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Evaluation of the Effect of Dusty Weather on the Performance of Flat Plate Solar Collector

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ABSTRACT

In the present work, experimental study had been done for estimating the performance of flat plate solar collectorby scattering different amounts of duston the cover of the flat plate solar collector.The tests were done with closed loop system.The absorber plate is made of Aluminum (80cm) and (180cm) dimensions coated with selective paint (absorption = 0.92 and emissivity = 0.28). In this study, the system has been operated in Bagdad city and orienteddue south with (43°) tilt angle. The results show that the daily efficiency reduced (12%) when the applied dust intensity on the collector cover reaches (10 ml/m²) during the test daysand reducing covertransmittance to (15%).

KEYWORDS: Flat plate solar collector, solar radiation, dust cover.

Nomenclature (English symbols):

A_C**:** Collector area.m^2W: Collector width. m$\dot{V}_w$:Volume flow rate. l/min
b: Time increment. s $\dot{m}_w$:Water mass flow rate. kg/s **Greek symbols**
C_W: Specific heat capacity of water. J/kg.°CQ_u: Useful energy rate. Wρ_w: Water density. Kg/s
F_RU_L: parameter of losses. W/m^2.°CQ_{ud}: Daily Useful energy. kJη_i: Instantaneous efficiency.
F_R (τα): parameter of gain.T_a: Ambient temperature. °Cη_d: Daily efficiency.
L: Collector length. mT_i: Inlet temperature. °C
G_T: Solar radiation. W/$m^2$$T_o$: Outlet temperature. °C
G_T*:Solar radiation below the cover (W/m^2) T.R_i: Transmittance reduction.
G_{Td}: Daily solar radiation. W/m^2 T.R: Daily transmittance reduction.

INTRODUCTION

Dust consists of particles in the atmosphere that comes from various sources such as soil, dust lifted by weather. Dust affects any system using solar energy through gathered of the dust on the cover of the solar collector and also in dusty weather through conversion of part of beam radiation to diffuse radiation. So there are many techniques for removing dust from surface of solar collector manually or automatically [1].

The amount of solar radiation that reaches earth surface be less than the radiation outside the atmosphere, because it is exposing to the scattering and absorption by atmosphere components. The solar radiation divided into the beam, diffuse and ground reflected solar radiation, and can be computed after estimating the time and position [1].

Many researchers have studied these subjects in the past. Fabio Struckmann [2] presented a precise and detailed analysis of a solar flat plate collector is quite complicated because of the many factors involved. From

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through combine a number of the most important factors into a single equation and thus formulate a mathematical model which will describe the thermal performance of the collector in a computationally efficient manner.Hamdy *et al*. [3] has researched the effect of dust on the transparent cover of solar collectors where found that increasing the accumulation of dust on the surface of the cover leads to reduce the permeability of solar radiation and thus affecting the performance of solar collector work.Vettrivel and Mathiaragan[4] studied experimentally performance of flat plate solar collector. The researcher designed flat plate collector double cover and adopted in the experimental analysis on the difference between the solar energy absorbed and emitted (losses). The researcher concluded thatthe efficiency of flat plate collector is found to increase with increasing ambient temperature and the performance of any solar collector is largely affected by various parameters such as glazing (single glazing and double glazing), absorber plate, and heating pipes. Sayigh [5] studiedeffect of dust on flat plate collectors using six flat plate collectors forming three pairs were tested. The first pair was placed at 60 ^{o}, the second pair was placed at 30^{o} and the third pair was placed at zero degree (horizontal).The researcher concluded that the dust detrimental effect on the solar collectors especially those which receive less beam radiation.

2. Experimental Work:

Experimental testswere carried out on solar test rigwhich is consisting of many parts: flat plate solar collector, thermal storage tank,extra tank with water pump, water circulation pump, connecting pipes with valves and measuring devices (water flow meter, solar power meter, temperature digital thermometer, and thermocouples), as shown in figure (1). Also volumetric flask was used to determining the amount of the dust. In parallel, a piece of glass is used and receives same amount of dust covering, for external measuring of the cover transmittance, as shown in figure (2).

Flat plate solar collector used during test, consists of absorber plate (Aluminum)with 0.5 mm thickness dimensions of 80cm x 180cm.Coated by selective paint which has absorption rating of (0.92) and a low emissivity rating of (0.28) [6], with one glass cover. Also it consists of ten equally spaced parallel aluminum pipes of (2 cm inner and 2.1 cm outer) diameters and (180cm) length. The distance between each centerline of adjacent tubes is (10cm). These pipes are connected with two headers, one at each end. The headers are made of Aluminum of (3cm) outside diameter and (85cm) length. The collector box is made of Aluminum of (12 cm) height thick with an area of (87 cm x 193 cm).The absorber plate is thermally insulated from bottom side by glass wool (30 mm thickness, 0.04 W/m.$^{\circ}$C thermal conductivity) and as well as the sidesare insulted by contains on armaflex insulation (13mm) thickness and (k=0.037 W/m.$^{\circ}$C).

The thermal energy that received byflat plate solar collector was stored in (100 l) water storage tank. The tank is cylindrical shaped, made of galvanized steel with (40cm) outside diameter and (80 cm) height and insulated by (13mm) thickness and (k=0.037 W/m.$^{\circ}$C) armaflex insulation [7].Also an extra tank is used to collect the water during the experiment. In order to circulate the water in the system, a circulation pump was used with (1.5 l/min) water flow rate [8]. Plastic pipes with 15 mm (0.5 in) diameter have been used to connect the system parts.

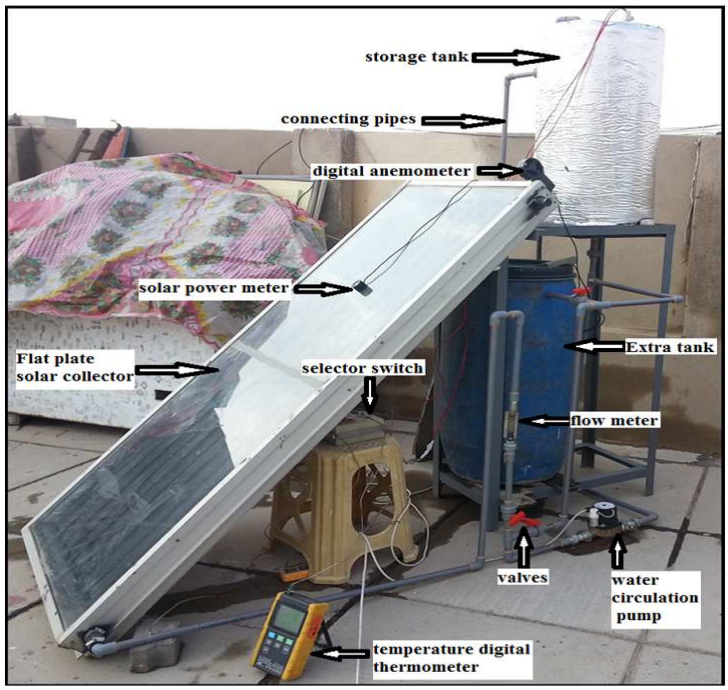

Fig. 1: Photography photo of the test rig

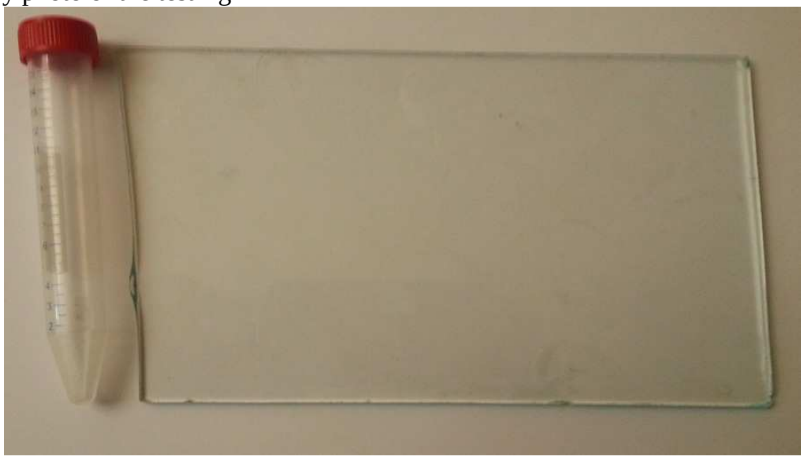

Fig. 2: Volumetric flask and small piece of glass

A three thermocouples of type (k) were used in the present work formeasuring ambient temperature,collector inlet water temperature and outlet water temperature. All thermocouples were connected with selector switch connectedto a digital thermometer type (BTM-4208SD)**.** Water flow rate and solar radiation were measured by flow meter and solar power meter respectively.Test rig was installed in Bagdad city with (33.3^o) latitude and (43^o) tilt angle an oriented due south. Experiment tests were made in sunnydayswith moderate wind speed. For obtaining more accurate results, the time interval taken at every half-hour. Table (1) shows the parameters of experimental test in this study.

Table 1: experimental operation modes [8]

$\dot{V}_w$: 1.5 l/min C_W: 4190 J/kg.˚C ρ_w: 1000 kg/m^3 A_C: 1.44 m^2			
NO.	Dust intensity (ml/m^2)	date	Operatingperiod
1	0	29-1-2016	7:30-17:00
2	2	7-2-2016	7:30-17:00
3	4	5-2-2016	7:30-17:00
4	6	12-2-2016	7:30-17:00
5	8	13-2-2016	7:30-17:00
6	10	14-2-2016	7:30-17:00

3. Theoretical Part:

The water flow rate can be calculated by [8].

$$\dot{m}_w = \rho_w \,.\, \dot{V}_w \quad (1)$$

The collected useful energy during half an hour is calculated by [8].

$$Q_u)_{water} = \dot{m}_w \,.\, C_w.\,(T_o - T_i) \quad (2)$$

Trapezoidal rule has been used to calculate the daily useful energy (Q_u) [9].

$$Q_{ud} = b\left[\frac{Q_{u1}}{2} + Q_{u2} + Q_{u3} + \cdots + \frac{Q_{un}}{2}\right] \quad (3)$$

Also by trapezoidal rule has been used to calculate the daily solar radiation (G_{Td}) [9].

$$G_{Td} = A_c.\,b\left[\frac{G_{T1}}{2} + G_{T2} + G_{T3} + \cdots + \frac{G_{Tn}}{2}\right] \quad (4)$$

The instantaneous collector efficiency (η_i)can be calculated by [1].

$$\eta_i = \frac{Q_u}{A_c.G_T} \quad (5)$$

The daily collector efficiency (η_d)can be calculated by[1].

$$\eta_d = \frac{Q_{ud}}{G_{Td}} \quad (6)$$

The average different temperature can be calculated by [8].

$$\Delta T_{av} = \frac{\sum_1^i (T_o - T_i)}{i} \quad (7)$$

Transmittance reduction ($T.R_i$) can be calculated by [3].

$$T.R_i = 1 - \frac{G_T^*}{G_T} \quad (8)$$

Also daily transmittance reduction ($T.R$) can be calculated by [3].

$$T.R = \frac{T.R_i}{i} \quad (9)$$

Where:
i:number of recorded readings in one day (20 times)

RESULTS AND DISCUSSION

The system is operates during the test days from 7:30 to 17:00. The parametric results were calculated from the measuring data and scheduled in Table (2).

Table 2: the final test results.

Dust intensity (ml/m^2)	T.R	Q_{ud} (kJ)	G_{Td} (kJ)	η_d	ΔT_{av} (˚C)	ΔT_{max} (˚C)
0	0.214844	19584.54	30750.91	63.68%	9.191	5.175
2	0.220737	19068.83	29718.14	64.16%	9.129	5.064
4	0.25543	18062.01	30020.83	60.16%	8.197	5.052
6	0.295837	18262.39	29463.74	61.89%	8.305	4.848
8	0.337229	16943.93	29038.84	58.35%	7.998	4.509
10	0.363237	15143.64	29304.41	51.67%	7.486	4.026

Figure (3) shows a relation between the behaviors of transmittance reduction with time for various amounts of dust. It is observed that the percentage reduction in transmittance increased with increasing dust cover intensity. Also, the reduction for each intensity is higher near sunrise and sunset. This is due to the attenuation nature of the solar radiation caused by dust (the dust scattered more beam radiation, which is low at the day beginning and ending hours).

Figure (4) shows that as the dust amount on the cover increasing the transmittance of the solar radiation is reduces. The reason for this is, the dust based on particles work on blocking solar radiation through absorption and emission part of solar radiation to the ambient.

Also, the increases in the amount of dust leads to reduce the daily useful energy, daily efficiency and temperature different, as shown in figures (5), (6), (7) and (8).

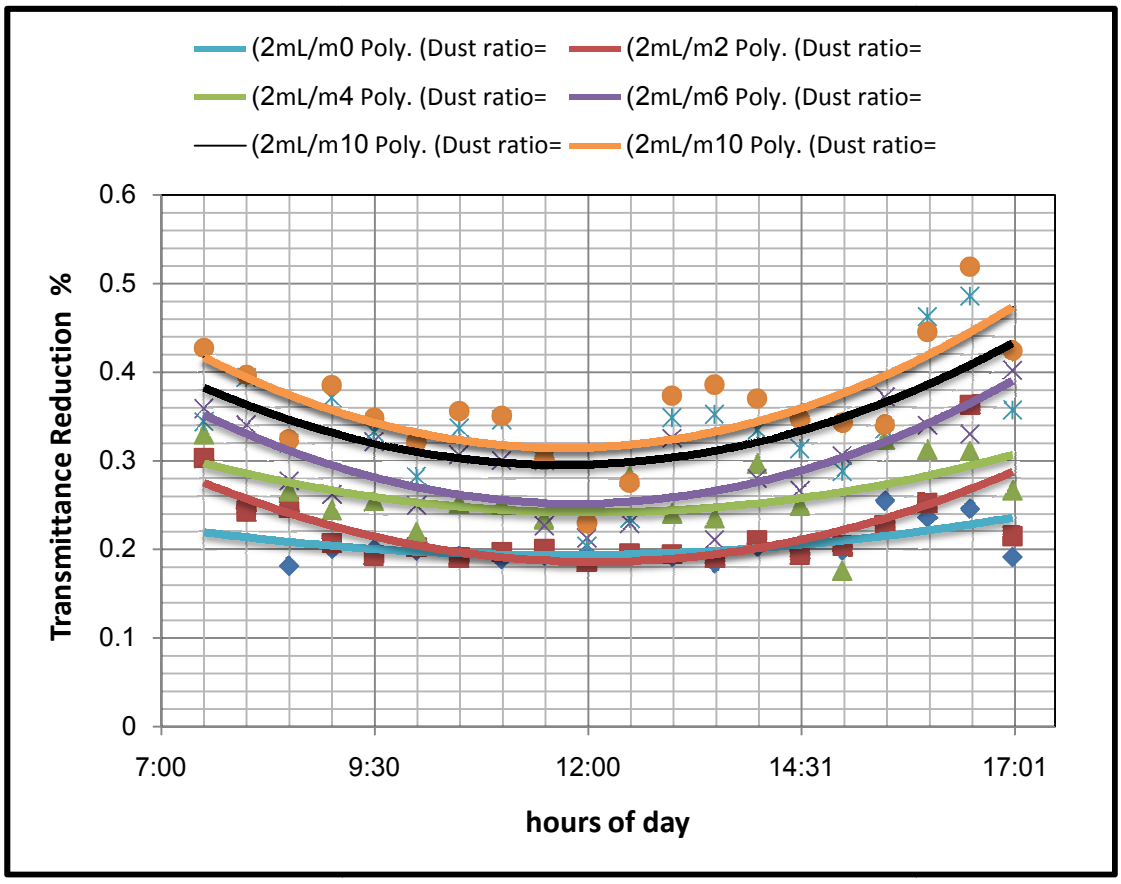

Fig. 3: transmittance reduction with hours of day

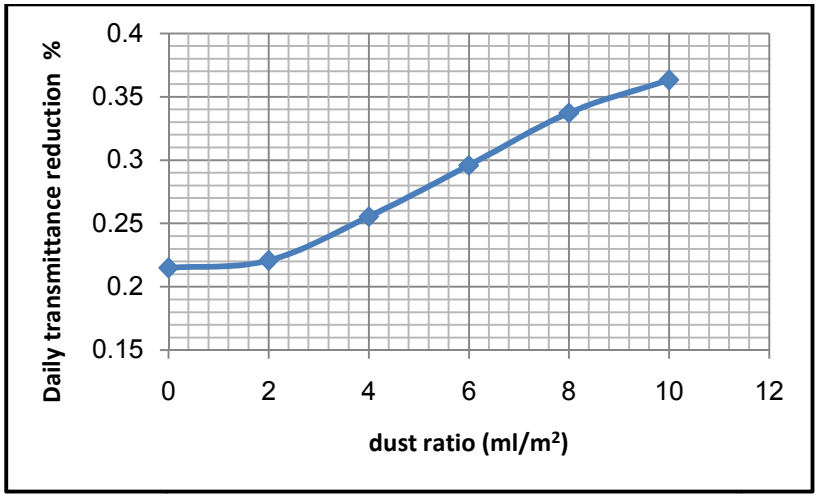

Fig. 4: daily transmittance reduction for different amounts of dust

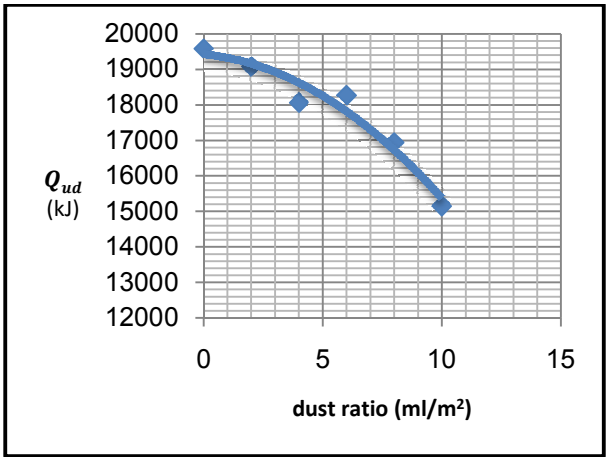

Fig. 5: daily useful energy for amounts of dust.

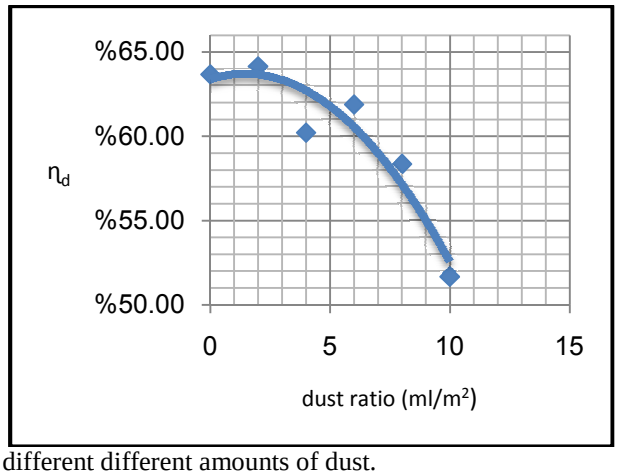

Fig. 6: daily efficiency for different different amounts of dust.

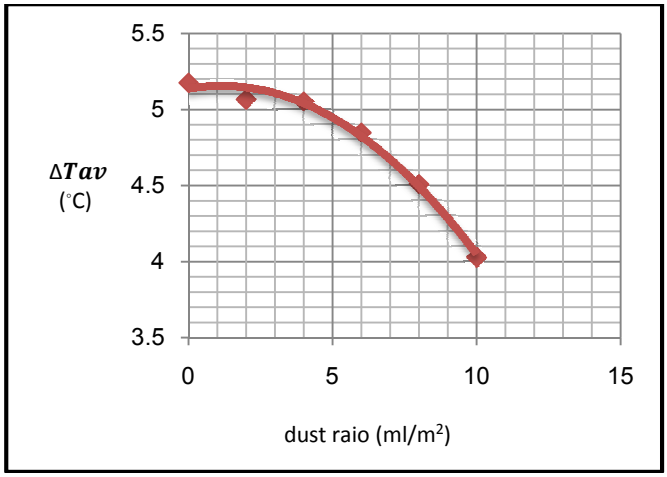

Fig. 7: average different temperature for different amounts of dust.

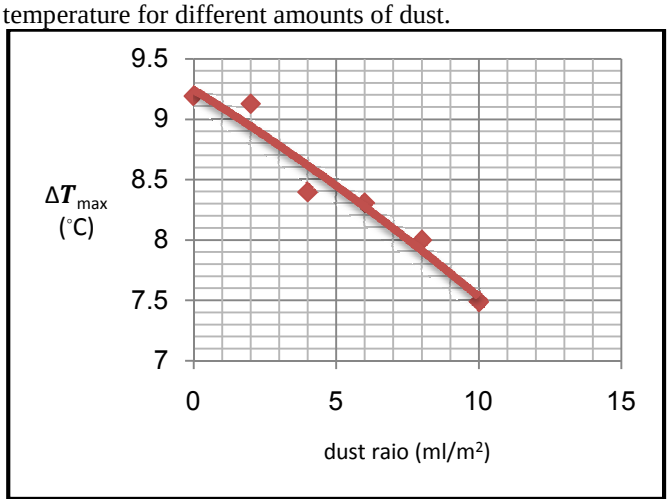

Fig. 8: maximum different temperature for different amounts of dust.

Conclusions:

The transmittance reduction directly proportional with the dust intensity.Increasing dust cover intensity reducing the maximum and average daily temperature difference. These results reflected on the useful energy. Where the maximum reduction in the useful energy reaches (22%) when the dust cover intensity reaches (10 ml/m^2). As a consequence, increasing in dust intensity by (10 ml/m^2) leads to decrease daily efficiency to (12%) and reducing covertransmittance by (15%).

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