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A study of dust accumulating process on solar photovoltaic modules with different surface temperatures

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Abstract

This paper experimentally investigated the dust particle deposition onto solar photovoltaic (PV) modules to examine the effect of temperature gradient (thermophoresis) on dust accumulation process under different operating temperatures. The measured deposition densities of dust particles were found to range from 0.50 mg/m^2 to 0.84 mg/m^2 under the experimental conditions. The PV module with higher surface temperature has a lower density due to the effect of thermophoresis force arising from the temperature gradient between its surface and the surrounding air. Moreover, the energy output ratios were found to increase from 0.947 to 0.971 with the increase of temperature gradient, showing the same effect of thermophoresis force as particle deposition density. In addition, the most obvious temperature gradient for the thermophoresis force was found to be lower than 40^{o}C. This work will help the engineers to understand the reduced impact of high surface temperature of solar cells on dust particle deposition process.

Keywords: PV modules; Accumulated dust; Particle deposition; Thermophoresis

1. Introduction

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In recent years, renewable energy has been attracting much attention. In a variety of applications of renewable energy, solar photovoltaic (PV) power generation is the most widely used one because of its low cost and high efficiency. PV technology is to convert solar radiation into the electric power by the solar cell and the most common application form of PV technology is PV modules.

PV modules' performance is influenced by many environmental parameters. For example, the wind velocity has to be considered when considering the performance of one PV module outdoor [1]. Besides, accumulated dust is a significant parameter that will influence the energy conversion output of PV modules. In general, the accumulated dust will decrease the energy conversion efficiency because the dust particles scatter the solar radiation and reduce the light intensity reaching the PV modules. Such findings have been reported. Hottel and Woertz [2] have firstly reported that the average reduction in the United States is 1% every month. In addition, Mani and Pillai [3] have presented that the efficiency degradation is 32% in 8 months in Saudi Arabia. Furthermore, the efficiency reduction ranging from 17% to 65% under different tilt angles in one month in Kuwait has been reported due to local severe dust conditions [4].

When the PV module is generating electric power, its surface temperature will increase due to the heating effect. This effect will lead to a temperature gradient between the surface with high temperature and surrounding air with low temperature. However, the effect of this temperature gradient on particle deposition process has not been reported. To study the influence of this temperature gradient and to investigate this effect, controlled experiments need to be done in the laboratory. This paper aims to design an experiment to examine the relation between temperature gradient and dust accumulated process. A controlled experiment was introduced, and the weighting results were analyzed and the energy conversion efficiency was compared to study the effect. This work will help researchers and engineers to better understand the dust accumulated process and know when the dirt PV modules require cleaning.

2. Experimental methodology and materials

2.1 Experimental setup and materials

In this experiment, small identical monocrystalline silicon PV modules were chosen to be the tested samples and the identical size of these samples was 156mm×156mm. This size is the basic unit of common commercial solar cells. As mentioned above, for PV modules, the long-term operation under strong solar irradiance will cause the temperature rise of the solar cells and module surface as well. In order to simulate the temperature gradient between the PV module's surface and the surrounding air, a heating plate was used to heat these samples and keep the surface temperature unchanged during the experimental time. Moreover, the particle deposition experiment was conducted in a dark environment to avoid the heat produced by the PV samples in case of working. The temperature gradient between PV module's surface and surrounding air can reach up to 50 degrees when the solar radiation is strong. Considering the ambient temperature in the experiment being 20^{o}C, the heating temperatures in our experiment were ranging from 20^{o}C to 80^{o}C to study the effect completely.

The experimental facilities consist of a test chamber and an airborne particle generator. The size of the test chamber with anti-static layer on its inner surface was 1m×0.6m×0.6m. Standard test particles were injected into the chamber by the particle generator (PALAS GmbH, RBG 1000, Karlsruhe, Germany). The Arizona test dust (Powder Technology Inc., 0-10μm ATD, Minnesota, USA) was chosen to act as the natural dry dust.

2.2 Experimental procedure and protocol

The experimental protocol for each aerosol deposition process in the chamber was summarized as follows. After measuring the temperature of the chamber, in order to keep the chamber aerosol deposition steady, the indoor air-conditioning system was turned off. Then, the heating plate was placed into the chamber with one PV module. When all the experimental facilities were well set, aerosol generator was turned on to inject dust into the chamber for about 20 minutes. Then, aerosol particle would naturally deposit onto the sample glasses placed in the center floor of the chamber. To offer sufficient dust for deposition process, the injection procedure was repeated twice.

After 18 hours, it can be assumed that the particle deposition process was finished and the accumulated dust didn't add up. The heating plate was turned off and the PV samples cooled down until the surface temperature reaching the ambient temperature of 20^{o}C. Then the samples were sent to the indoor environmental quality laboratory (IAQ Lab) for dust weight measurement. The dust was measured by a high-accuracy digital microbalance (Precisa, Model 40SM-200A) in a clean container.

Afterwards, the solar simulator was turned on and the illumination intensity was to remain unchanged. PV modules were placed at the center under the irradiation of the solar lamp and the output power results were analyzed by an I-V tracker and a computer program which was called MP-160. Next, the accumulated dust was cleaned away by a special clean cloth and the weight and the energy performance were recorded by the same process as described before. Then the heating temperature was changed and the identical processes were repeated for each scenario.

3. Results and discussion

3.1 The results of particle deposition density

Table 1 Particle deposition densities under different surface temperatures

Surface temperature (°C)	Particle deposition density (mg/m^2)
20	0.85
30	0.80
40	0.73
50	0.65
60	0.58
70	0.54
80	0.50

Table.1 shows the particle deposition densities of identical PV modules with different surface temperatures. In summary, the particle deposition densities range from 0.50 mg/m^2 to 0.85 mg/m^2. When the surface temperature equals to surrounding temperature, surface density is the highest. However, it can be found that the particle deposition densities are decreased with the rise of surface temperature. So, the PV module with highest surface temperature has the lowest particle deposition density. The reason for this phenomenon is that the particle deposition process was influenced by a force which was called thermophoresis force. This force arises from the temperature gradient between atmosphere and the PV module's surface. Furthermore, the direction of thermophoresis force is from high temperature area to low temperature area. So the role of this force which is played in particle deposition process is pushing the particle moving from an area with a high temperature to a lower temperature area. There is no doubt that dust accumulated velocity is lower on the PV module's surface when it was working at the same time. What's more, the density decreases slowly at first. When the surface temperature is above 40°C, the result decreases dramatically. Finally, the descent speed slows down after the surface temperature is above 60°C. Changed falling speed of the density line results from that thermophoresis force affects the particle deposition process greatly when the temperature gradient is lower than 40°C. In contrast, if the temperature gradient is higher than the best section, the effect of thermophoresis force is small in comparison with other important forces, such as gravity and Brownian movement force.

3.2 The results of energy performance

Energy performance is another parameter to examine the dust deposition situation on the PV module's surface directly. To analyze the energy output results of tested samples effectively, the "energy output ratio" (η) is defined to describe the difference of energy output due to dust accumulation, as follows:

$$\eta = E_A/E_C \quad (1)$$

where E_A is the energy output of dirty PV module, E_C means energy output of clean PV module.

Generally, the higher dust deposition density means the enormous change in the energy performance.

Table 2 Energy output ratio under different surface temperatures

Surface temperature (°C)	Energy output ratio
20	0.947
30	0.952
40	0.955
50	0.959
60	0.964
70	0.967
80	0.971

Table.2 presents the energy output ratios of each PV module under different surface temperatures. In general, the energy output ratio of dirt PV module ranges from 94.7% to 97.1%. It is clear that clean PV modules' outputs are higher than the identical one when it was dirty due to the function of scatting light by accumulated dust.

In addition, PV module with higher surface temperature has a higher energy conversion ratio. At this point, Table.2 shows similar results as Table.1. It is another evidence that the surface with high temperature is hard for small particle depositing because of thermophoresis force. Finally, the trend of this result line is in accordance with the result of particle deposition density. Thus, the most observably temperature gradient for the thermophoresis force is lower than 40 °C. However, the efficiency of solar cell will decrease due to the high surface temperature. Hence, trying use thermal insulation coating to reduce the particle deposition density is not economic for solar power stations.

4. Conclusion:

This paper experimentally studied the dust particle deposition onto PV modules to investigate the effect of temperature gradient (thermophoresis) on particle deposition under different operating temperatures. Controlled experiments were designed in a test chamber to study the influence of distinct surface physical properties on fine aerosol accumulation and glass light transmittance. The major findings can be summarized as follows:

1) The measured deposition densities of fine aerosols are ranging from 49 mg/m^2 to 84 mg/m^2 under the experimental conditions. The PV module with higher surface temperature has a lower density due to the effect of thermophoresis arising from a temperature gradient.

2) The energy output ratios increase with the increase of temperature gradient, ranging from 0.947 to 0.971. The results also show the effect of thermophoresis force on particle deposition process.

3) The most distinct temperature gradient for the thermophoresis force is lower than 40°C. If the temperature gradient is higher than 40°C, the influencing increase by thermophoresis force is insignificant.

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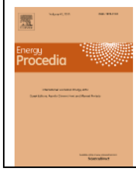

Biography

My name is Jiang Yu, a Phd student from The Hong Kong Polytechnic University. I am focued on the dust accumulating process on PV modules and tryto use model based on aerosol science to explain and calculate some important findings and factors.