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DUST EFFECT ON EVACUATED TUBE SOLAR COLLECTOR IN MINQUIN, CHINA

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ABSTRACT: *In the present work, the effect of dust on the efficiency of an Evacuated Tube Solar Collector was investigated experimentally and theoretically. Experiments were performed on Evacuated Tube Solar collectors exposed to the ambient winter season in Minquin, China from 8 to 18h00. A mathematical model used for two modules, one present dust accumulation of 0 mg/m^2 (clean collector) and 2.6E-05 mg/m^2 (dusty collector with 15.24 % of the reduction in radiation). The ASHRAE Standard 93-86 was used to calculate the efficiency. The results show in comparison with and without dust, the daily optical efficiency decrease of 17.6 % and the average stagnation temperature decreases from 7.3^{0}C–1.8^{0}C in a solar collector with 2.6E-05 mg/m^2.*

KEYWORDS: Dust, Efficiency, Evacuated Tube Solar Collector, Minquin-China.

INTRODUCTION

Life is directly affected by energy and its consumption. With the growing significance of environmental issues, clean energy generation has become increasingly important. Solar radiation is one of the cleanest energy sources, but their disadvantage it can't persist continually for long durations at a given location. Seasonal production is not the same because of climate changes and environment effect. Therefore, the presence of dust and how to clean solar energy equipment is the main problem facing the researchers in the fields of the use of the solar energy.

Fifty years ago, (Garg,1972) studied the effects of dirt on the transmittance of solar radiation on various glass plates and plastic films which are used as a transparent cover for flat-plate collectors with different title angle. Finally found that dirt correction factor for glass plate inclined at an angle of 45^0 from the horizontal is 0.92. In work of (Sayigh, 1978) studied a detailed investigation on the effect of dust on solar flat-plate collectors. The experiment comprised seven flat plate collectors, with six arranged in pairs and subjected to various inclinations of 0^0, 30^0, and 60^0, with the seventh collector inclined vertically at 90^0. In each pair, one collector was cleaned while the others were kept uncleaned. The comparison was between the amount of absorbed solar energy of the unclean plates and to that of the cleaned ones. It indicated a dust collection of about 2.5 g/m^2 /day between April and June. (Adel and Hegazy, 2001; Elminir HK and Ghitas, 2006; Jia Yun Hee and Lalit Verma Kumar, 2012) investigated about Dust accumulation on glass plates with different tilt angles. The horizontal accumulates much than a vertical one. Referred to a collection of data obtained, they founded

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an empirical correlation of ±6%, which allows for the calculation of the glass transmittance percent in reduction in for a given tilt angle after a number of days of exposure to the atmosphere.

The output production of solar energy in the dusty conditions is a big challenge facing researchers, and several articles have been conducted for this purpose. (Mastekbayeva and Kumar, 2000) discussed the influence of dust on the transmittance of a 0.2-mm-thick low-density polyethylene (LDPE) glazing commonly used in solar air heaters. For one-month period shows that dust accumulation of 3.72 g/m^2 can reduce the global transmittance radiation of the glazing from about 87.9% to 75.8%. (Ahmad and Adel, 2009; Shaharin, 2011; Hai Jiang and Lin Lu, 2011) carried out the experimental and theoretical to investigate the effect of sand dust concentration on the efficiency of PV panels. It indicated that as dust particles present on the panel surface up to a concentration of $1g/m^2$, the short circuit current and the maximum output power start to decrease.

Most panels are designed with the intention of correct operation for over two decades; however, their performance time is reduced by environmental conditions of the area especially with settling the dust. At that time In Malaysia (Sulaiman, 2011) proved the effect of dust accumulation on the performance of solar panels, but the results were not quantified. He used dust particles on solar panels with a constant-power light source, to determine the output electrical power generated and efficiency. It found that dust on the surface of the photovoltaic solar panel can reduce the system's efficiency up to 50%.

As more problem of dust comes more complicated, some research discovered theoretically model based on the experiments and recorded data on period of time. (Niel and Beattie, 2012) developed models based on experimental data and indicate that the reduction in the free fractional which described by an exponential decay resulting from the formation of clusters of particles. (Jianbin Zang and Yawei Wand, 2011) analyzed the effect of the shape and size distribution on the transmittance and verify it by test data of relevant references. They also showed that this computation model can accurately calculate the effect of particles deposition on the transmission of photovoltaic panels. (Kaldellis and Kapsali, 2011) proposed a theoretical model using the effect of red soil, limestone and carbonaceous fly-ash particles on the energy performance of PV installations. An active cooling technique method which contains the using of nano-fluid and heat exchanger at the surface of PV was presented by (Hussein and Numan, 2017). Nano-fluid ($Zn\text{-}H_2O$) with five concentration ratios (0.1. 0.2, 0.3. 0.4 and 0.5%) was used in this article. The temperature of the solar panel reduced from 76 t0 70^0C which causes increase the electrical efficiency.

Few studies considered the effect of dust accumulation on the performance parameters of solar thermal collectors, such as heat gain rate and thermal efficiency. (Mohammad, 2015) investigated the effect of dust on the glass cover of solar energy conversion systems. He founded that fractional reduction of the useful heat gain rate due to dust accumulation during a period of one and two months is 11.4% and 17% respectively. The percentage decrease in the efficiency during the same duration periods is 4% and 6.1% respectively. (El Nashal, 1994) studied the performance of evacuated tube collectors with dust accumulation over periods extending from 30 days to a whole year. He used two blocks and each one consists of 168 collector panels connected together in a series/parallel arrangement. Each panel contains $1.75m^2$ of absorber area.

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The importance of the current article is because of the fact that Minquin county weather is characterized by high level of solar radiation. Furthermore, it is known for hot and dust weather especially in the days of summer. So, the efficiency of collectors will be low because of high temperature and dust disposition. The present paper studies the effect of dust accumulation on the instantaneous Efficiency, Solar Radiation, inlet and an Outlet temperature of evacuated tube solar collectors. First, the steady-state tests on the thermal efficiency of evacuated tube solar collectors without dust had been performed according to the experiments. Finally, a Theory model is calculated and able to evaluate the efficiency of an Evacuated Tube Solar Collector when it is affected by a dust.

Experimental setup

The evacuated tube solar water heater semi-continuous process was experimentally investigated at Minquin, China (latitude $38^0$34'N, Longitude $103^0$3'E). The relative collector position is shown in Fig.1. The specification of the collector used in this investigation is given in Table 1.

Table 1: Specification: Evacuated Tube Solar collector

1.	Solar water tank capacity: 400L
2.	Heating collecting type: Glass Evacuated Tube Solar Collector
3.	Vacuum tube: ⦰58/1800mm, 30 pieces of solar tube
4.	Output hot water temperature: 45^0C-95^0C
5.	Inner Storage Tank Material: Food-grade stainless steel SUS304-2B
6.	Tank Exterior Shell Material: SUS304 Stainless Steel 0.4MM

Figure 1: Evacuated Tube Collectors Used for Experiments

This experiment was conducted during the winter season, where different amount of irradiance was considered in order to study the behavior of evacuated tube solar collector system, in

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addition to the influence of dust on the mount of their efficiency. A concept of ASHRAE Standard 93 used in measuring collector energy gained. The experiment outcomes indicate the effectiveness of the proposed method in all situations. There are number of instruments are utilized here for monitoring purpose includes two pyranometers (Kipp & Zonen CM11) to measure irradiance of the panels (daily accuracy of this pyranometer is ±2% and it meets the requirements for this experiment), the computer records all data with a time step of 10s by Agilent Hp34970A data acquisition instruments. The solar collectors are at 45^{o} tilt angle. Calibrated Pt-100 temperature sensors were used to measure the inlet and outlet water-based fluid temperatures of the Evacuated Tube Solar collectors and reservoir tank. The tank is probably to store up to 400litres of water. The pyranometer, wind velocity, and ambient temperature probe sensor are all calibrated against reference instruments and supplied by Soldata Instruments.

Theoretical Model

When considering solar collector under steady state, the absorbed solar radiation equals the rate of heat gain from solar collector plus the rate of heat loss from absorber surface. The rate of useful heat from the solar collector is:

$$Q_u = mC_p(T_0 - T_i) \quad \textbf{(1)}$$

The rate of useful energy extracted by the collector, expressed as follows:

$$\mathrm{Q_u = Q_i\text{-}Q_o = A_c(\tau\alpha)G_T\text{-}U_LA_c(T_c\text{-}T_a)} \quad \textbf{(2)}$$

The maximum possible useful energy gain in a solar collector at inlet fluid temperature is:

$$Q_u = F_RA_c[(\tau\alpha)G_T - U_L(T_i - T_a)] \quad \textbf{(3)}$$

Where Fr is the collector heat removal factor

$$F_R = \frac{mC_p(T_0 - T_i)}{A_c[(\tau\alpha)G_T - U_L(T_i - T_a)]}$$

The collector efficiency can be calculated by integrating hour step efficiency and is expressed as: $\eta = F_R(\tau\alpha) - F_RU_L\frac{(T_i-T_a)}{G_T}$ **(4)**

Where:

- A_c is Evacuated tube solar collector absorber area, m^2
- F_R is collector heat removal factor
- G_T is the global intensity of solar radiation, W/m^2
- T_C is collector average temperature, ^0C
- T_0 is outlet temperature, ^0C
- T_i is inlet temperature, ^0C
- T_a is ambient temperature, ^0C
- T_h is Highest temperature, ^0C

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- T_{hd} is Dusty Highest temperature, ^0C
- G_T is the Global intensity of solar radiation, W/m^2
- G_{Td} is the dusty Global intensity of solar radiation, W/m^2
- U_L is collector overall heat loss coefficient, $W/^0C/m^2$
- Q_i Collector heat input, W
- Q_u Useful energy gain, W
- Q_0 heat loss, W
- m mass flow rate of fluid through the collector, kg/s
- C_p Heat capacity of water, kJ/kg^0C
- η_c clean collector efficiency
- η_d Dusty collector efficiency
- F_d is Heat transmittance ratio (clean collector transmittance over dusty collector transmittance)
- τ_c is Clean transmission coefficient of glazing
- τ_d is Dusty transmission coefficient of glazing
- α is The absorption coefficient of an evacuated tube

(Khushaboo and Pooran, 2017) conducted the effect of dust with a Parabolic and Tube. Reduction in radiation through a reflective surface is determined by experiments and represents the relation between dust particle concentrations with the reduction in irradiation value. Simulation setup consists of a collector have 30 piecesφ58 × L1800 all-glass vacuum tubes. We founded an Equation used for determining the reduction in radiation value with a concentration of dust particles.

$$f(x) = 0.774\text{E} - 07\text{x}^2 + 0.516\text{E} - 06\text{x} + 0.516\text{E} - 06 \quad \textbf{(5)}$$

Where y is concentration of dust particle in gm/m^2 and x shows the percentage reduction in radiation

Value $\left(1 - \frac{\tau_d}{\tau_c}\right)$ %.

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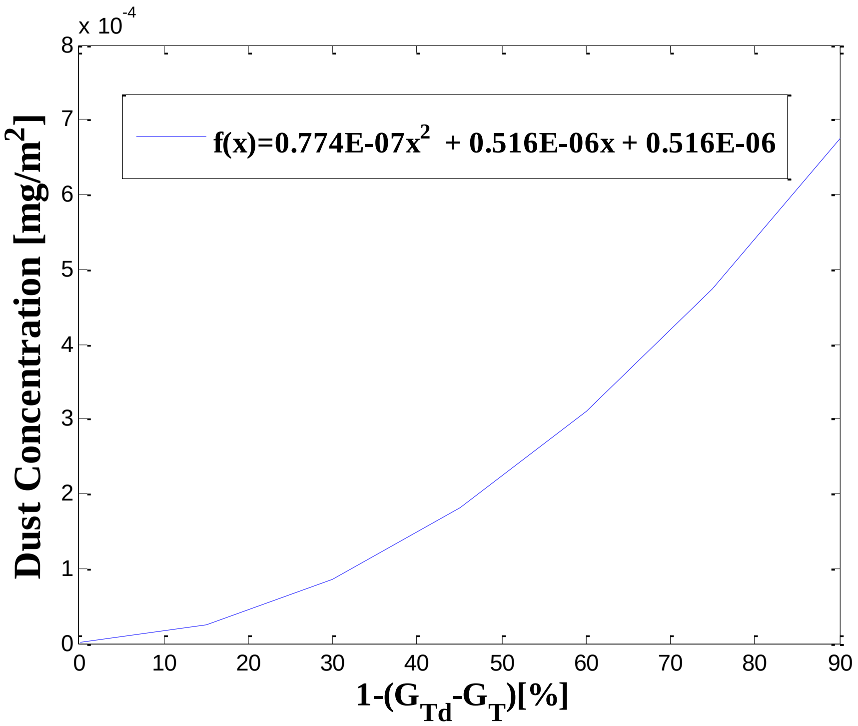

Figure 2: Dust Concentration Vs percentage reduction in radiation

By assuming the collectors operate constantly at steady-state standard conditions, and heat loss coefficient U_L is constant during the whole day, the optical efficiency and temperature rise can be described separately by:

$$F_R(\tau\alpha) = \eta + F_R U_L \frac{(T_i - T_a)}{G_T} \quad \textbf{(6)}$$

$$\Delta T = T_0 - T_i = A_c[F_r(\tau\alpha)G_T + F_r U_L(T_i - T_a)]/C_p m \quad \textbf{(7)}$$

Therefore, the efficiency difference and temperature rise difference for both collectors with and without dust can be calculated separately from Eq. (6,7 and 5):

$$\eta_c - \eta_d = F_r(\tau\alpha)(1 - F_d) \quad \textbf{(8)}$$

$$\Delta T_c - \Delta T_d = F_r(\tau\alpha)(1 - F_d)G_T A_c/C_p m \quad \textbf{(9)}$$

RESULT AND DISCUSSION

The tests have performed around at 8 to 18h00. The experimental results are presented in the form of graphs and equations that will be used in determining the solar collector efficiency against a reduced parameter temperature ($\frac{(T_i - T_a)}{G_T}$). Fig.2 presents an example of typical recorded data for one day in December at Minquin county. All presented data were divided into several test runs (each test run was chosen 10 sec). MATLAB R2014 is used to analyze the result. The maximum ambient and global radiation reach its maximum value of 12.2^{0}C and 944.6W/m^2 at 13h00 while inlet and outlet temperatures of 60.1^{0}C and 60.9^{0}C at 16h00

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respectively. The data presented in the figure below satisfy the necessities presented in ASHRAE Standard 93-86.

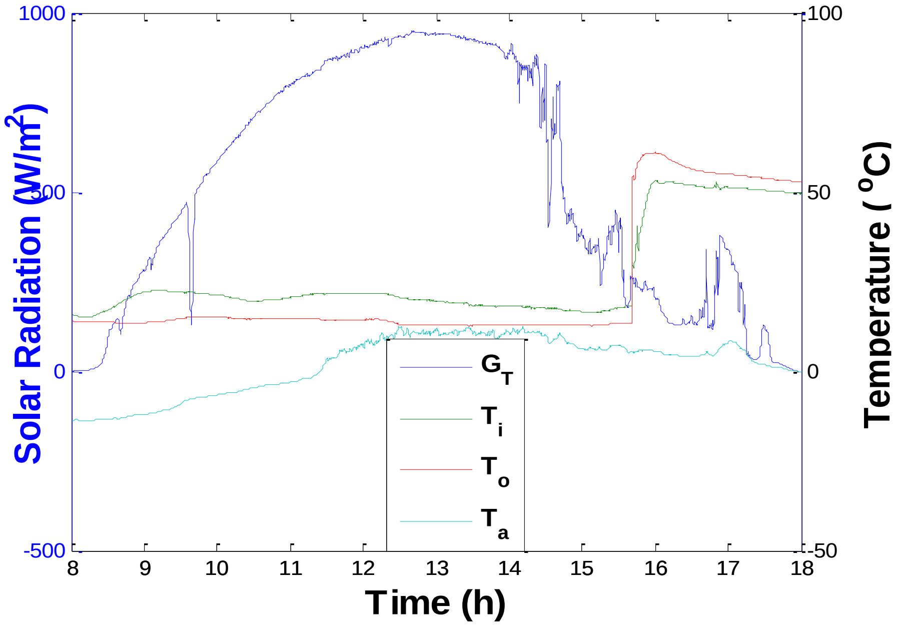

Figure 3: Recorded data in one of the test days

Efficiency Calculation

In order to present the effect of dust on the Evacuated Tube Collector water heater performance, a mathematical model is proposed with some experiments was carried out with hot water withdrawal from the collector. It is noticed that always there is a probability in variations of weather conditions such as wind velocity, solar radiation, and ambient temperature, which is causing the medium drop and rise thermal efficiencies. The solar collector was tested for two modules, one present dust accumulation of 0 mg/m^2 (clean collector) and 2.6E-05 mg/m^2 (dusty collector with 15.2470 % of the reduction in radiation). By integrated eq. (1) over until day, it is found that thermal efficiency of the dust collector is lower than a clean collector. The total daily thermal efficiency was 23.58% for the clean collector and 5.89% for a dusty collector.

Fig.3 shows the variations of collector efficiency with temperature parameters $\left(\frac{(T_i - T_a)}{G_T}\right)$ for each module as shown in Eq. (4 and 5). When the ambient temperature equals the inlet temperature, the system efficiency is maximum. This occurs at the intersection of the line with the vertical axis. At the intersection of the line with the horizontal axis, system efficiency is zero. From the results of the experiments and calculation, the relationship expressed as:

Clean collector:

$$\eta_c = 57.08\text{-}1.8879\left(\frac{T_i\text{-}T_a}{G_T}\right) \quad \textbf{(10)}$$

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Dusty collector:

$$\eta_d = 14.25 - 0.4720\left(\frac{T_i - T_a}{G_T}\right) \tag{11}$$

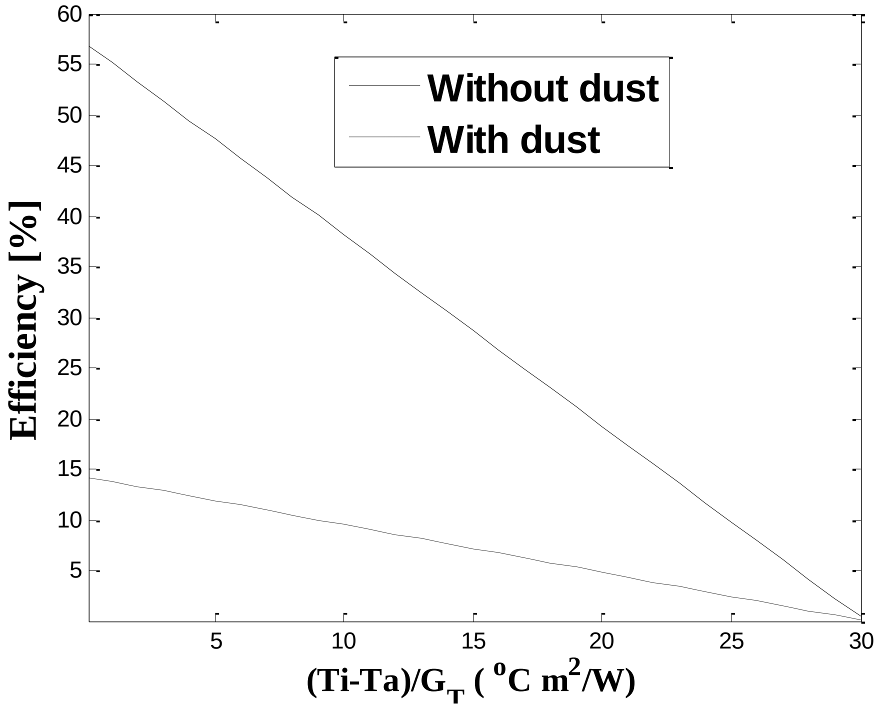

Figure 4: Dust effect on the relationship between thermal efficiency and the (Ti -Ta)/G_T

The experimental data are fitted with linear equations to provide the characteristic parameters of the evacuated tube solar water collector in order to compare the effect of various dust accumulation. In compare Eq. (8,9) with (5), it found that $F_R(\tau\alpha)$and F_RU_L equal to 57.08 and 1.8879 for the clean collector and 14.25 and 0.4720 for dusty collector respectively. When a dust accumulates on solar collector their efficiency reduced very speedily as temperature increases due to the decreasing of the solar irradiation that absorbed by the solar collector.

Table 2: $F_R(\tau\alpha)$and F_RU_L of the evacuated tube collector at various dust disposition.

Module	F_RU_L	$F_R(\tau\alpha)$
1. Clean collector	1.8879	57.08
2. Dusty collector(5g/m2)	0.4720	14.25

Highest collecting temperatures

Highest temperature reflects the highest collecting temperature that the solar collector reached under certain environmental conditions. This happens when efficiency equals to zero (T_i=T_a). The highest temperature from Eq. (4) is calculated as

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$$T_h = \frac{G_T F_R(\tau\alpha)}{F_R U_L} + T_a \quad \textbf{(12)}$$

The difference between the inlet temperature of the collector with and without dust can be calculated as:

$$T_h - T_{hd} = F_R(\tau\alpha)\,(1 - \mathrm{F_d})\mathrm{G_T}/F_R U_L \quad \textbf{(13)}$$

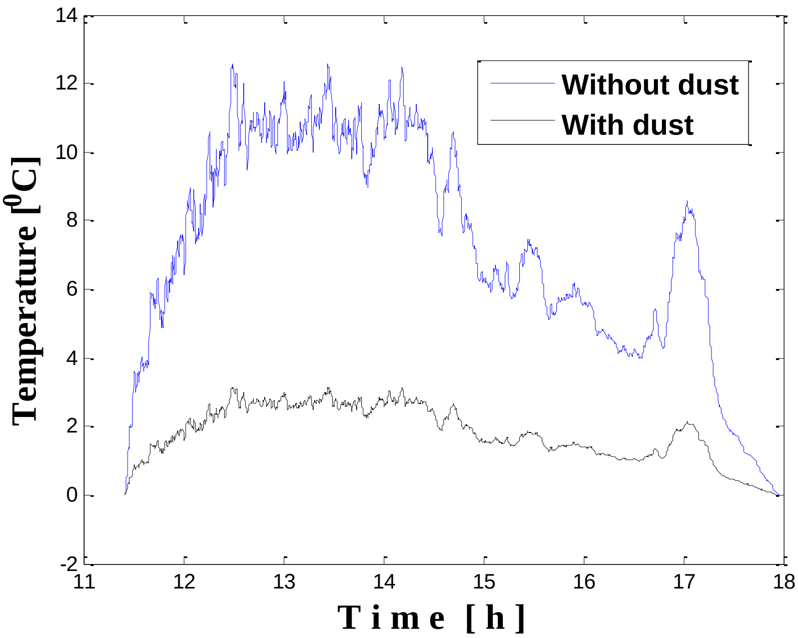

Figure 2: Experimental points in Highest temperature with and without dust

The stagnation temperature of the Evacuated Tube Solar Collector with and without dust is compared in Fig. 4. It can be found from Fig. 4, dust accumulation has an effect on the stagnation temperature, that is, it influences the heat-collecting quality in certain environmental conditions. The average stagnation temperature decreases from 7.3^{0}C–1.8^{0}C in a solar collector with 2.6E-05 mg/m^2. The difference between the stagnation temperature of the collector with and without dust increases from 11:30 am to 14:00 am until water medium reaches its boiling point. referred to the data of ambient temperature, inlet, and outlet temperature, and total solar irradiance, the optical efficiency with and without dust are calculated by Eq. (12).

CONCLUSION

The effect of dust on the efficiency and stagnation temperature of the evacuated tube collector was experimentally and theoretically studied. The effect of the dust on the outer surface of the collector is decreasing the thermal efficiency as a result of decreasing in the intensity of solar radiation. The previous results show that the daily efficiency with and without dust decrease to 23.58 to 5.89%. Daily average highest collecting temperature is 7.2^0, and 1.8^0 in a solar collector exposed for 2.6E-05 mg/m^2.

That is to say under certain environmental conditions, the heat-collecting temperature of the solar collectors without dust can reach temperature requirement. However, the heat-collecting temperature of the solar collectors with dust may be lower than the temperature requirement rather than reach it. It is recommended to clean everyday solar collector because it is shown as even 1g/m2 can reduce the output efficiency.

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