Dust Effect on the Efficiency of Silicon Mono Crystalline Solar Modules at Different Tilt Angles at Al-Jadryia Climate Conditions

Emad Talib Hashim
Assistant Professor
Department of Energy Engineering
College of Engineering/ University of Baghdad
emadchem70@yahoo.com

Tabark Abed Hussien
M.Sc. Student
Department of Energy Engineering
College of Engineering/ University of Baghdad

ABSTRACT

Solar energy usage in Iraq is facing many issues; one of those is the accumulation of the dust on the surface of the solar module which would highly lower its efficiency. The present work study the effect of dust accumulation on installing fixed solar modules with different inclined angles 15^o, 33^o, 45^o, 60^o. Evaluation of the solar modules performance under different circumstance conditions such as rain, wind and humidity are considered in study of dust effect on solar module performance. The results show that the lowest output average efficiencies of solar modules occurs at 15^o horizontally inclined angle are 7.4% , 6.7% , 8.0% , 8.1%, and 8.4% for the corresponding months; June, July, August, October, and September respectively while the highest average efficiencies are 8.9% , 9.1% , 9.4% , 9.6% , 9.6% for an inclined angle 60^o for the same month. lose power output rate for angle 15^o horizontally inclined solar modules are as following 32.6%, 32%,31.6%,34.9%,26.2% for months; June, July, August, October, and September respectively , while the results for the 60^o horizontally inclined solar module are 26.9%, 17%, 24.2%, 28.1%, and 9.7% for the same five months. As a final result is that the 15^o horizontally inclined solar panel is less efficient compared with the 60^o horizontally inclined solar panel and the difference in the results in the months was mainly due to the weather changes (summer and winter). The solar modules efficiency and lose power rate values for the inclination angles 33^o and 45^o are ranged between the values of $15^o$and 60^o inclination angles.

Keywords: dust, solar module, humidity, wind, and efficiency.

تأثير الغبار على كفاءة وحدات الالواح الشمسية احادية التبلور وبزوايا ميل مختلفة وضمن الظروف المناخية لمدينة الجادرية

عماد طالب هاشم
أستاذ مساعد
قسم هندسة الطاقة/كلية الهندسة/جامعة بغداد

تبارك عبد حسين
طالب ماجستير
قسم هندسة الطاقة /كلية الهندسة/جامعة بغداد

الخلاصة

أن تطبيقات الطاقة الشمسية في العراق تواجه مشاكل كثيرة, واحدة من أهم هذه المشاكل هي تراكم الغبار على سطح الألواح الشمسية التي تسبب انخفاض أدائها بشكل حاد. في العمل الحالي.تم دراسة تأثير تراكم الغبار على كفاءة الخلية الشمسية من خلال نصب ألواح شمسية ثابتة بزوايا ميل مختلفة 15^o,33^o, 45^o,60^o مع الأفق تمت القياسات خارج المختبر. تم تقييم أداء الألواح الشمسية تحت الظروف الجوية مثل هطول الإمطار, العواصف الترابية, الرياح, والرطوبة.تشير النتائج التجريبية إلى أن معدل الكفاءة الخارجة للوح الشمسي المائل بزاوية15^oمع الأفق تصل إلى حوالي 7.4%, 7.6%, 8%, ,

8.4%8.1%لأشهر حزيران, تموز,أب, أيلول,تشرين الأول على التوالي. بينما تصل لحوالي 9.4% ,9.1% ,8.9% , 9.6%,9.6% لنفس الأشهر المذكورة سابقا للوح الشمسي المائل بزاوية 60º مع الأفق. وكنتيجة نهائية فان أقصى قيمة لخسائر القدرة الخارجة للوح الشمسي المائل بزاوية 15º وصلت لحوالي 31.6% 32% ,32.6% ,, 34.9% , 26.2 لأشهر حزيران , تموز, آب, أيلول و تشرين الأول على التوالي. بينما وصلت لحوالي 9.7%28.1% ,24.2% ,17% 26.9% لنفس الأشهر المذكورة سابقا للوح الشمسي المائل بزاوية 60º. من هذه النتائج يمكن ملاحظة إن اللوح المثبت بزاوية 15º مع الأفق اقل فعالية مقارنة مع اللوح الشمسي المثبت بزاوية 60 مع الأفق وان تغير النتائج للأشهر المختلفة (الصيف و الشتاء) هو نتيجة التأثر بصورة كبيرة بالظروف الجوية. كفاءة الالواح الشمسية والتي زوايا ميلها 33º و45º وخسارة القدرة محصورة بين قيم النتائج للزاويتيين 15º و60º.

كلمات رئيسية: الغبار ، اللوح الشمسي، الرطوبة، الرياح، الكفاءة.

1. INTRODUCTION

Most renewable energy sources come from external sources to the earth, primarily from the sun. The most important point is that renewable sources do not run out, in contrast to conventional energy sources based on fossil fuel such as carbon, petrol and gas. The amount of solar energy reaching the earth every year is roughly 10^{24} J. This is more than a thousand times the annual energy consumption of the entire world, indicating that (in principle) the worldwide requirement for energy could be supplied by solar energy. This energy is capable of producing large quantities of electricity for present as well as for future uses, **Delfina, 2008.** Iraq has a good value of solar insolation and the maximum value of insolation distributed in the mid and south of it, as well as, the average annual insolation of Baghdad is equal to about 5.27 kwh/m^2/day. This value is supported by the solar insolation data from NASA research center. Over years, many researchers have studied the characteristics of PV modules and the factors that affect them. **Walker, 2001** has proposed a MATLAB-based model of a PV module to simulate its characteristics and to study the effect of temperature, insolation, and load variation on the available power . The mono and poly crystalline modules output are greatly dependent on the solar radiation perpendicular to the modules, whereas the amorphous panel works even with the diffused radiation. Though the efficiency of the amorphous panels is less but their energy yield is high compared to the others in some cases. Moreover the output of crystalline modules suffers more from dust accumulation as compared to the amorphous modules.

Qasem et al., **2012,** exposed the south-facing glass samples at different tilt angles under outdoor environment conditions for one month in Kuwait. A non-uniformity index defined as transmittance values at the top, middle, and bottom of the samples. Non-uniformity of the vertical sample was found to be 0.21%, while the sample tilted at 30° showed 4.39% non-uniformity between the three sections . This observation suggests non-uniform dust deposition as a function of tilt angle .

Lorenzo et al., 2013, investigated the impact of non-uniform dust deposition pattern on PV arrays in a 2 MW PV park in south-eastern Spain. It has been observed that dusty modules have significantly lower operation voltage than the less dusty or clean ones in the same string. Partially-shaded cells act as loads to clear cells connected in series. Consequently, more output power losses occur in the formation of hot spots. Infrared (IR) images taken from the array showed that hot spots formed in areas with higher dust concentration with up to 23° C higher compared to that of the surrounding panel surface . In long-term exposure, these hot spots cause the thermal degradation of the PV arrays.

The objective of the present work is to study the effect of dust on the efficiency and the efficiency loss of silicon mono crystalline solar modules at different tilt angles at Al-Jadryia climate conditions.

2. DUST EFFECT ON THE PV SOLAR PANEL

Soiling is a term used to describe the accumulation of dirt on solar panels that reduces the amount of sunlight reaching solar cells. Also Soiling includes not only dust accumulation, but also surface contamination by plant products, soot, salt, bird droppings, and growth of organic species, adversely affecting the optical properties. “Major performance-limiting factors other than soiling include temperature effects (primarily in mono-crystalline silicon and multi-crystalline silicon PV modules), high relative humidity (RH), high wind speed, corrosion, and delimitation of the energy conversion devices”. It is often a problem in the areas where it is not raining for months in a row. This has a cascading effect on performance, from the reduction of sunlight to causing reduced energy absorption by solar cells. This can cause the whole system to work harder and consequently reduces energy output, **Al-Hasan, 1998.** While dust is term generally applying to minute solid particles with diameters less than 500 μm. It occurs within the atmosphere from various sources such as dust lifted up by wind, pedestrian and vehicular movement, volcanic eruptions, and pollution. Dust would also refer to the minute pollens (fungi, bacteria and vegetation) and micro fibers (from fabrics such as clothes, carpets, linen, etc.) that are omnipresent and easily scattered through the atmosphere and consequently, settle as dust**, Mani and Pillai, 2010**. Studying the dust effect on the PV panel will help to select panel technology for a particular type of application and location. The accumulation of dust particles on the surface of PV module greatly affects its output power, especially in the desert areas. However, desert countries are suited for photovoltaic power generation due to abundant availability of sunlight throughout the year. Experiments have shown that just 2 mg/cm^{2}of fine dust on solar panel can reduce its output by nearly 30%. At 8 mg/cm^2 dust deposition, output is reduced to just 10% of that obtainable for a clean panel, **Horenstein et al., 2011.** In bigger PV solar panels, more work forces and machines will be needed to keep making the rounds and cleaning the panels, especially after a sand storm **CSEM, 2010.**The dust accumulation on the PV panel surface depends on different parameters like PV panel inclination, kind of installation (stand alone or on tracker), humidity, etc.

3. OUTPUT CHARACTERISTICS OF SOLAR MODULES

The output characteristics of solar cells are expressed in the form current-voltage curve. A test circuit and typical current-voltage curve produced are shown in **Fig.1**. The current-voltage curve is produced by varying R_L (load resistance) from zero to infinity and measure the current and voltage along the way. The point at which the current-voltage curve and resistance (R_L) intersect is the operating point of the solar cell. The current and voltage at this point are I_p and V_p, respectively. The largest operating point in the square area is the maximum output of the solar cell as it's demonstrated in **Fig.2**. Fill factor (FF) is the relation between the maximum power that the panel can actually provide and the product $I_{SC} .V_{OC}$. This gives you an idea of the quality of the panel because it is an indication of the type of I-V characteristic curve. The closer FF is to 1, the more power a panel can provide. Common values usually are between 0.7 to 0.8. Solar module efficiency (η) is the ratio between the maximum electrical power that the module can give to the load and the power of the solar radiation (P_L) incident on the module. This is normally around 10-12%, depending on the type of cells (mono-crystalline, polycrystalline, amorphous or thin film). Considering the definitions of point of peak power and the fill factor as its follows:

$$\eta = \frac{P_{max}}{P_L} = FF \ \frac{I_{sc}V_{oc}}{P_L} \tag{1}$$

$$FF = \frac{I_{mp}V_{mp}}{I_{sc}V_{oc}} \quad (2)$$

4. EXPERIMENTAL MEASUREMENTS

4.1 Description of the System

Four different tilt angles were chosen for the fixed system of four monocrystalline solar module (solar module specification are available in **Table 1**). The first angle was (15^o) with the horizon as it is assumed to be the appropriate angle for summer application because the average of solar zenith angle is about (15^o), in addition to that Iraq suffers from an increase of solar radiation in Summer. The second angle was (33^o) with the horizon as it is assumed to be the appropriate angle in Baghdad for the annual applications to get a good match with latitude of Baghdad (33^o), according to the information data of NASA (NASA 2002) and other research results, **Al-Sudany 2009.** The third and fourth angles are 45^o and 60^o respectively with the horizon as it is assumed to be the appropriate angle for winter applications because the average of solar zenith angle is about 45^o and 60^o, in addition to that Iraq suffers from a decrease of solar radiation in Winter due to optical path of radiation (air mass) compared with that in Summer season. Four similar solar panels with power of 50 watt (dimensions; length, width, and thickness =845x545x35mm) are fixed at previous angels.

All of the modules are calibrated according to standard procedure supplied by the manufacturer and to be cleaned at the beginning of every month (June, July, August, September, and October) to study effect of accumulated dust for each month. The solar modules system is available in **Fig.3**.

Solar module analyzer (prova 200) is used for testing and maintenance of solar panels and modules (see **Fig.4**). **Table 2** provides the general specification of prova 200. **Table 2** provides the accuracy and solution of the solar module analyzer. The prova 200 solar panel analyzer can be used in the manufacturing and testing the solar panels and cells. The portability of this device is useful in quality assurance at various stages on the production line and can be taken from one location to another .

Data Logging Solar Power Meter TES-1333R is used for measuring solar radiation flux (W/m^2) (see **Fig.5**). Besides dealing with high power (up to 2000W/m^2 / 634Btu) it also handles a range of spectrum, from UV (400nm) to IR (1000nm).The sensor is a photovoltaic sensor, which ensures stable and good measurements over a long time. The instrument is also Cosine-corrected for the angular incidence of solar radiation. Also that TES-1333R has four digit displays with 0.1W/m^2/0.1Btu resolution.

Prova 200 and TES-1333R are calibrated according standard procedure supplied by the manufacture using on-line software programs.

5. RESULTS AND DISCUSSION

Present work was performed to evaluate the performance of PV solar module under the effect of natural dust deposition on the fixed solar panel with different tilt angles and fix solar radiation 1000 W/m^2 (to get this values at outdoor condition, depending on time and tilt angle of the module; for example module with tilt angle 15^o will be have a solar radiation 1000 W/m^2 at 11.00 a.m.). The exponential work have made during the five months from June to October 2014. This work is done at an average temperature of 40^oC and average wind speed 2 km/hr. **Figs.6** and **7** show the relation between the efficiency and efficiency drop for Jun month as a function of the deposition period for four tilt angles: 15^o, 33^o, 45^o, and $60°$

respectively. **Fig.8** to **Fig.15** demonstrate the efficiency and efficiency drop for months; July, August, September and October respectively. The perturbations in the curve are due to the effect of weather conditions which occur during the test period such as wind, dust storm, and rainfall .The first day of month represents the start of the work where all the panels were cleaned. In Jun, it can be seen that the value of output power losses reached the maximum value compared with that of the other months July, August, September and October because a heavy dust storm was occurred which caused a deposition of dust on the solar panels surface. It can be seen after eight (8) days for deposition period that the losses were increased with respect to decrease in efficiency as the deposition period continued and then followed by wind storms that lead to natural cleaning and hence to a reduction of losses. With the deposition period continued the losses increased. Consequently, the maximum efficiency losses reached about 32.6% for the tilt angle 15^oin June and the average of losses for this period are about 23.8%.On the other hand, the case of other tilt angles 33^o, 45^o, and 60^o facing the south, the losses in the efficiency of solar modules are less than that of solar module at tilt angle 15^o because the increasing of the tilt angle of the PV solar panel leads to the reduction of the deposited dust on the solar module surface due to the small change of the gravitational force for dust particles and therefore leads to the decrease of losses resulting from the accumulation of dust. From **Fig.8** it can be seen that the maximum losses in June are about 30%, for tilt angle 33^o, 28.4 % for tilt angle 45^o, and 26% for tilt angle 60^o, it can be seen that tilt angle 60^o is much butter compared with the other angles.

In June, although a heavy dust storm was occurred after 13 days of deposition period with average value of relative humidity about 34.3%, but the average efficiency and losses in efficiency were reduced than other months due to the activity of high winds which plays an important role in reduction of accumulated dust on the solar modules surface. In addition to that this month was characterized by high temperatures with average of 46.1^oC and low humidity which leads to decrease the adhesion force for dust particles on the solar modules surface which means for dry months the accumulated dust is low. The weather conditions for this month, play an important role in reducing the accumulation of dust on the solar panels surface; therefore, the maximum efficiency losses reach to 32%, 30.3%, 30 % and 17% for fixed solar panels at tilt angle (15^o, 33^o, 45^o, and 60^o) respectively, whereas the average losses in efficiency for this month reached to 24%, 18%, 15.4% and 8.8% for all four cases. This month is similar in behavior with the dry months (June and July), which is characterized by dust storms occurred for several times , While the maximum losses in efficiency reached to 31.6%, 30.4%, 28.4% and 24.2% for fixed solar panels at tilt angles (15^o, 33^o, 45^o, and 60^o) respectively because the activity of winds which plays an important role in reduction of accumulated dust on the solar panels surface and low humidity which leads to decrease the adhesion force for dust particles on the solar panels surface, Where the average value of humidity for this month of about 25%, whereas the average losses in efficiency for this month reached to 20.3%, 16.6%, 10.46 and 8.6% for all four cases. Finally we can see that the losses in this month are less than previous months.

From these results it can be seen that the average loss in the efficiency of fixed solar panel at tilt angle (60^o) are less than that of solar panel at tilt angle (33^o) for the before mentioned reason. From all results which are previously mentioned, this method is very effective for reducing the accumulation of deposited dust on the solar panel surface dramatically and effectively. This is illustrated in the **Figs.16** and **17** for five months of the year, namely: June, July, August, September, and October .

The percentage efficiency loss of mono-crystalline solar module with tilt angle 33^o is 25% during period date 1 July 2014 to 1 August 2014(at Baghdad/ Al-Jadryia city), while the percentage efficiency loss for the same type of solar module and during period date 1 July 2012 to 1 August 2012 with tilt angle 30^o is 15% (at Kuwait city), **Qasem, 2013**. He also found the long exposure patterns (30 day) led to higher losses in efficiency of 19.4% in comparison to 14.8% for the short exposure (few days). While the present work result for the same approximated conditions is 12% and 20% respectively.

The percentage efficiency loss of mono-crystalline solar module with tilt angle 15^o is 33% during period date 1 September 2014 to 20 September 2014 (at Baghdad/ Al-Jadryia city), while the percentage efficiency loss for the same type of solar module and during period date 1 September 2011 to 30 September 2011 with tilt angle 15^o is 45% (at University of Technology/ Energy center), **Jasim et al., 2015**.

6. DUST PARTICLE SIZE

A sample of dust 0.3gm has been collected from the panel which was instilled at altitude of 10 m. The sample weighted then it has been solvent in 100 mm of water. The sample is put in grain size measurement device (SALD-2101) and by special program; the range of grain size is collected. The result of grain size test is shown in **Fig.18** (the analysis of dust grain size has been made at ministry of science and technology). The graph shows that 10% of the total amount has an average diameter of 0.798µm, 50% of the total amount has an average diameter of 9.146µm, and 75% has an average diameter of 16.800µm. As it clear, the larger amount of dust belongs to the particles which have bigger diameter. Because the bigger grains are heavy, they tend to instill on the surfaces because of the gravity. Whenever the altitude increased, the dust particle becomes lighter and smaller and that is the reason behind this small dust size grain. As it is mentioned before the finer particles become more adhesive and stick to the surface of the solar panel, reduce panel's performance and make the cleaning operation more difficult.

7. CONCLUSION

The results of the experimental work are used for evaluating the performance of PV solar panels under natural deposition of dust in Baghdad environment conditions. The losses in the power of fixed solar panel at tilt angle 60^o with the horizon are less than that of solar panel at tilt angle 15^o with the horizon. The weather conditions affect significantly on the accumulation of dust on solar panels which leads to effect on their performance such as the rain in some months causes natural cleaning for PV solar panels especially during October. The high wind speed plays an important role in natural cleaning which leads to reducing the accumulated dust on the solar panels surface especially in summer months. The accumulated dust on the solar panels surface in summer months is more than that in winter months.

Nomenclature

FF =fill factor, dimensionless.
I_L =photocurrent of the solar cell, A
I_m, I_{mp}, I_{max} =maximum current of solar cell, A
I_{sc} =solar module short- circuit current, A
K =Boltzman's constant, J/K
L =latitude angle, degree
N =number of aerosol particles.

PV =photovoltaic.
P_L =solar radiation, W/m^2
P_m, P_{mp}, P_{max} =maximum power, W
R_L =load resistance, Ω
V_{mp} =solar module maximum voltage, V
Voc=solar module open-circuit voltage, V
η =solar module efficiency, %

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Table 1. Technical specification of used solar module at standard test conditions (STC)

Rated power	**50 W**
Voltage at maximum power (V_{max})	17.2V
Current at maximum Power (I_{max})	2.9A
Open circuit voltage (V_{oc})	21.8V
Short circuit current (I_{sc})	3.25A
Total number of cells in series	36
Module weight	6 kg

Table 2. Specification of solar module analyser (prova 200).

Battery type	**Rechargeable, 2500mAh(1.2V)*8**	
AC Adaptor	AC 110V or 220V input DC 12V / 1~3A output	
Dimension	257(L) * 155(W) *57(H) mm	
Weight	1160g	
Operation environment	$0^oC \sim 50^oC$,85% RH (relative humidity)	
Temperature coefficient	0.1% of full scale/ ^oC (<18^oC or >28^oC)	
Storage environment	$-20^oC \sim 60^oC$,75% RH	
accessories	User manual * 1, AC adaptor*1 Optical USB cable*1 Software CD *1, software manual *1 Kelvin clips(6A max) *1 set	
DC voltage measurements		
Range	**Resolution**	**Accuracy**
0-6	0.001V	±1% ±(1% of V_{open}±9 mV)
6-10 V	0.001V	±1% ±(1% of Vopen±0.09 V)
10-60 V	0.01 V	±1% ±(1% of Vopen±0.09 V)
DC current measurements		
Range	**Resolution**	**Accuracy**
0.01-6 A	0.1mA	±1% ±(1% of I_{short}±0.9 mA)
0.6-61A	0.1mA	±1% ±(1% of I_{short}±0.9 mA)
1-6 A	1mA	±1% ±(1% of I_{short}±0.9 mA)

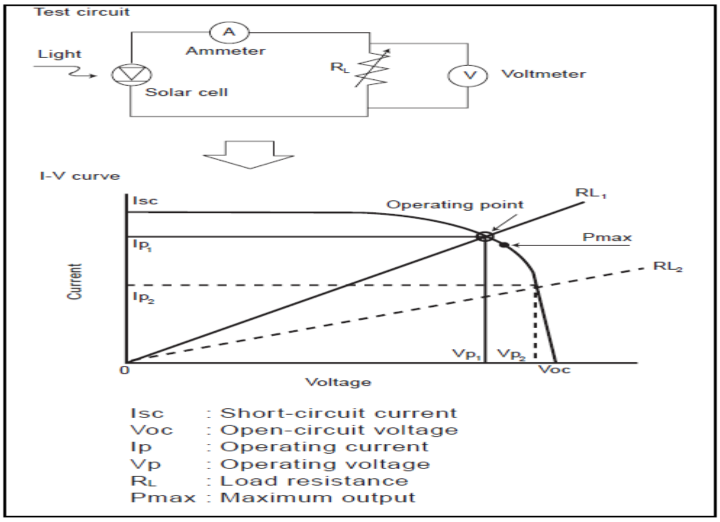


Figure 1. Current-voltage curve is produced by varying RL (load resistance) from zero to infinity, **Gracia et al., 2006.**

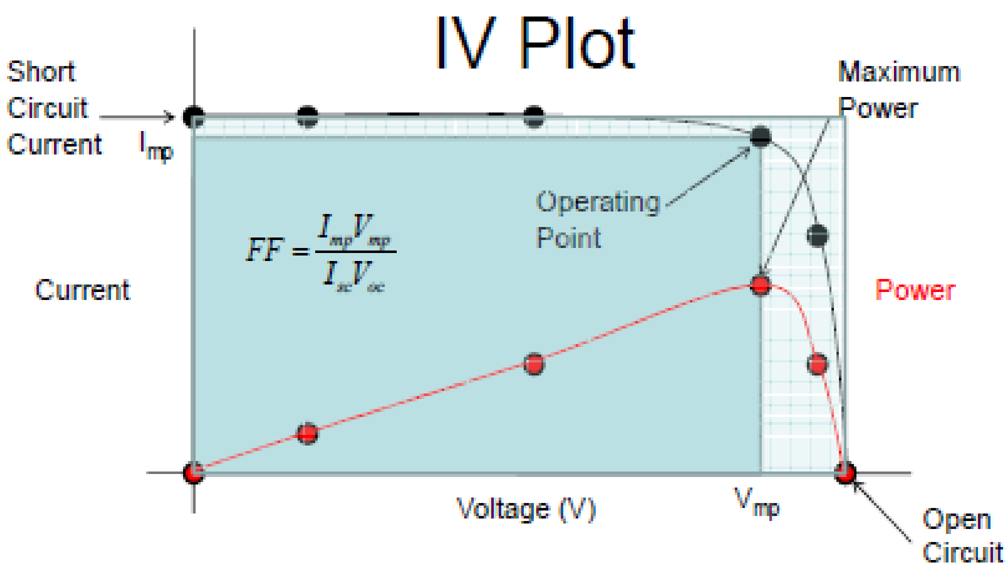


Figure 2. Square area gives maximum power output of the solar module**, Gracia et al., 2006.**

Tilt angle: 60^o 45^o 33^o 60^o

Figure 3. Photograph of the setup of the fixed solar modules system with different tilt angles 15^o ,33^o, 45^o and 60^o.

Figure 4. Prova 200 solar panel analyzer.

Figure 5. Solar power meter.

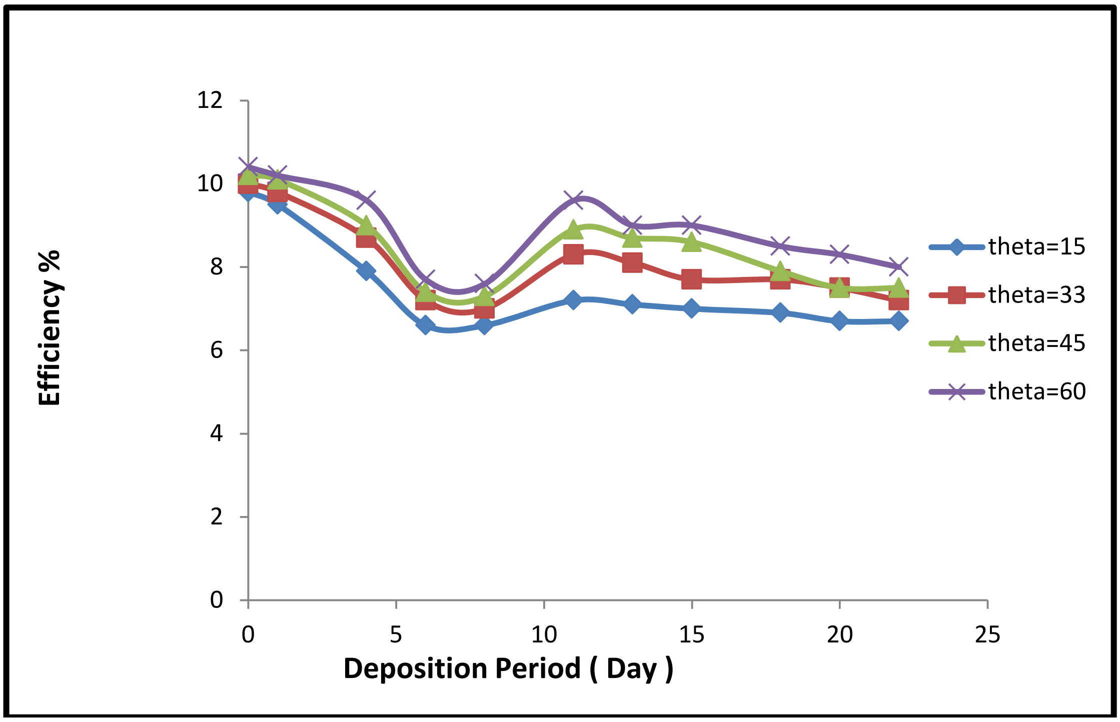


Figure 6. Efficiency versus deposition period for fixed panels at tilt angles (15°, 33°, 45° and 60°) in June.

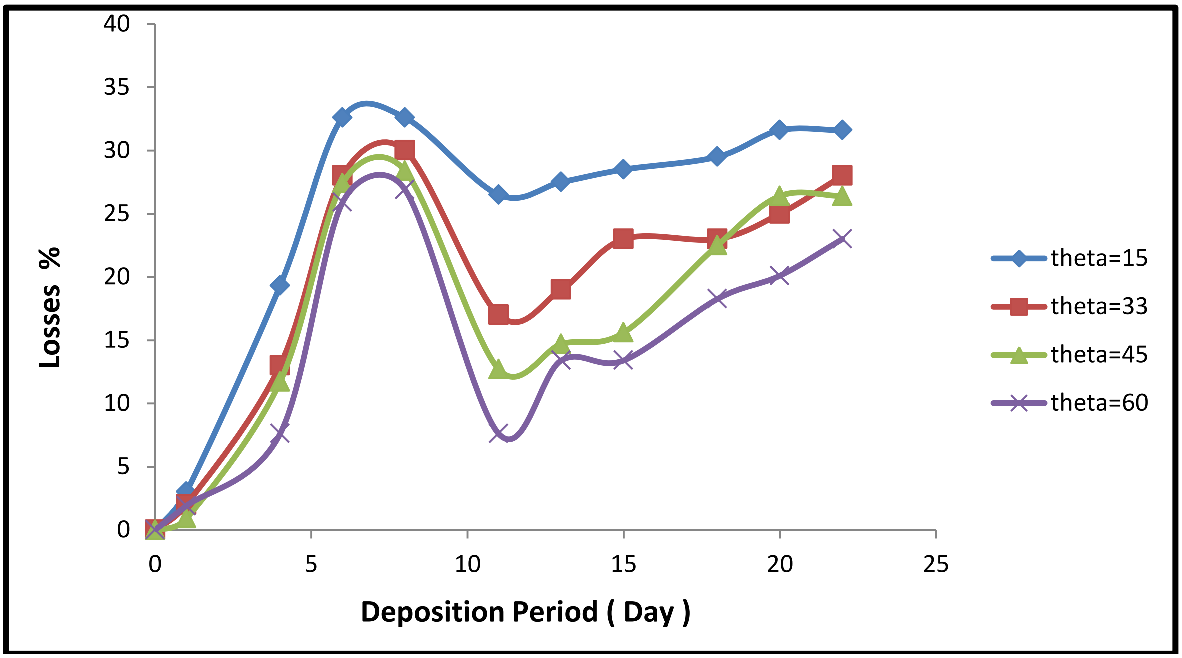


Figure.7 The efficiency losses versus deposition period for fixed panels at tilt angles (15°, 33°, 45° and 60°) in June.

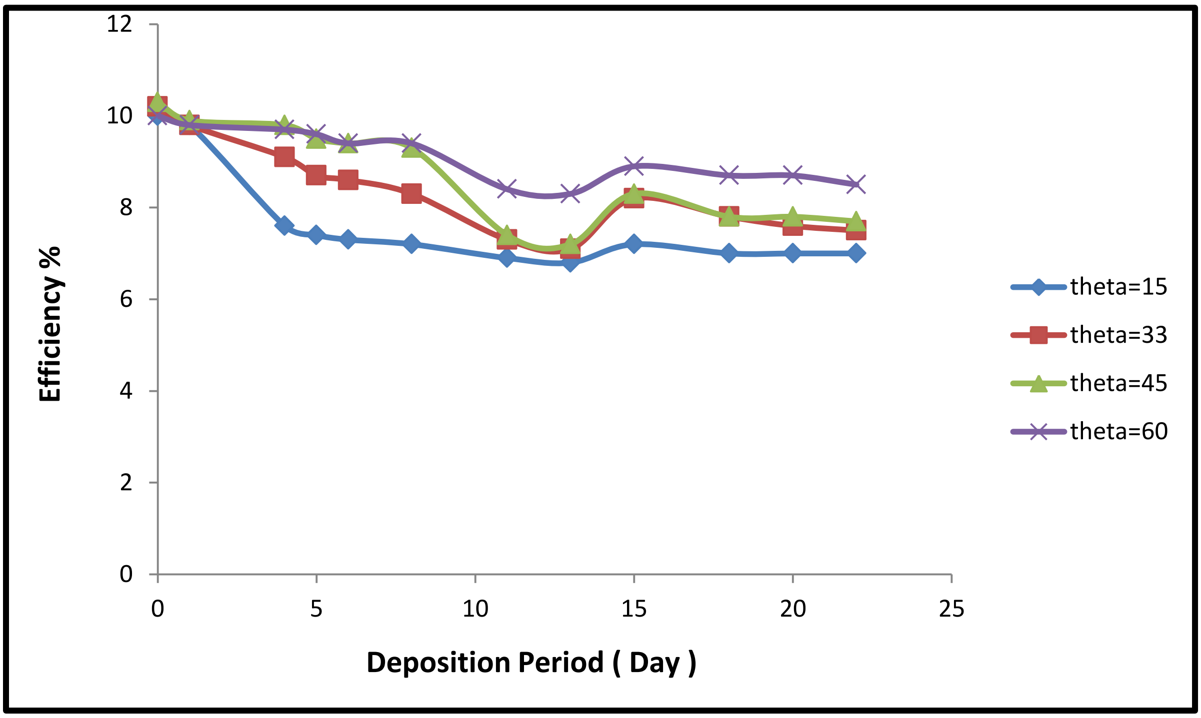


Figure.8 The efficiency versus deposition period for fixed panels at tilt angles (15°, 33°, 45° and 60°) in July.

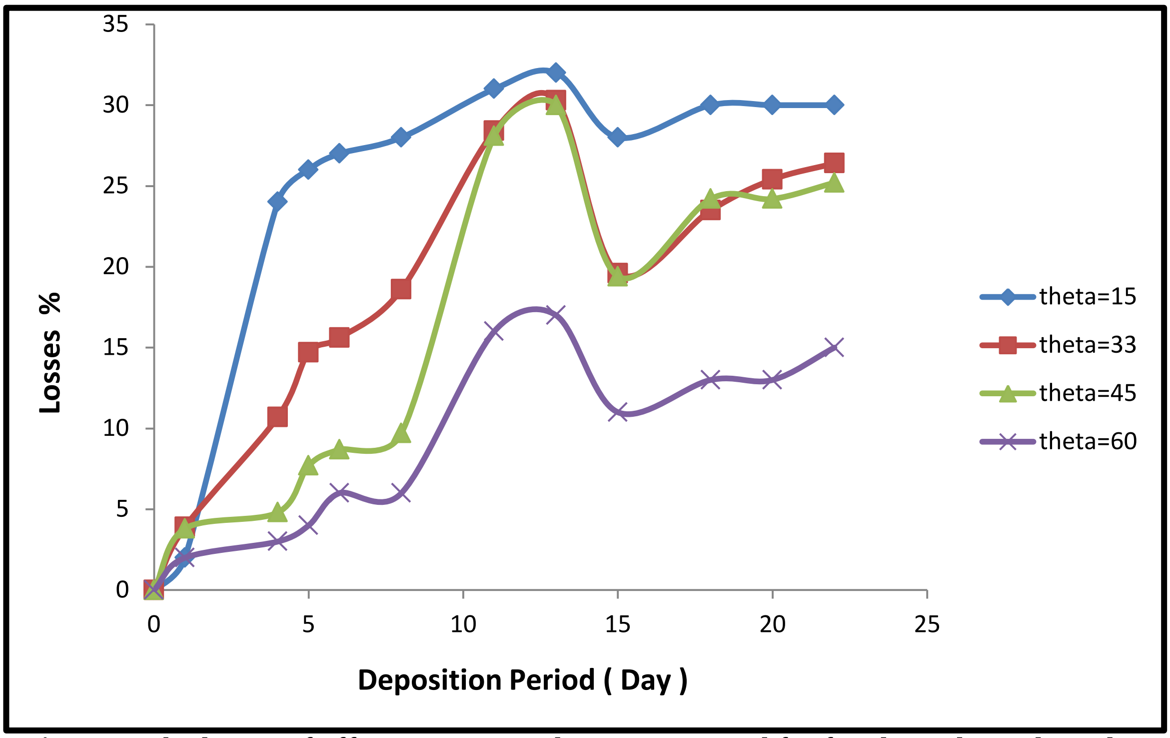


Figure.9 The losses of efficiency versus deposition period for fixed panels at tilt angles (15°, 33°, 45° and 60°) in July.

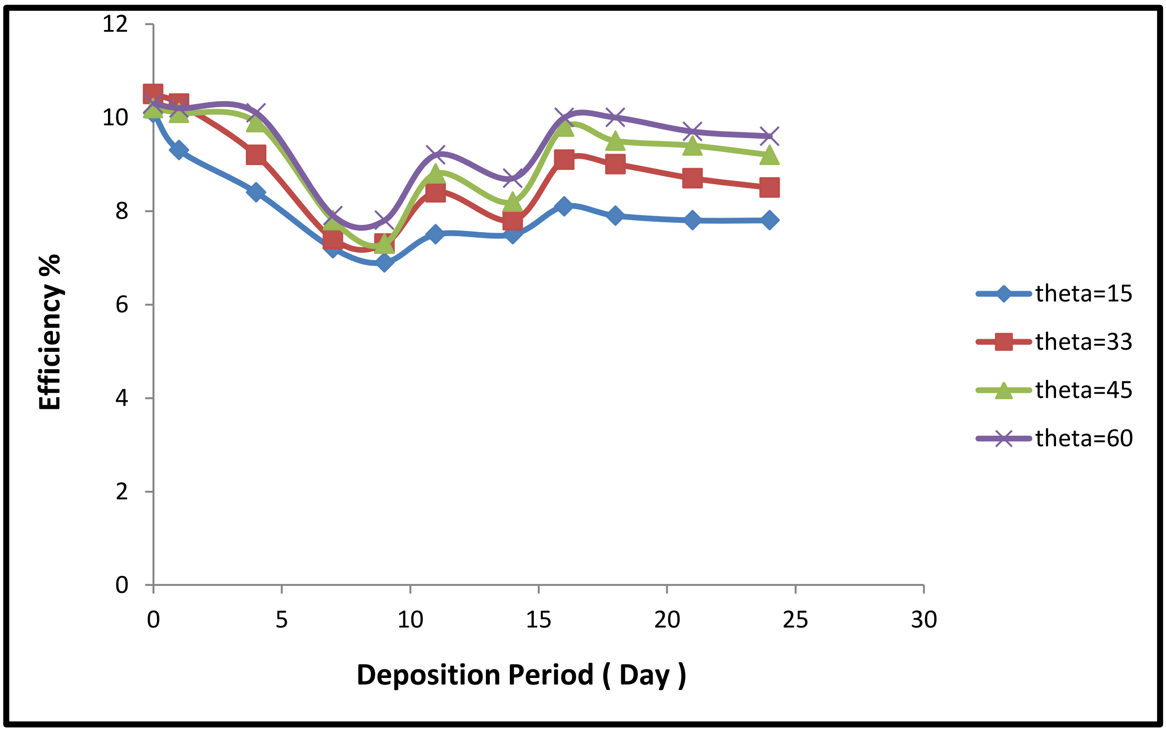


Figure.10 The efficiency versus deposition period for fixed panels at tilt angles (15°, 33°, 45° and 60°) in August.

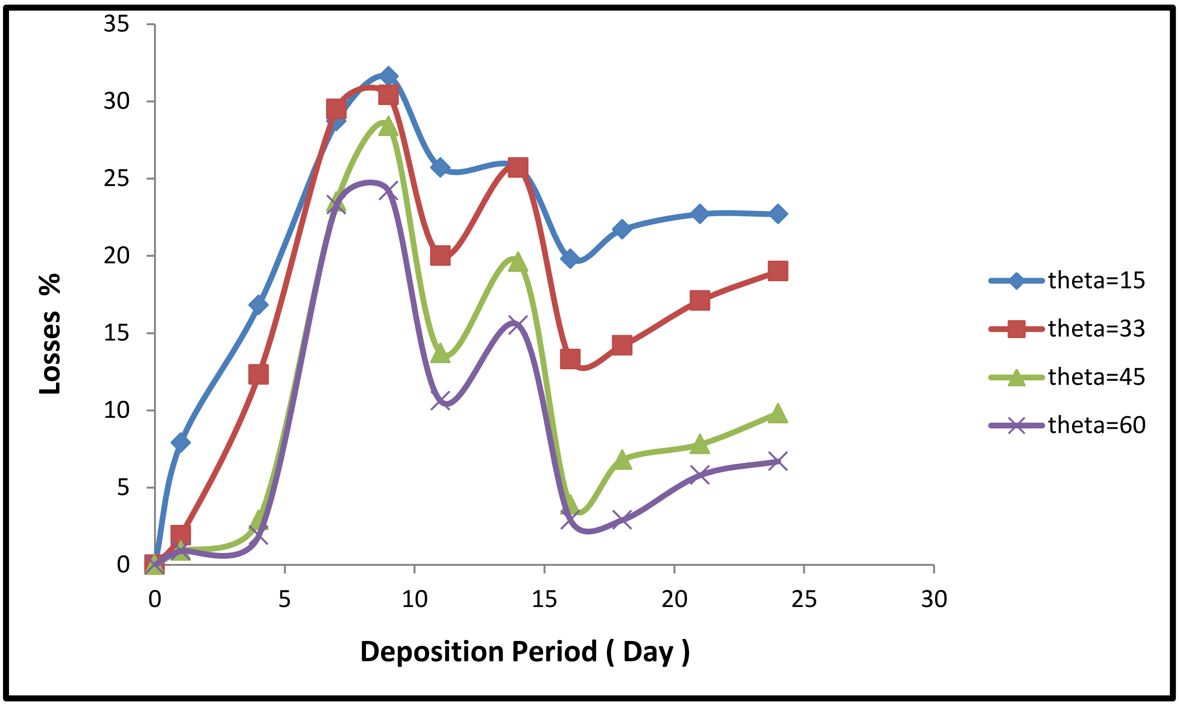


Figure 11. The losses of efficiency versus deposition period for fixed panels at tilt angles (15°, 33°, 45° and 60°) in August.

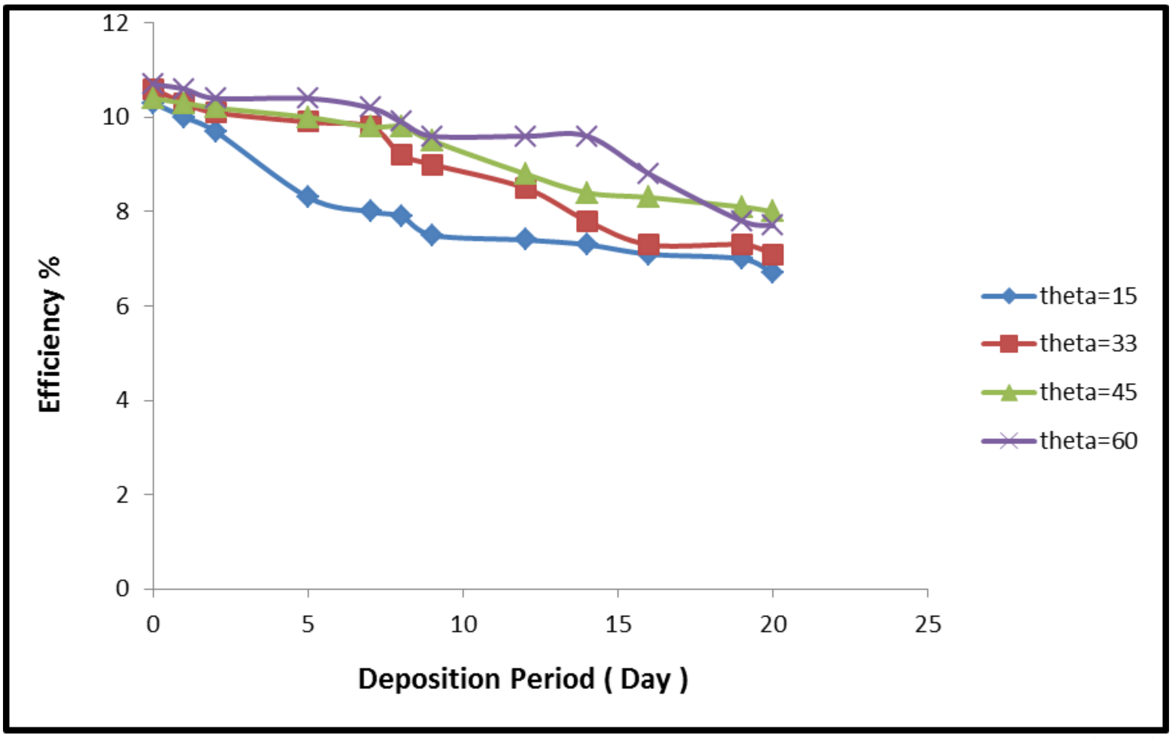


Figure 12. The efficiency versus deposition period for fixed panels at tilt angles (15^{o}, 30^{o}, 45^{o}and 60^{o}) in September.

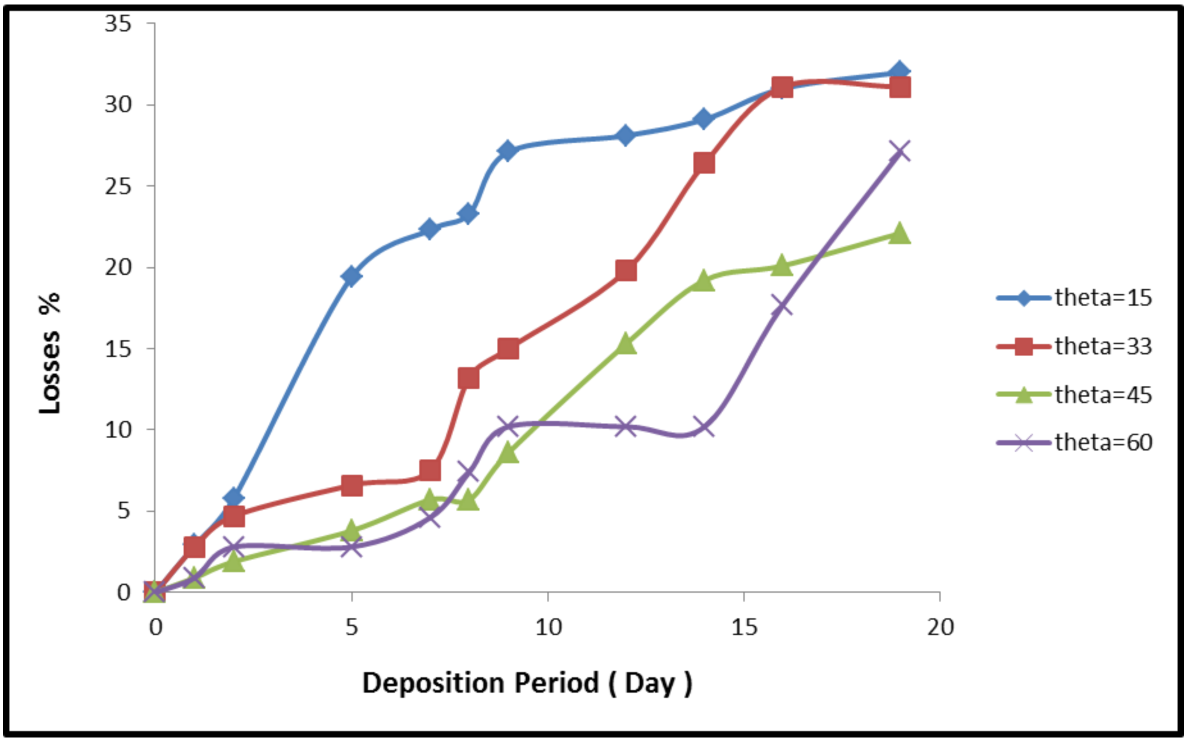


Figure 13. The losses of efficiency versus deposition period for fixed panels at tilt angles (15^o, 33^o, $45^o$and 60^o) in September.

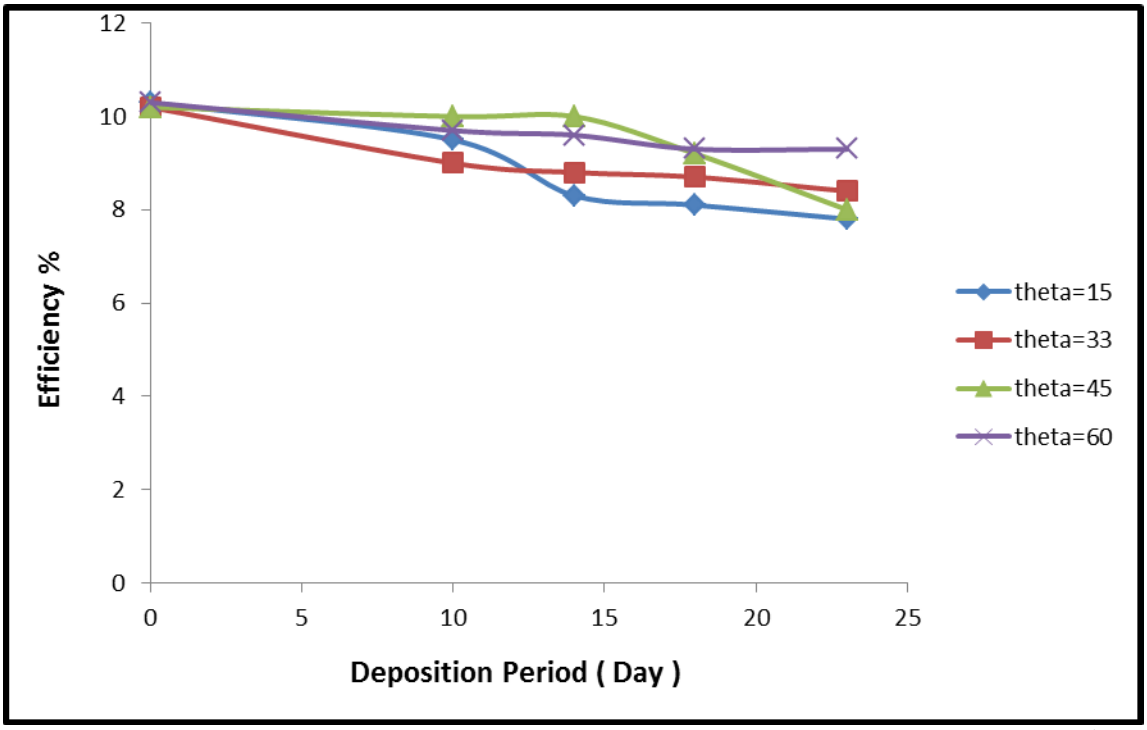


Figure 14. The efficiency versus deposition period for fixed panels at tilt angles (15^o, 33^o, $45^o$and 60^o) in October.

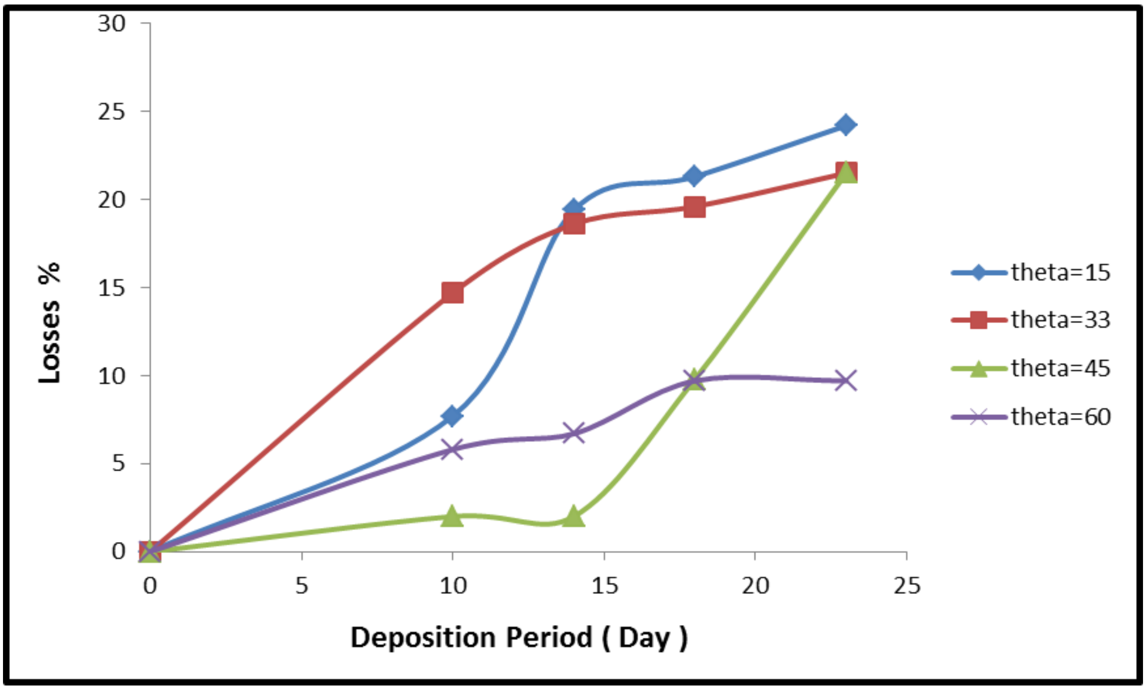


Figure 15. The efficiency losses versus deposition period for fixed panels at tilt angles (15^o, 33^o, 45^{o}and 60^o) in October.

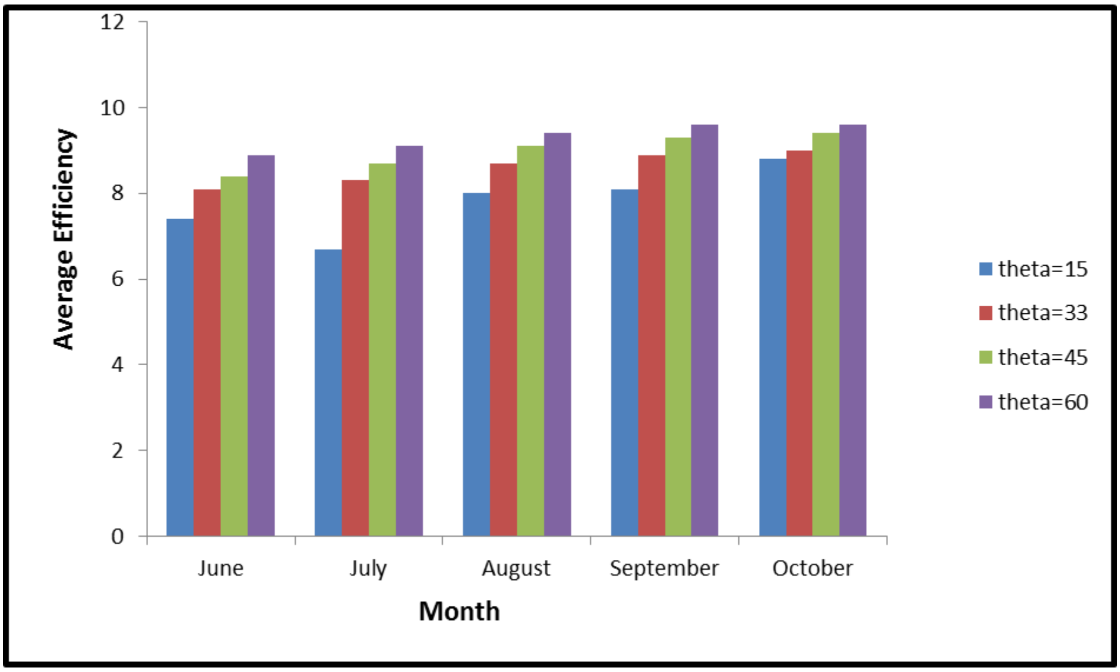


Figure 16. The monthly average efficiency due to dust in Baghdad for fixed panels at tilt angles (15^o, 30^o, 45^{o}and 60^o).

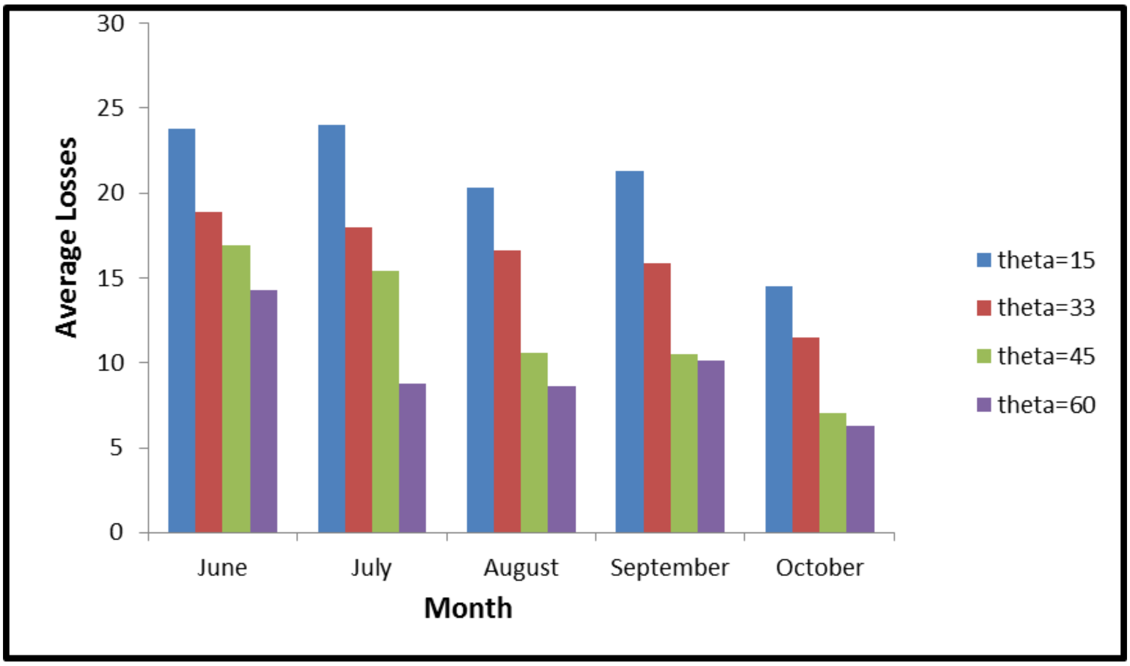
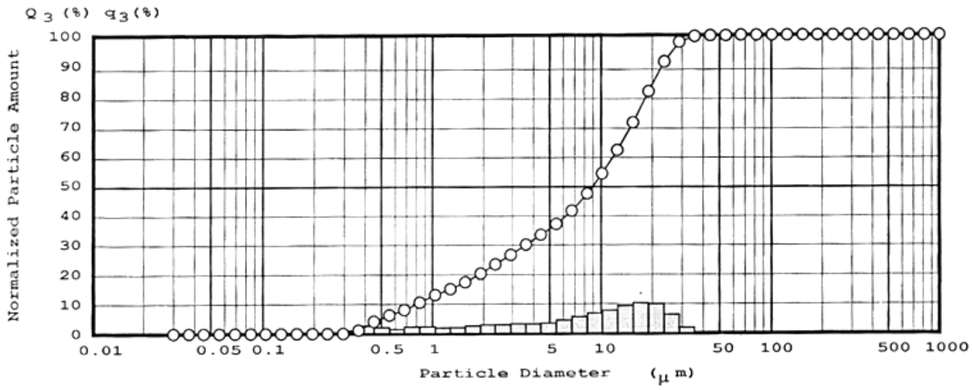


Figure 17. The monthly average loss in the efficiency due to dust in Baghdad for fixed modules at tilt angles (15^o, 30^o, 45^{o}and 60^o).

SHIMADZU SALD-2101 (SALD-2101-WEA1:V1.20)

(File Name)
(Sample ID) m
(Date)
(Sample #)
(Time) 00:41:08

R Index=1.60-0.10i	Median D : 9.116	Mean V : 6.218	10.0%D : 0.798	S Level : 0
	Modal D : 17.222	Std Dev : 0.540	50.0%D : 9.146	D Func :None
			75.0%D : 16.800	D Shift : 0



	Diam x(μ m)	Cum Q_3(%)	Diff q_3(%)		Diam x(μ m)	Cum Q_3(%)	Diff q_3(%)		Diam x(μ m)	Cum Q_3(%)	Diff q_3(%)
1	1000.000	100.000	0.000	18	28.988	97.684	6.516	35	0.840	10.462	2.417
2	811.975	100.000	0.000	19	23.538	91.167	9.847	36	0.682	8.046	1.696
3	659.303	100.000	0.000	20	19.112	81.321	10.400	37	0.554	6.350	2.213
4	535.337	100.000	0.000	21	15.518	70.921	9.276	38	0.450	4.137	2.846
5	434.680	100.000	0.000	22	12.601	61.645	7.857	39	0.365	1.291	1.177
6	352.949	100.000	0.000	23	10.231	53.788	6.834	40	0.297	0.114	0.112
7	286.586	100.000	0.000	24	8.308	46.953	5.774	41	0.241	0.002	0.002
8	232.700	100.000	0.000	25	6.746	41.179	4.472	42	0.196	0.000	0.000
9	188.947	100.000	0.000	26	5.477	36.706	3.547	43	0.159	0.000	0.000
10	153.420	100.000	0.000	27	4.447	33.160	3.389	44	0.129	0.000	0.000
11	124.573	100.000	0.000	28	3.611	29.771	3.422	45	0.105	0.000	0.000
12	101.150	100.000	0.000	29	2.932	26.348	3.176	46	0.085	0.000	0.000
13	82.131	100.000	0.000	30	2.381	23.172	3.081	47	0.069	0.000	0.000
14	66.689	100.000	0.000	31	1.933	20.091	2.881	48	0.056	0.000	0.000
15	54.149	100.000	0.008	32	1.570	17.210	2.276	49	0.046	0.000	0.000
16	43.968	99.992	0.224	33	1.275	14.934	1.984	50	0.037	0.000	0.000
17	35.701	99.767	2.083	34	1.035	12.950	2.488	51	0.030	0.000	0.000

Sampling Mode : Manual
Refractive Index : 1.60-0.10i
Signal Accumulation Count : 1
Interval (sec) : ___ Signal Averaging Count : 64
Max of Absorbance Range : 0.200
Min of Absorbance Range : 0.010
Ultrasonic Dispersion Time (sec) : ___
Waiting Time After Ultrasonic Dispersion(sec) : ___

Figure 18. The relation between particle diameter and normalized particle amount