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Energy Yield Loss Caused by Dust and Pollutants Deposition on Concentrated Solar Power Plants in Iraq Weathers

Miqdam T Chaichan[1], Khaleel I Abass[2], Hussein A Kazem[3]
[1]Energy and renewable Energies Technology Center, University of Technology- Baghdad- Iraq
[2]Mechanical Eng. Dep.-University of Technology- Baghdad- Iraq
[3]Faculty of Engineering, Sohar University, Sohar, Oman
E. mail: 20185@uotechnology.edu.iq

Abstract**—***Concentrated solar power plants are promising applications in the field of renewable energy as their fuel is available and free of charge, namely, solar energy. Like any solar application, the first enemy is dust, which causes a kind of shadow that reduces the amount of solar radiation reaching the system, and its accumulation on the surface of the parts of the solar system reduces its performance. In this study, a miniature model of a concentrated solar plant was constructed and examined for several cases, the most important of which is when it is left to accumulate dust and dirt. In the second part of the study, the effect of the type of detergent used to restore the efficiency losses was studied due to accumulation of dust and contaminants. The results of the study showed that leaving the system exposed to external conditions for two weeks, caused losses of 22% of its efficiency. Cleaning the system returned 14.5, 17.39, and 19% of the efficiency losses when using water, alcohol, sodium cleaner, respectively.*

Keywords**—** *Concentrated solar power, dust and pollutants deposition, target, reflectors, glass transmissivity.*

I. INTRODUCTION

Mitigating the effects of climate change and reducing greenhouse gas concentrations from burning fossil fuels in the atmosphere are the most important human priorities [1, 2]. Access to this goal requires a significant reduction in the emissions of pollutants from burning fossil fuels for energy purposes, and should be switched to the use of alternative and renewable types of energy [3]. Therefore, there is a need to develop and disseminate awareness using carbon zero or low carbon emission technologies [4]. Oil and natural gas played an important role in the progress of humanity during the past two centuries, but today, with the high volatility in its prices, it has become a burden on both producing and consumer countries, in addition to environmental encumbrance [5, 6].

Renewable energy sources such as solar, wind, and biofuels can meet the human need for energy efficiently and are as immortal as fossil fuels as they are spread across the entire globe and are free [7]. Renewable energy sources such as oceanic tides, ocean thermal energy, hydraulics, biomass, solar heating and cooling; solar photovoltaic power, solar thermal electricity and wind are renewable sources [8]. Sources such as solar energy can generate the community's demand for electric power efficiently. Today, solar electricity production techniques have become widespread in the world and at an acceptable economic cost [9]. The production of solar electricity is carried out through photovoltaic stations or solar concentrating stations [10]. The price of photovoltaic cells began to decline as manufacturing defects and weather conditions were all improved and research and development continued in this area and in a rapid and clear development [11-15]. For concentrated solar power stations (CPS), studies are being carried out extensively to improve the thermal storage of solar energy, both as thermal storage and as a chemical fuel [16-18].

All solar systems are directly affected by solar radiation, which is the source of energy. This radiation varies from region to region and from moment to moment due to many topographical, environmental, and ritual factors [19]. From these factors: the influence of the tendency of the Earth's axis, the air mass with its suspended materials directly affecting solar radiation by absorbing part of it or reflecting another part [20, 21]. Working with concentrated power stations requires an abundance of solar energy, so such systems provide an environmentally friendly source and produce virtually no emissions or pollutants [22].

CPS concentrates solar energy using reflectors, mirrors and focused lenses to generate the heat needed to generate electricity [23]. In these systems, the sunlight is concentrated on a thermal receiver, which absorbs sunlight and converts it into heat, and then this heat is used to generate the steam needed to rotate the turbines generating electricity [24]. The concentrated solar power station system uses a set of large mirrors that track solar radiation and focus it on a central receiver installed at the top of a tower in the center of the circle [25]. Now, power stations connected to the grid can be built at capacities exceeding 200 megawatts [26]. The focus in this scientific field is on increasing the reflection of solar radiation, increase the absorption of this radiation, and increase the thermal storage of the system [27]. Just as heat acquisition is important for solar systems, retaining it helps dampen the oscillation caused by instantaneous change in solar radiation [28]. The research and development work is continuing to improve the production capacity of these systems, and its results are beginning to be realized through the transformation of this technology to marketing on a global level. The concentrated solar power plants projects are being held in USA, Spain and many other countries.

Table 1 lists some of the latest studies in this field.

TABLE 1. Updated studies in CPS technology.

Ref.	Year	Location	System description	Key findings
[29]	2004	Germany	The researcher conducted a review study on three major technologies that have been deployed over the past decades to generate electricity at capacities ranging from 10 kW to several thousand MWs.	The generation of electricity using solar concentrating technology is currently ready for the market. The experience needed to build commercial enterprises has been used all over the world since the early 1980s. These stations will greatly contribute to the supply of energy during the next decade. These stations are efficient, economical, and environmentally friendly.
[30]	2010	USA	The study examines the possibility of using the concentrated solar power (CSP) system and the thermal energy storage (TES) in four regions in the Southwest of the United States.	The results of the study showed that thermal energy storage (TES) can increase the efficiency of the CSP system by allowing more solar field absorption.
[31]	2011	India	In this study, different types of concentrates were explored.	Concentration values for parabolic trough plants and linear Fresnel systems have low convergent concentrations. The area of land that must be provided for the construction of a plant with a solar tower is about 8-12 square meters per megawatt generation per hour per year, while the amount of land to be provided for the same amount of electricity generated using an equivalent parabolic trough and linear Fresnel stations are 6-8 and 4-6 square meters per MW generation per hour per year respectively.
[32]	2011	USA	The article reviews the innovations with concentrated solar technologies over the past decade.	Several improvements have been made during this period, including improvements in the design of the inverter, the collector, the heat-insulating materials, the quality of heat transfer absorption, and the production of electrical energy and thermal storage.
[33]	2012	Spain	The review article reviews the principles of the concentration of solar radiation and the latest developments in these technologies and their future prospects.	The implementation of concentrated solar energy systems has been increasing in recent years as a sign of its success and its successors. According to research and development, the next generation of this technology is expected to reach a temperature of more than 1000 ° C.
[34]	2012	Austria	The study compares carbon powered coupled with CO2 capture and storage, and solar concentrating (CPS) technology.	Both technologies work to provide electricity and are still in the early stages of maturity, both of which are now more expensive than steam power plants.
[35]	2012	Switzerland	The study examined the establishment and evaluation of the performance of the thermal energy storage system. This system consists of a bed packed with rocks for storing high heat and then transported to water and air. For this purpose, a thermal storage unit of 6.5 MW was installed in the ground. The model of the liquid and solid phases was monitored separately as the variable thermal properties were studied within the limits of 20-650° C, and validate the theoretical results with experimental results.	The results show that the industrial design and simulation model can be applied to storage units and stations with a capacity of 2 GW.
[36]	2013	Iraq	Small prototype consisted of mirrors and a target. Three methods were investigated. Coloring the receiver with black, covering the receiver with a glass box, and coloring the glass box by black color.	The study result showed that enclosing the receiver by a glass cover produced the higher receiver temperature indicating promising enhancement.
[37]	2013	Belgium	The study examines the variation of daily and monthly solar radiation flow. The short-term changes in cloudy days and the inability to save energy during night hours can only be possible if storage systems and/or backup systems are created to operate continuously. The study determined the optimal design and optimal operation required to accurately estimate daily solar radiation.	The paper developed new equations to calculate several variables such as monthly extra-terrestrial irradiation, the monthly average clearness index, the daily total irradiation, and the direct (beam) irradiation. The use of concentrated solar power plants with molten salts in a hybrid system will enable the generation of solar electricity at 69.5 GWh, if 13% efficiency can be maintained.
[38]	2013	USA	The paper discusses the design methodologies of the thermal energy storage system and the factors affecting the concentration of solar power plants (CSP).	The results of the study showed that storage is the main component of the concentrated power plant and any enhancement in this system will be reflected positively on the whole system efficiency.
[39]	2014	Syria	This paper explains the main concept of the CPS system and its working method and the component parts of the system. The paper examined the feasibility of implementing such solar systems in Syria.	CPS is a technology that provides a clean and cheap energy source and is an effective method that can be used to produce electricity depending on the sun. These projects can be implemented commercially by the type of aquarium technique equivalent solar power tower technology.
[40]	2014	UK	This article explains high efficiency heat cycles and their applicability in solar energy systems.	The study showed that from many systems, the steam Rankin system can be considered as the highest thermal efficiency and its concentration temperature is about 600°C.
[41]	2014	Brazil	The study is reviewing and analyzing the potential of concentrated solar power plants in Brazil and linking them to Brazil's long-term electricity system.	The study focused on four types of spike terminals with EQ basins and hybrid terminals Thermal storage stations. The study predicted that the first solar power plants would be

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				introduced in 2020 as an alternative to natural gas-fired power plants, while hydroelectric plants would not stop working and would not be replaced.

Table 1 indicates that the research and development is a cross-cutting issue and a critical perspective for mechanical advance and quick market section. To present the innovation, venture accomplices must work intimately with look into establishments. Research and development plants assume an extensive part here. With a specific end goal to decrease the last acknowledgment time frame toward the finish of the development and authorizing period of a business plant, new strategies for testing are required. A government sanctioned testing and checking system for introduced sunlight-based fields will be an essential undertaking for every future task

Dust is one of the environmental variables in the atmosphere that has a strong impact on solar systems [42]. Various studies have shown that the accumulation of dust, pollen, and air pollutants from burning hydrocarbon fuel, on the surface of solar systems reduces the efficiency of these systems and causes its degradation [43]. Table 2 lists some important studies that have highlighted this issue.

TABLE 2. The impact of dust and pollutants deposition on solar systems' surfaces

Ref.	Year	Location	System description	Key findings
[44]	2011	Mexico	The study examined experimentally the effect of dust accumulation on the efficiency of electric photovoltaic panels. Three types of commercial silicon plates were used for this purpose: monocrystalline, polycrystalline, and amorphous.	The results showed that the maximum reduction in efficiency was 6% for monocrystalline and polycrystalline and 12% for amorphous silicon units.
[45]	2013	USA	The accumulation of dust and pollutants on the surface of solar energy systems has negative impact on the solar systems; the methods of mitigation of the resulting losses were studied. The study focused on efficiency losses due to the accumulation of dust on photovoltaic unit, concentrated power plant systems (CPS). The study presented some methods that can be used to clean solar collectors such as: natural cleaning using falling rain, manual cleaning using water and detergents, and electrodynamics dust removal (EDS).	The study showed that the electrodynamic screen system can be a good alternative to remove the particles of dust deposited on the surfaces of solar systems without the need for water or moving parts.
[46]	2013	USA	The paper reviewed the impact of dust pollution (sand) especially in wet conditions found in many solar-rich locations around the world.	The concentration of dust pollution is on surfaces, whether PV panels or reflective surfaces such as mirrors or heliostats in energy concentration systems.
[47]	2014	USA	The accumulation of dirt and dust on the concentrated solar system causes low efficiency due to the optical system. However, extensive geographic data is available for PV systems. The study carried out satellite tracking of changes in the efficiency of PV systems during 2010.	During the drought period in the summer of 2010 and for no rainfall, using satellite solar data, losses due to accumulation of dust and dirt were observed at 0.21% per day. The efficiency of the system decreased from 7.2% to 5.6% during 108 days in the summer without cleaning. Rain recovered most of the lost efficiency to reach 7.1%.
[48]	2014	USA	The study examined the efficiency of reflection of solar mirrors and the effect of dust accumulation on the efficiency of electricity generation.	The study showed that the accumulation of dust on the surfaces of mirrors reduces the efficiency of reflection and need in this case to clean repeatedly to avoid deterioration of efficiency. The use of the electrodynamic screen (EDS) provides an effective way to maintain mirror reflection above 90%. Repeated dust removal keeps the reflectivity of the mirror above 90%.
[49]	2014	USA	The study reviews the losses caused by dust deposition and its impact on the efficiency of solar systems. The study focused on PV systems. The study also compared between some studies that have been addressed with energy productivity and performance losses in several regions of the world.	The study presented an analysis of the advantages of cleaning operations to provide an expected forecast database for solar power plant designers, and evaluated effective cleaning methods to compensate for the loss of system power.
[50]	2015	Iraq	Three PV modules were subjected to outdoor environmental conditions and the effect of the dust and dirt deposition on the system performance was evaluated	The examined samples of accumulated dust and dirt showed high rate of hydrocarbon particulate matter resulting from exhausts of traffic and generators.
[51]	2015	Morocco	The researchers studied the effect of the accumulation of dust on various solar mirrors on the efficiency of the solar system and studied in Morocco. Thirteen glass and aluminum mirrors were exposed for three months (April, April, and June). One mirror was installed horizontally and twelve mirrors were installed in four different directions (north, south, east and west) using three tilt angles to vertical: + 45° (against the sky), 0° (vertical) and 45 ° (facing the ground). The reflective diameters were measured after each month of exposure to mirrors used in the study.	For each mirror, a reduction in the reflectivity of the radiation was observed depending on the decrease in its cleanliness. The average monthly reduction rate for horizontal mirrors was 45% and 33% for glass and aluminum mirrors, respectively. The mirrors come + 45° in second place with a 14% lower cleanliness for both reflectors. However, the mirrors were installed at 0° and 45° angles with a cleanliness rate of around 97% for both mirrors.
[52]	2015	India	This study evaluates the possibility of treating the minerals	The study showed that some dust particles deposited in the

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			and the accumulated dust on the surface of the concentrated solar tower systems and the effect of this accumulation on the smooth operation of such a system.	recipient pores and in heliostat. The deposition of dust on heliostat is affected by its location within another set of variables. The wind velocity sweeps the mirror according to the size of the deposited particles.
[53]	2015	USA	The article studied the effect of dust accumulation with high relative humidity, high surface temperature, and a long accumulation time of dust on the surface of the system conditions. These conditions caused the formation of stubborn clay such as paint, and its disposal needs mechanical cleaning and rubbed to the surface of the system. The study introduced the use of a transparent electrical screen (EDS) to remove dust, to maintain energy efficiency greater than 90% compared to the plate under clean conditions.	The study showed that the proposed system has dust removal efficiency (DRE) of more than 90% when used on dust samples collected from dry areas. The consumption of this system of energy for the EDS process is less than 0.03 W/m^2/ cleaning cycle.
[54]	2015	Iraq	The study examined the effect of six types of total dust on the efficiency of photovoltaic cells in dust from different regions of the northern region of Oman.	The results of the study showed that the dust of two areas of Oman have the greatest negative impact on the performance of the electrical system and that because of the high moisture content in their dust.
[55]	2016	Oman	In this study, six samples of accumulated dust on a clean surface were collected for three months from six cities in northern Oman. Their physical properties and the effect of these properties on the performance of solar cells were evaluated.	The study showed that about (64%) of the deposited dust particles are the size of 2 to 63 μm. The researchers measured the loss of electricity output due to the accumulation of dust and found that the loss of efficiency was 0.05%, which is considered a small value when compared with losses in neighboring countries.
[56]	2016	Malaysia	The researchers reviewed the effect of pollution on the loss of energy for solar panels and the effect of pollution due to pollution on PV output.	The study showed that shading due to pollution is divided into two parts: soft shading due to air pollution, and solid shading due to accumulation of dust blocks. Soft shading affects the cell stream but the voltage is not affected by this contamination. Some cells have been subjected to deformation. As long as some cells still receive solar radiation, there will be cell productivity despite the low voltage in the PV unit.

The main key findings in table 2 are:

- Most examinations in literature have concentrated on simulated tidy, with less investigations on regular clean.
- Just couple of studies have models for specific cases and specific parameter (i.e. voltage, current, power or effectiveness).

Most examinations into exploratory examination of clean gathering did not show the properties (optical, size, geometry, and electrostatic testimony conduct) of regular tidy. These properties require be portrayed. The natural and electro-concoction properties of clean should be researched for different dust types in different areas.

Cleaning the surface of solar systems from dust, dusty minutes and dirt restores to the system a proportion of the loss of efficiency, and depends on the percentage of cleaning technology, the type of detergent used, and the period between cleaning and another [57]. Given the importance of this subject, many researchers have studied this subject in detail. The details achieved the reason for the dust blowing and its specifications and movements [58]. Table 3 lists the most important articles studied this issue.

TABLE 3. Cleaning effect on the solar systems efficiency recovery studies

Ref.	**Year**	**Location**	**Cleaning methods and materials**	**Key findings**
[59]	1999	Kuwait	The researchers studied solar field performance and the direct effects of mirror reflectivity.	The results of the study showed that the mirrors' average reflective should be maintained above 90%. Mirrors should be washed frequently to preserve this value.
[60]	2009	Germany	A method of measurement has been devised to determine the optical keys of systems that use reflective materials such as concentrating solar power stations (CSP).	Practical experiments have proven that glass mirrors are of high quality as reflective material. Silver is another material that is good reflective material, but its reflectivity is less than glass. Careful cleaning of the reflectors increases their efficiency.
[61]	2011	China	The article reviewed the existing ways to remove dust and dirt from the surface of PV cells.	The study concluded that solar cell self-cleaning technology will improve the resulting electrical efficiency, protect cells, and increase their operating life.
[62]	2014	Spain	The study focused on the methods used to clean the solar reflectors at the plants in the conditions of exposure to air in a semi-desert environment. Different cleaning methods were used.	The results of the study showed that the best methods are effective using mineral water and brush, which returned to the cell 98.8% during the rainy season and 97.2% in the dry seasons. The use of steam cleaning with soft tissue is ineffective.
[63]	2014	UK	The study compares the optical characteristics and texture of the collectors' surface, one of which was glass	The results of the study showed the possibility of using anti-pollution and self-cleaning coatings on glass surfaces

			and the other was polymer. The cleaning process was also simulated for the cleaning of the collectors and the deterioration of the reflection properties of the glass and polymer due to sand and dust.	and polymer. The measurements taken for the polymer film supported the good performance of this material in terms of durability and visual performance.
[50]	2015	Iraq	Three cleaning methods were used in the study to evaluate which one is the best? Water, alcohol, and cleaning detergent using sodium solution were used in cleaning deposited dust and pollution on PV panels.	The results of the methods of cleaning the PV cells showed that the use of a detergent containing sodium as well as the use of alcohol compensates a large part of the performance of the system lost due to the accumulation of dust and pollutants can be recovered. When using water to clean the photovoltaic cells improved system performance but remained less than the clean system completely by 14% after exposure for six weeks to external conditions.
[64]	2015	India	The article studied the benefits of Fresnel Lens in PV/T applications. As these lenses introduce a possible alternative to the conventional reflector, which is often exposed to failure of mirrors/ reflectors.	The study results confirmed that the Fresnel Lens can be a promising alternative in the PV/T technology.
[65]	2015	UK	The study reviewed the possibility of using coating techniques to improve the performance of reflectors and absorbers in concentrated solar systems.	The results of the study showed that the need for much better data on the physical and chemical properties of the coating still exists.
[66]	2018	Iraq	The authors used water to clean the surface of the solar collector of a solar chimney prototype.	The results indicated that the washing of the solar chimney collector surface was not enough to recover the lost power and the inner surface must be cleaned also.

Iraq is one of the first countries in the world to produce oil and gas as it is also in terms of stock reserve for both materials [67]. This has caused the country to rely entirely on oil and natural gas in the production of electricity and has decreased the dependence on alternative sources to a 2.3% of the hydropower [68]. Over the past four decades, the country has been subjected to two devastating major wars, a brutal occupation and an unjust 14-year economic blockade. These abnormal conditions have caused the deterioration of the country's infrastructure, especially power plants [69]. The two decades of drought have caused the transformation of a large part of the agricultural land in Mesopotamia into desert and converted it to a source of sand and dust to neighboring areas [70].

Several studies have shown the success of using solar energy to generate electricity in Iraq, as the shining hours exceed 3300 hours/year. Also, the solar radiation intensity is high, ranging from 416 W/m^2 in January to 833 W/m^2 in June. Therefore, the use of solar systems is a quick and mature solution to the acute shortage of the country in the processing of electricity [71]. Many citizens have become dependent on personal and public generators of varying capacities, working with gasoline and diesel to compensate the lack of power supply [72]. The use of these generators doubled the problem of acute environmental impact and concentrations of motor pollutants and adding to those resulting from the exhaust of millions of cars, trucks, and heavy construction equipment. The problem of air pollution in Iraq has become critical and need urgent and serious solutions [73, 74]. The use of available and free energy such as solar energy is the most effective solution.

The objective of this practical study is to investigate the effect of accumulation of dust and air pollutants on parts of the CPS prototype system such as reflective mirrors and the central receiver, and retrieval the lost efficiency using different cleaning materials. In this study, we will use distilled water, alcohol, and a detergent containing sodium.

II. Experimental Setup

The accumulation of dust on the surfaces of the reflectors and the receiver was studied in practical. Depending on the results of the References [24, 29], the model that is supposed to give the best performance and concentration of solar radiation was constructed. It consists of four rows of reflective mirrors in the shape of an arc with an inner circle diameter of 0.25 m and an external diameter of 1 m. The curved reflectors' rows were distributed at a 150-degree angle facing the south. Heliostats are mirrors with measurements of 2.0 x 2.0 cm^2. The first arc of heliostats was fixed at a height of 3 cm from the ground. The second row of heliostats piled at a height of 4 cm from the ground and at a distance of 25 cm from the first row. The third row of reflectors was placed at a height of 6 cm from the earth's surface and at a distance of 25 cm from the second row. The fourth row of heliostats was fixed at an altitude of 8 cm from the ground surface and away from the third row by 25 cm distance. These arrangements were designed to enhance the access of solar radiation to all mirrors and their aimless targeting the receiver without any barriers.

In the center of the arcs circle the receiver was placed at a height of 30 cm above ground level. The receiver is made in the form of a cylindrical rod of wrought iron material with a diameter of 6 cm, height 10 cm and weighing 2.8 kg. The specific temperature of the receiver material is (Cp = 0.46kJ / kg ° C), and its thermal conductivity is (k = 59 W/m °C). The target was covered by a glass box with a dimension of 25 cm × 25 cm × 25 cm, to take advantage of all the absorbed radiation based on the effect of greenhouse effect and to prevent convection heat transferred to the outside air. Three previously calibrated thermocouples were used to measure receiver temperature during experiments. These thermocouples are fixed at the receiver's top, base, and in the middle.

In order to improve the reflection efficiency of the system and to collect all the scattered radiation, an aluminum reflector was manufactured and fixed away from the receiver by a distance of 20 cm. This reflector wall was installed behind the receiver from the north side and the reflector is designed to be arc-shaped. The primary objective of using this receiver is to reverse the incoming light from the mirrors, which deviate from the receiver to return to it after it is being reflected by the northern reflector. Fig. 1 illustrates the system used in the tests.

Air temperature was measured using a previously calibrated mercury thermometer fixed in the shade. The solar radiation on the mirrors was measured using a radiometer. The thermal efficiency of the system was calculated using the equations:

The hourly saved energy in receiver at each hour, Q_{act}, is

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

Energy supposed to hit the receiver from sunrise to sunset, Q_{theo}, calculated using the equation:

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

The equation of hourly efficiency η_h is:

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

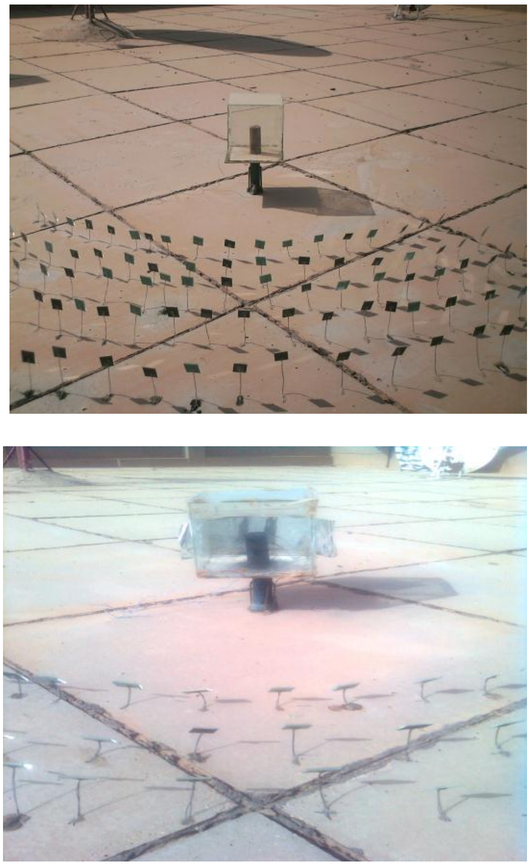

Fig. 1, Photographic pictures for the prototype assembly

A. Test Procedure

As the present study focuses on the accumulation of dust and pollutants on the surfaces of mirrors and the receiver, the practical tests were conducted in the spring of Baghdad city-Iraq, 2017. Dust storms are frequent in the spring, as well as, pollen suspended in the air. Work has been divided into the following stages:

1. Clean system was tested for the period from 10 to 12 March 2017.
2. The system was kept to expose to external conditions for two weeks without cleaning for the period from 13 to 27 March.
3. The polluted system was tested for the period from 28 to 30 March.
4. The mirrors and the receiver glass casing were cleaned by distilled water and the system was tested for the period from 1 to 3 April.
5. The system was left to expose to the external conditions for two weeks without cleaning, for the period from 4 to 18 April.
6. The mirrors and the receiver casing were cleaned using alcohol and the system was tested for 19-21April. The system was left to expose to external conditions for two weeks without cleaning, for the period from 22 April to 5 May.
7. The mirrors and the receiver cover were cleaned with a Sodium detergent and the system was tested for the period from 6 to 8 May.

The use of manual control in directing the reflective mirrors to the target made the use of three systems in the same time a difficult issue. So, the previous technique was used in the study, with the emphasis that the solar radiation varies from day to day and from month to month, and the study lasted over three months. In this study, the temperature of the receiver was not taken as a comparison parameter between the systems because it would be an unfair comparison. The change in the hourly efficiency of the system was used to compare the performance of different systems. In the same time, the tests for each case were repeated in three consecutive shiny days, to ensure the repeatability justice of the tests and to eliminate the random uncertainties.

III. RESULTS AND DISCUSSIONS

Solar radiation is the fuel of solar systems. The higher the radiation, the higher the systems' thermal effect is. Iraq is characterized by a clear atmosphere from clouds most of the year, and high radiation intensity that is very suitable for solar applications. Fig. 2 shows the reflected intensity of solar radiation during the studied periods. Because the study was completed in a period of days spread over three months, the solar radiation intensity was increased especially for the case of the use of the Sodium detergent because it was done in May. Spring in Iraq is characterized by the dust and dust and sand storms, and this is one of the most important reasons to choose this period for tests. The figure shows that leaving the system without cleaning up the accumulation of dust and contaminants suspended in the atmosphere caused the reflected radiation intensity to be much lower than the rest of the cases.

Fig. 3 shows the distribution of target temperatures for the studied cases during the examination hours. The temperature of the target reached high degrees compared to the size of the

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model used in the study. The target temperatures for the late cases in April and May were higher than the rest due to the high solar radiation reaching the target during these days. At the same time, the lowest temperature of the target was when using the contaminated system, because of the low energy coming with solar radiation reflected from mirrors.

Fig. 4 declares the stored heat distributed over the trial hours for the studied cases. The thermal storage of the target depends on the intensity of the solar radiation reflected from the mirrors and reached to it. Thus, the cases of cleaning by alcohol and sodium cleaner were the highest stored temperature as its testing periods were at the highest days of solar radiation.

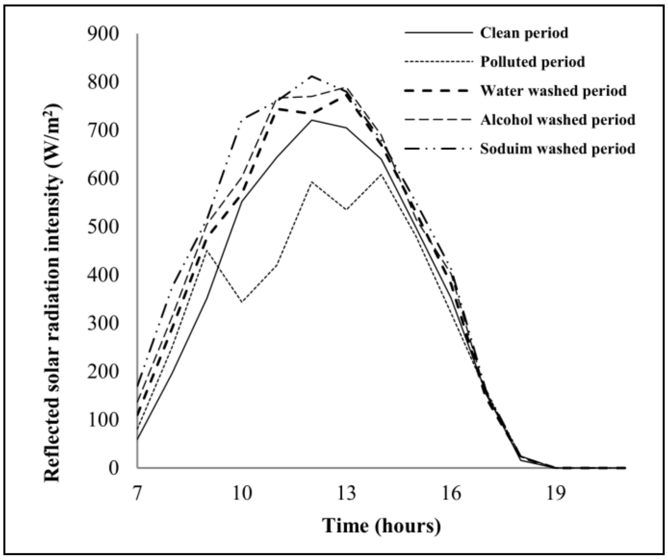

Fig. 2. The reflected solar radiation intensity from mirrors for the studied periods

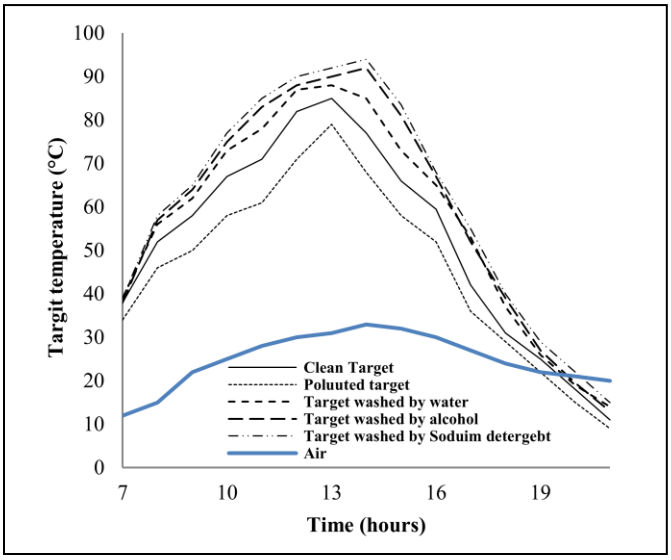

Fig. 3. The target temperature distribution through the day for the studied cases

The previous figures clarify that washing the system with water is not enough to restore the performance lost 100%, and therefore, the system used water cleaning results in the last three figures were lagging behind the Clean system, although its tests were conducted in early April. The water can clean mirrors and reflectors as well as the glass of the receiver from dust and sand, but cannot clean it from the hydrocarbon pollutants and dust with low sizes in nanometers as Ref. [42] indicated.

As mentioned previously, the actual comparison between the studied systems will be done by comparing their efficiencies, Fig. 5 shows this comparison. The clean system will maintain the highest efficiency throughout the day while the contaminated system efficiency reduced about 22.5%. Washing and cleaning the system using water increased its efficiency and compensates a large part of the loss, but it did not compensate all losses. The figure shows that the water-cleaned system was less efficient than the clean system about 7. 97%.

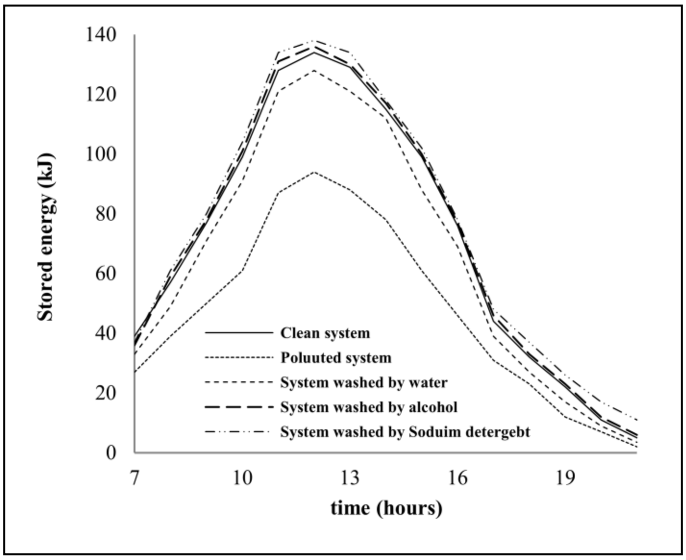

Fig. 4. The stored energy in the target for the studied cases distributed with time

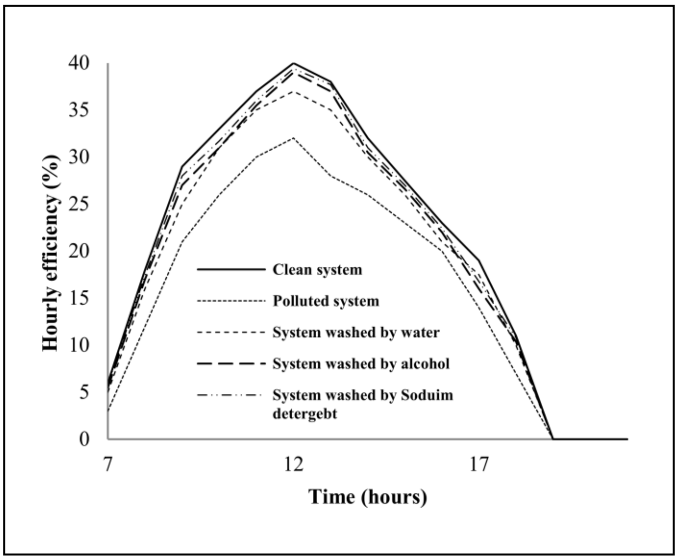

Fig. 5. The hourly efficiency distribution during the day for the studied systems

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Cleaning the system either with alcohol or with sodium cleaner returns most of the energy and efficiency lost to the system and the results of both cleaners are close. However, the results suggest that cleaning with sodium cleaner is somewhat better than alcohol cleaning. Both materials cleaned the reflectors and the receiver glass better than water, which means that they have better cleaning influences on nano scale dust and hydrocarbon pollutants. If we consider that the clean system represents 100% efficiency, then the contaminated system reduced this efficiency by 22.5%. The use of water to clean the system caused a decrease in efficiency by the limits of 8%. The use of alcohol caused a decrease in efficiency of about 5.11%. The use of sodium detergent reduced efficiency losses to 3%.

IV. CONCLUSIONS

In this study, a small model of a concentrated solar station was studied. The effect of dust and air pollutants deposition on the system reflectors and the output efficiency was investigated. The use of different detergents to recover energy losses as water, alcohol, and sodium cleaner, was also studied. The tests were conducted in the city of Baghdad, Iraq in the spring season (March, April and May) 2017. The results of the study showed that the accumulation of dust on the surface of the system caused the reduction of reflected radiation that resulted in losses of efficiency. The use of water in the cleaning process of reflectors and the receiver recovers part of the efficiency loss, but the use of alcohol and sodium cleaner is much better. These compounds treat dust nanoparticles and hydrocarbon pollutants better than water.

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