem facing the widespread of solar energy technology [26], [27]. This atmospheric phenomenon has a severe effect on the performance of PV and CSP power systems by reducing the sunlight radiation reaching the mirror surface [28], [29]. Dust storms are natural hazards in Iraq and neighborhood countries that caused the authorities of these countries to reconsider using CSP systems [30], [31].

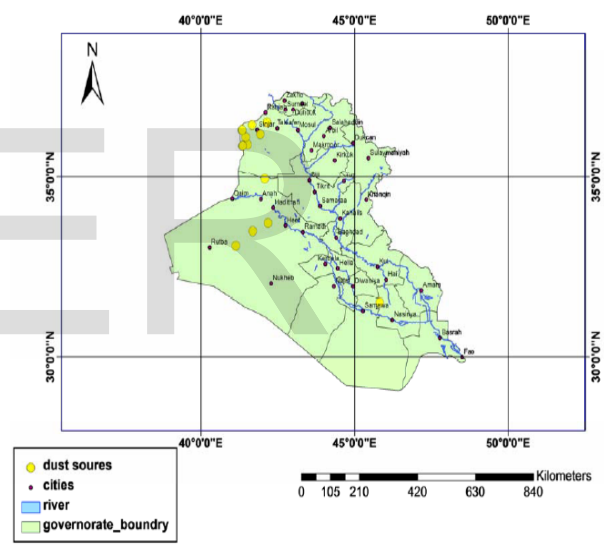

Fig. 4, the spatial distribution of the regions those are responsible for the occurrence of dust phenomenon in Iraq for year 2012 [22]

The aim of this study is to investigate the effect of dust experimentally as a meteorological phenomenon on the mirrors of CSP plant on the resulted plant efficiency in Iraqi weathers as a sample of Middle East Desertec weathers.

2 EXPERIMENTAL SETUP

The CSP system used in the study was designed and fabricated depending on the calculations of tower position, heliostat, number of heliostats, trend angle of mirrors ….etc [32], [33]. The following analyzes for the heat balance of the target of CSP system:

Sky temperature

$$T_s = 0.0552 T_\infty^{1.5} \qquad (1)$$

Where ambient air temperature (T_∞) is 20 °C,

$$\therefore Ts = 0.0552 * (273 + 20)^{1.5}.$$

. From Steven-Boltzmann equation

$$q_r = \sigma A\left(T_p^4 - T_s^4\right) \quad (2)$$

$$h_\infty = c(T_p - T_\infty)^{\frac{1}{4}} \quad (3)$$

This coefficient is for zero wind velocity, for wind speed is higher than 5 m/s, h∞=20W/m2 ºC. Then,

$$q_c = h_\infty A\left(T_{p-}T_\infty\right) \Rightarrow \therefore q_{total} = q_r + q_c \quad (4)$$

The following values were assumed depending on references [34], [35]:

1- The reflection coefficient of a mirror $\eta_p = 0.75$ (for commercially available).

2- The guidance efficiency for heliostat $\eta_e = 0.8$.

3- The optical efficiency of the heliostat $\eta_{eo} = 0.9$.

4- The absorptance of sunlight by target plate is 0.9

Due to some difficulties in the preparation and adjustment trends of mirrors practically, the dimension of the mirror was taken (2×2) cm. This choice was suitable to lessen the dimensions of the model.

The location of the field of mirrors must be away from the shading whether from building or target tower. Also, the shading ofa mirror on the rear mirror must be avoided to secure reaching the sun rays without any loss. Plywood board with dimensions (180×120×1.6) cm was used. The usage of a wooden foundation was to regulate the position of each heliostat on the arcs and to simplify the tracking of the sun during daytime. The base material was chosen to meet the requirement for open air usage, like water resists, temperature variation resistance, rigid with low flexibility and smooth surface for ease of cleaning. Four rows of heliostats arranged in a form that enhanced reflected radiation aiming to target by mirrors. The internal diameter was 0.25 m, and the external diameter was 1 m with 0.25 m step for each row. The rows distributed as arcs facing south. The mirrors were made up of 2.0×2.0 cm2 dimensions. The height of the first-row heliostats fixed 3 cm from the ground. The second heliostats row made 4 cm height from the ground. The third row's mirrors seated at 6 cm height from the ground. The forth heliostats row fixed 8 cm height from the ground. These arrangements were taken.

The cylindrical receiver made of a wrought iron rod of 6 cm diameter, 10 cm height, and 2.8 kg mass. Target thermal conductivity is (k=59 W/m °C) and its specific heat is (Cp= 0.46kJ/kg °C) [34]. The target fixed on a box with a height of 30 cm above ground level. A glass cover box with diminutions of (15 cm×15 cm×15cm) covered the target to preserve all the incident radiation. Also, to prevent the effect of wind velocity heat transfer by convection to ambient air, and to utilize the greenhouse effect. The tower was manufactured using four 5mm steel rods formed a square section tower. The target base welded to the tower at a height 30cm.The receiver temperature measured by means of three calibrated thermocouples. One thermocouple fixed at the top of the receiver while the second one fixed at its bottom, and the last one fixed in the middle. The ambient air temperature measured by means of a calibrated mercury thermometer fixed in the shadow. The resulted thermal efficiency of the system affected by falling solar radiation was calculated employing the following equations:

The target saved energy at each hour Qact

Qact= m CpΔT (kJ) (5)

Where: m (the mass of the target) = 2.8 kg

Cp (the specific heat of the target (Cp) = 0.46 kJ/kg °C

ΔT (temperature differences between every one hour from sunrise until sunset) = °C

While the theoretical energy supposed to reach target every hour from sunrise until sunset Qtheo is calculated by the equation:

$$Q_{theo} = I_h \times \eta_r \times \varepsilon_g \times \eta_{ab} \times A_p \times N \quad (6)$$

Where, Ih - solar intensity at every hour time of the day, the solar intensity data obtained from the Iraqi Metallurgy Organization.

η_r - mirrors reflection efficiency (%)

ε_g - The glass surrounded the target transmissivity.

η_{ab} - Target absorptivity

Ap–the area of a single mirror (m2)

N - Mirrors numbers

The hourly efficiency η_h was calculated by the equation

$$\eta_h = \frac{Q_{act}}{Q_{theo}} \quad (7)$$

2.1 EXPERIMENTAL PROCEDURE

Two heliostats field fabricated, adjusted and examined. The first prototype left in its place exposed to the environmental conditions as dust, wind and rains…etc all the testing period. The second prototype was covered all the time except at measuring state where it exposed to the environment. Before any measuring day, it was cleaned and prepared. At the beginning of every experimental day, the rig was oriented in the direction of the sun coming ray by adjusting the base. So, the shadow length of the tower is the same as that at the solar noon. This procedure assures that the focusing is the same as that of noon. Air temperature and central target temperature measurements were recorded hourly using calibrated thermocouples (type K) connected to the electronic thermometer. The weather conditions data measured by the meteorological station at Ministry of Science and Technology, Baghdad. The testing period was lasted for one continuous year starting from 1-2-2014 ended at 31-1-2015. Tests were conducted southwest Baghdad city at Al-Saydia territory. The year divided into four seasons that are:

- Spring season started from 1-2-2014and lasted to 31-4-2014.
-The summer season started from 1-5-2014 until31-9-2014.
-The autumn season lasted from 1-10-2014 to 30-11-2014.
- Winter season started from 1-12-2014 and lasted to 31-1-2015.

In each week, two measuring days were conducted. The measurements started from 7 AM and lasted till sunset. The comparison between the seasons carried out using the readings average. At the end of each month, the lifted heliostats field was cleaned, prepared and adjusted for the next month. The measurements of the two areas started on the first day of each month, to ensure the two fields are in equivalence. Differences of about 1% were accepted while higher differences meant that the cleaning procedure must be repeated.

3 RESULTS AND DISCUSSIONS

Desert areas (which many Iraqi areas considered as it) distinguished by high solar intensity. This solar intensity makes these areas evaluated as places for CSPs, except for its severe environmental conditions. Dust can be considered the primary environmental factor restrict CSP erections. Desert dust can affect widespread areas away from it with hundreds of kilometers. This study conducted in Baghdad city that bordered on the west by Al-Anbar desert, and from the east of sand dunes and desert areas.

Fig 5 represents the effect of environmental conditions on target temperatures at spring season. Iraqi spring characterized by its medium solar intensity with an average of 430 W/m2 and high dust storms frequency. Due to the former factors dust accumulation increased on mirrors in this season, but it varies from one month to another. The reduction in target resulted temperature was 7.5, 24 and 38% for February, March, and April respectively. At February rainfall twice that caused the temperatures limited reduction compared to the other months. Iraqi's April days characterized by its dusty weather and much more dust storms than any other month.

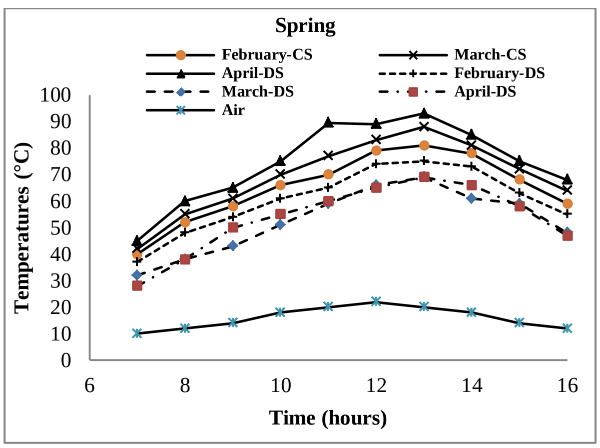

Fig. 5 The effect of environmental conditions on target temperatures at spring season

Figures 6 and 7 illustrate the environmental conditions impact on target temperatures at summer season. Iraqi summer characterized by its length where it lasts for five months and its high solar intensity and air temperatures. The figures clarify the former factors where target temperatures raised for high levels (to reach 236°C at August noon). Dust affected the target temperature at summer in a same manner as at spring season except with lower impact. The reductions in target temperatures were 15, 14, 15, 11 and 12 for May, June, July, August and September respectively. Although the high discount rates but the high solar intensity compensated, it is manifesting the possibility of CSP operation in these weathers.

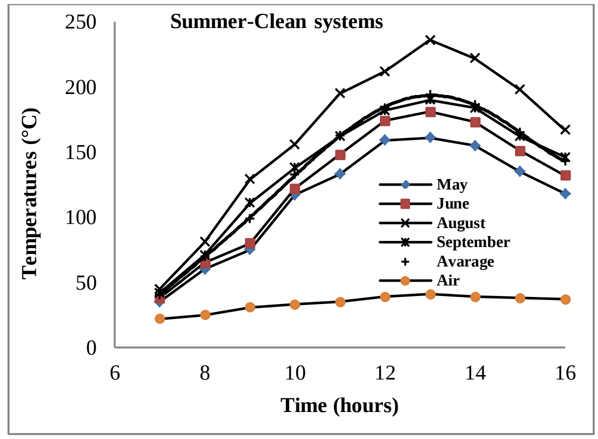

Fig. 6 Target temperatures variation with time for summer season

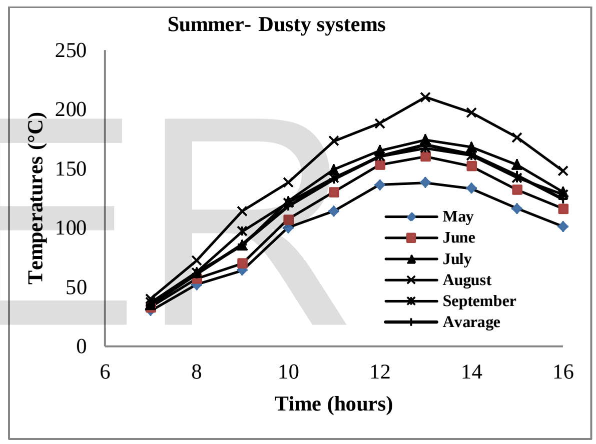

Fig. 7 The effect of environmental conditions on target temperatures variation at summer season

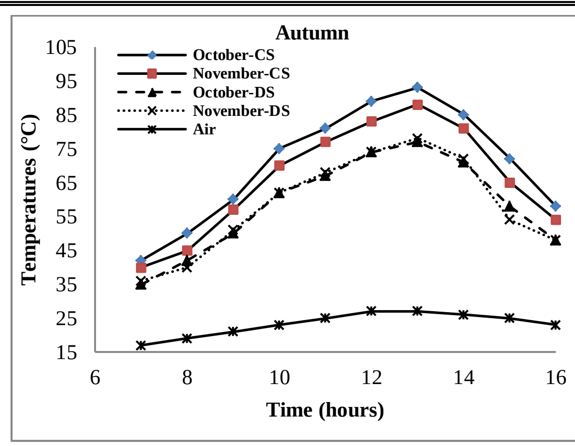

Fig. 8 The effect of environmental conditions on target temperatures at autumn season

Fig. 8 explicates the effect of environmental conditions on target temperature variation during the autumn season. Iraqi autumn season characterized by its limited period (two months only) and its dusty weather due to the blowing of dusty winds. The figure illustrates that target temperature reduced by 17 and 10% for October and November respectively.

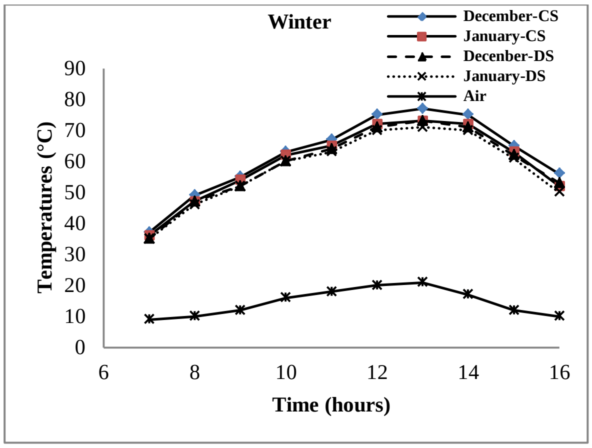

Fig. 9 The effect of environmental conditions on target temperatures at winter season

Fig 9 represents the effect of environmental conditions on target temperature variation at winter season. Iraqi winter characterized by its short period (two months) and medium solar intensity. In the Iraqi winter season for the studied year the rain falls several times resulted in limiting the dust effect although it was insignificant. The reductions in target temperatures were 5.5 and 2.8% in December and January respectively. Rain limits the dust effects and the volatile dust due to locomotives and trucks.

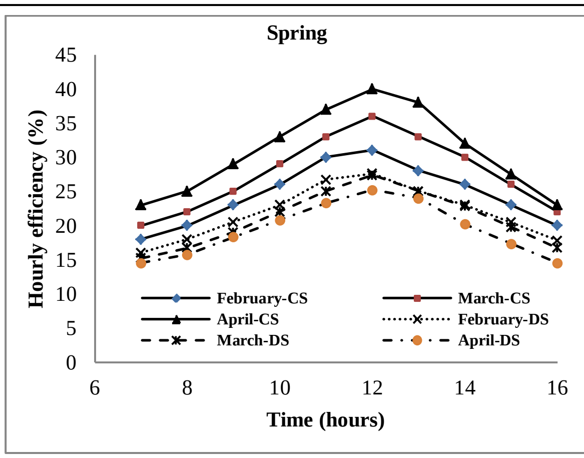

Fig. 10 The effect of environmental conditions on hourly efficiency at spring season

Hourly efficiency reduced highly in the spring season as fig. 10 indicates. The reductions in efficiency were 12, 34 and 37% for February, March, and April respectively. Spring season achieved the higher reductions all over the year.

Due to the high solar intensity that concentrates on the target the reductions in hourly efficiency reasonable and CS plants can operate in these conditions. Fig. 11 illustrates these reductions that were 15, 13, 12, 10 and 11% or May, June, July, August and September respectively. These results are similar to target temperature reduction rates, which is reasonable where the efficiency depends on temperature when the other factors are constant.

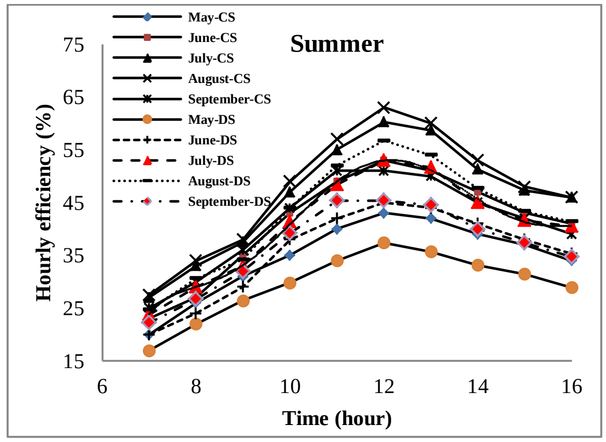

Fig. 11 The effect of environmental conditions on hourly efficiency at summer season

Fig. 12 reveals the reduction in hourly efficiency because of environmental conditions. The reductions were 12.5 and 10% for October and November respectively. The rainfall washes the mirrors and increases the efficiency and that what limited the reduction in November. Due to the repetition of rainfall the reductions in hourly efficiency at winter months were 5 and 3% in December and January respectively, as fig. 13 elucidates.

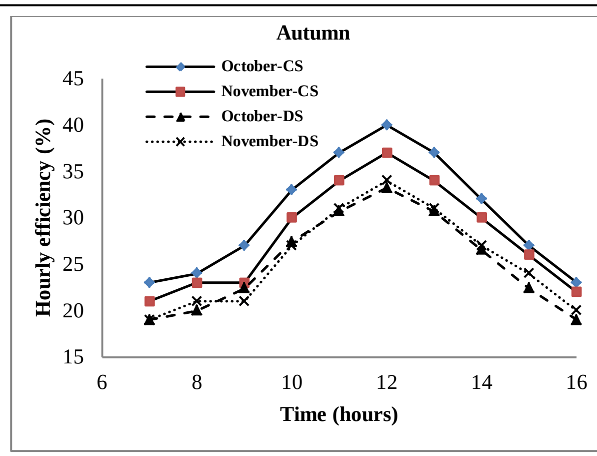

Fig. 12 The effect of environmental conditions on hourly efficiency at autumn season

The figures from 14 to 17show the effect of environmental conditions on the average seasonally stored energy. In the regions near deserts like Baghdad city where the study conducted two primary factors control CSP productivity (dust and rain). Each one influences the other, and the resulted stored energy depends on the dominant effect. The present figures clarify that dust is the dominant factor all over the year except for winter months and may be November where rain falling equalize dust effect for a high rate. The average stored energy reductions were 24, 11.8, 14.3 and 4% for spring, summer, autumn and winter seasons respectively.

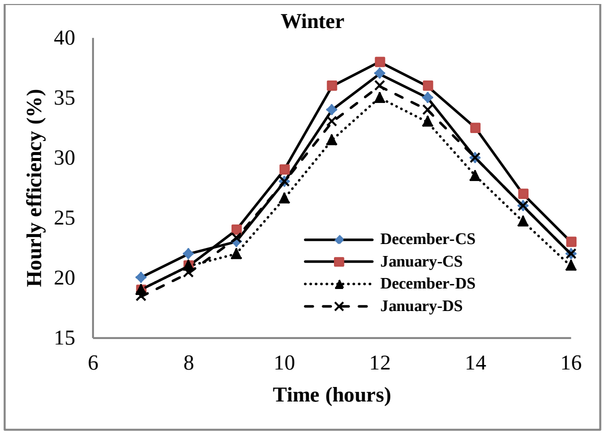

Fig. 13 The effect of environmental conditions on hourly efficiency at winter season

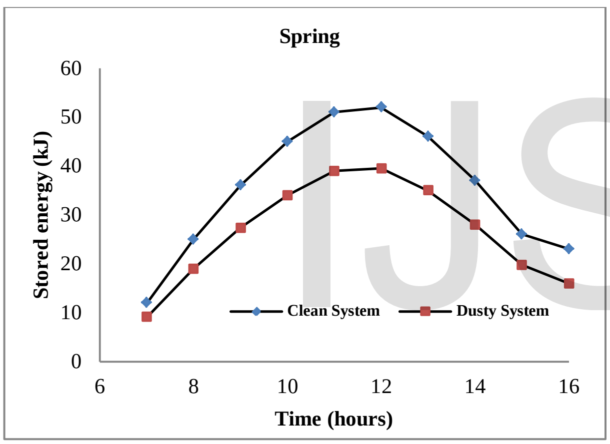

Fig. 14 The effect of environmental conditions on average storage energy for spring season

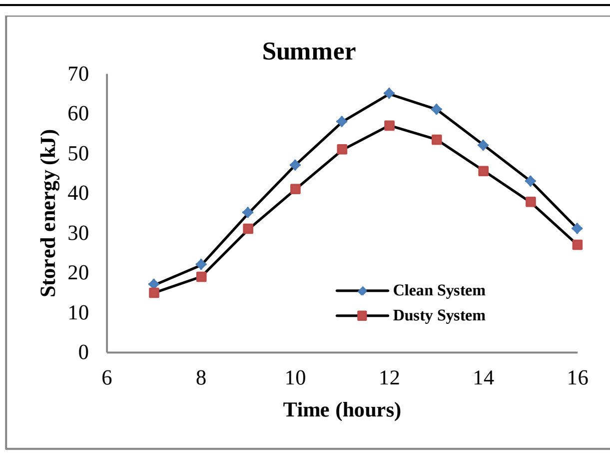

Fig. 15 The effect of environmental conditions on average stored energy for summer season

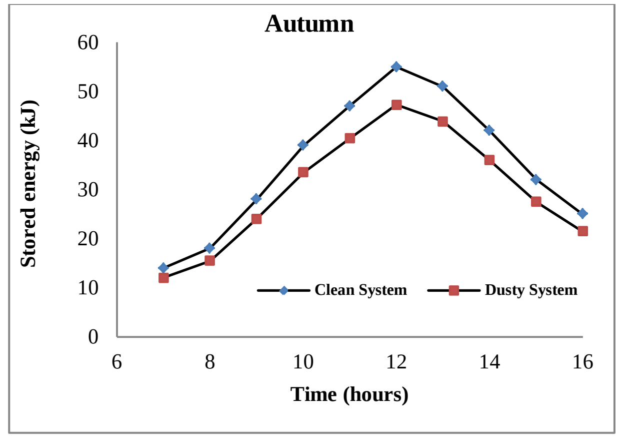

Fig. 16 The effect of environmental conditions on average stored energy for autumn season

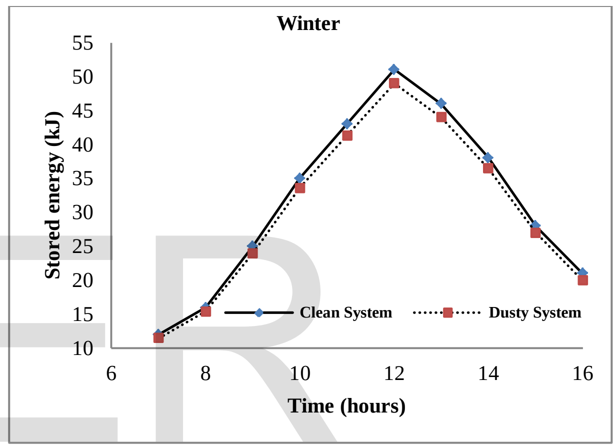

Fig. 17 The effect of environmental conditions on the stored energy for winter season

4 CONCLUSIONS

Concentrated solar planets considered suitable for continental hot weathers areas as Middle East region. In the recent study, the effect of desertic environmental conditions on two heliostats fields was measured and evaluated. The main effect was the desert dust that accumulates on heliostats causing high reduction for the target temperature, efficiency, and stored energy. The average reductions measured were 24, 12, 15 and 4% for spring, summer, autumn and winter seasons respectively. Spring season ranked the highest reduction due to the high dust and sand storm repeatability during it. At winter season, the rainfall limits the dust effect. The High solar intensity of Baghdad city manifests the possibility of construct and operates CS plants with high efficiency in spite of desertic environmental conditions. The present study results depended on washing the dusty field ones every month, so increasing washing repetitions reduces dust effects.

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