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Numerical study on polydispersed dust pollution process on solar photovoltaic panels mounted on a building roof

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Abstract

Dust accumulation on photovoltaic panels would greatly reduce the efficiency and lifetime of the PV system. This study presents a study on deposition behaviors of polydispersed dust on photovoltaic panels mounted on a building roof. Computational fluid dynamics method was adopted to model air flow around the building and dust pollution process. The results showed that dust deposition behaviors are significantly affected by different dust sizes. Besides, dust deposition rates are obviously enhanced when the wind velocity increases. The maximum deposition rate can be up to 11.45% for 5m/s wind velocity. This study may be helpful for understanding dust deposition characteristics on PV system and further developing more efficient solution.

Keywords: Dust pollution; PV system; Building roof; Numerical simulation

1. Introduction

Solar photovoltaic (PV) is developing rapidly due to its cleanness and sustainability. However, dust pollution has become a serious problem for solar PV system. A large number of studies found that dust pollution would greatly reduce the efficiency and lifetime of the solar PV system after only a short time of installation [1-4]. Therefore, dust pollution on solar PV system should be investigated carefully.

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Most of studies investigated the influences and mechanisms of dust on PV power performance. El-Nashar [5] found that about 70% of PV output efficiency was decreased by dust pollution after only twelve months' installation in the United Arab Emirates. Besides, the transmittance degradation of PV glass can reach up to 10% per month. Moreover, Jiang [6] examined the influence of dust density on efficiency of different kinds of solar PV modules: monocrystalline silicon, polycrystalline silicon and noncrystalline silicon modules. PV power reduction is not significantly influenced by different PV module properties. Chaichan [7] investigated influence of traffic air pollution on PV module and found that PV efficiency was reduced by 12%. Qasem et al. [8] investigated dust effect on spectral transmittance of PV glass and found that dust with smaller size plays a crucial role on transmittance attenuation. Lu et al. [9] studied dust deposition on a building-integrated PV panels. Dust with medium size has maximum deposition density on PV panel. However, studies of dust pollution process on solar PV system are very limited. To resolve particle pollution on PV panels, dust deposition characteristics need to be well investigated first. In last several decades, computational fluid dynamics method has become an effective way in energy engineering [10-13]. Therefore, the study aims to investigate pollution process of polydispersed dust particles on solar PV system mounted on building roofs by CFD simulation. The air flow around building and dust deposition behaviors on PV system would be studied carefully.

2. Numerical Models

The Navier-Stokes governing equations of air flow around a building are described as,

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0, \tag{1}$$

$$\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + \frac{1}{\rho}\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \overline{u}_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right), \tag{2}$$

In Eq.(1-2), $\overline{u_i}$ is air velocity and $\overline{p}$ is pressure. The *N-S* equations were closed by the *SST k-ω* model.

Moreover, discrete particle model (DPM) was employed to simulate dust accumulation process on PV panels. In DPM model, the movement trajectories of each dust particle would be tracked. The governing equation of dust motion can be described by,

$$\frac{du_p}{dt} = \frac{1}{\tau}\frac{C_D \mathrm{Re}_p}{24}(u_g - u_p) + \frac{g(\rho_p - \rho_g)}{\rho_p} + \zeta\sqrt{\frac{\pi S_0}{\Delta t}} + \frac{2\rho K_c v^{0.5}}{\rho_p d_p (S_{lk} S_{kl})} s_{ij}(u - u_p) \tag{3}$$

Finite volume method and Runge-Kutta method were used to solve wind and dust governing equations. No-slip and symmetry boundary conditions were used on the ground and upper boundary, respectively. It was assumed that the dust particles would deposit when touching PV surfaces.

4. Computational Cases

The schematic of dust pollution on PV system was displayed in Fig.1. The PV panels were mounted on building roof and the wind flow with polydispersed dust particles flows around the building.

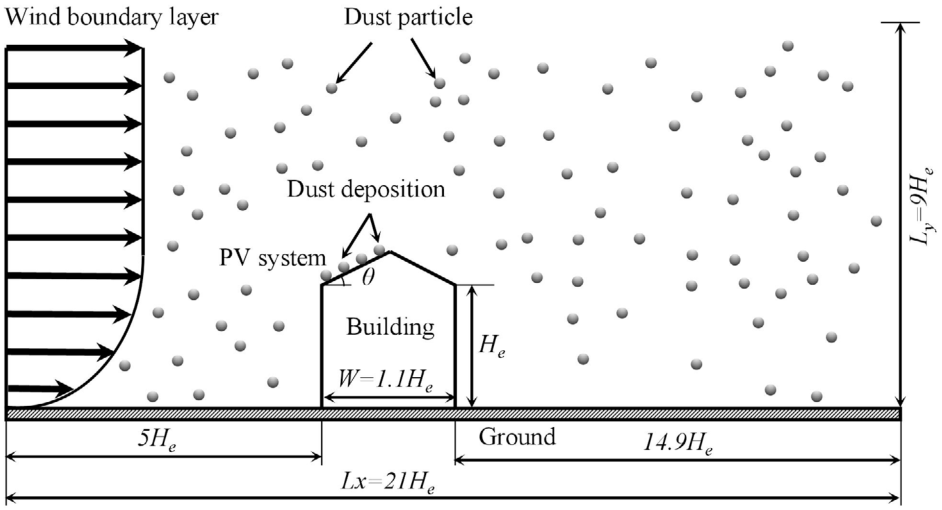

Fig. 1. Schematic of dust pollution on PV panels mounted on a building

In this study, the building eave height *He* was 0.6m. The building width W was 0.66m, as shown in Fig.1. The tilt angle of building roof was 26.6° [9]. The computational size was 21 *He* long and 9 *He* high. The distance between computational inlet and building was 5 *He*. The distance between the building and computational outlet was 14.9 *He*, which was long enough for the wind wake development behind the building. The wind velocities were 1, 3 and 5m/s. The Reynolds number based on the building eave height and wind velocity was 40,000, 120,000 and 200,000 respectively. A grid independence test was conducted to check grid sensitivity. A total number of 89600 grids were adopted in the computation. The first mesh spacing was 3 mm. The mesh growing factor was 1.2.

Air flow around the building was first calculated to convergence, then 10,000 particles were released in the flow fields. ANSYS FLUENT allows polydispersed dust particles released in the computational domain with uniform particle size distribution. The dust sizes were from 1 to 50μm. The initial dust velocities equaled to the inlet wind velocity.

3. Results and Discussions

3.1. Wind flow fields around the building

The time-averaged velocity contour map of air flow is shown in Fig. 2. From the figure, it can be observed that air flow fields are quite complicated. Wind velocities are relatively low near the building. Moreover, a large-scale turbulent separation vortex can be seen in the rear of the building, as shown in Fig. 2. The complex wind flow fields would lead to complicated dust deposition characteristics.

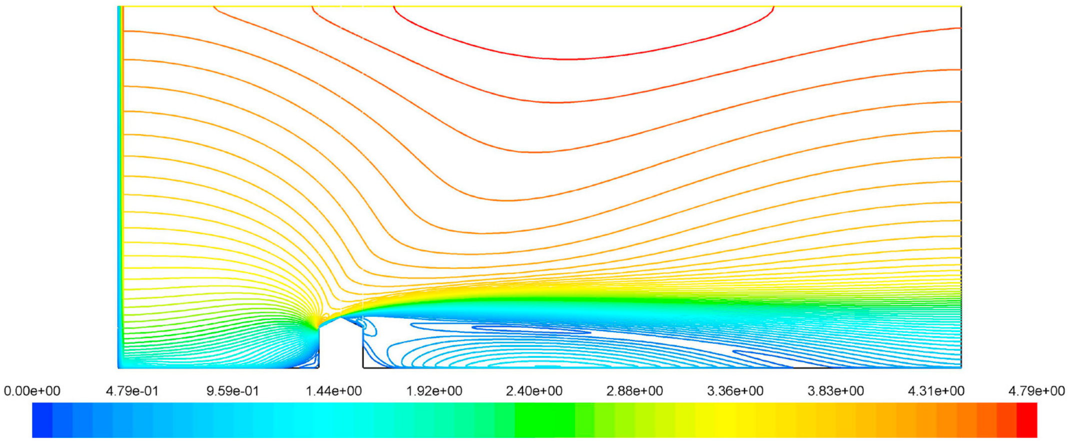

Fig. 2. The time-averaged velocity contour map of air flow over a building

3.2. Wind flow fields around the building

To investigate dust deposition characteristics, Fig.3 shows spatial distribution of polydispersed dust particles when wind velocity is 5 m/s. 1,000 dust samples were selected in Fig.3. The color in the figure represents the dust size. From the figure, it can be observed that several dust particles deposit on PV panels mounted on windward building roof. This indicates that the present numerical methods can simulate dust deposition behaviors correctly. Moreover, it can be found that the small dusts are almost following with the wind flow streamlines and distributed in front of the building. Large dust was moved behind the building due to the large inertia. Besides, the deposited dust on PV panels was almost medium particles. These imply that dust deposition behaviors are different for different dust diameters.

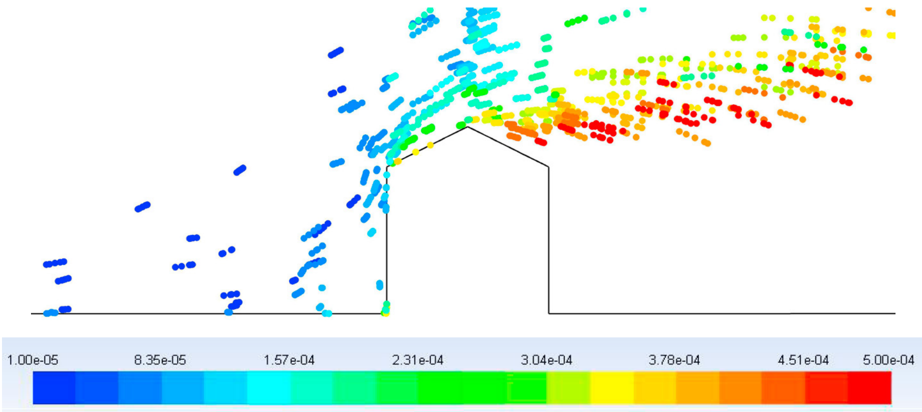

Fig. 3. Spatial distributions of polydispersed dust particles around the building at U=5m/s

3.3. Wind flow fields around a building

Fig.4 shows dust deposition rates on PV system with different wind velocities. Dust deposition rates are enhanced with growth of air velocity. The dust deposition rates are 0.21, 0.78 and 11.45% for U=1, 3 and 5 m/s, respectively. As the increase of wind velocity, turbulent diffusion and inertia-impaction of dust particles are dramatically enhanced. Therefore, more dust would be deposited on the PV system. Therefore, the degeneration of PV efficiency would be more serious with the growth of wind velocity.

So far, preventative coating and mechanical cleaning are two main methods to mitigate dust pollution on solar PV panels. The preventative coating can reduce dust deposition density by the rain wash, while the mechanical cleaning is to wash PV panels by water. This study may be helpful for understanding dust deposition characteristics on PV system and further developing more efficient solution.

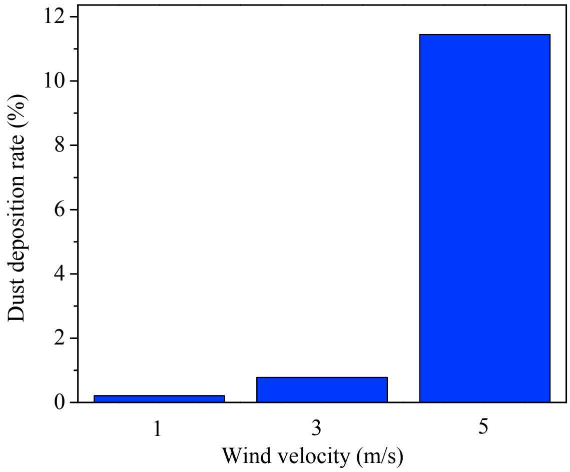

Fig. 4. Dust deposition rate on solar PV panels with different air velocities

4. Conclusions

Pollution process of polydispersed dust particles on solar photovoltaic panels mounted on building roof was studied by CFD simulation. Wind flow fields were predicted by *SST k-ω* turbulence model, while the dust deposition behaviours were modelled by DPM model with turbulent particle dispersion. Dust trajectories and deposition rates were obtained and discussed in the study. It was found that dust sizes have great influence on deposition behaviours. Moreover, the dust deposition rates are increased with the increased of wind velocity due to the enhancement of turbulent diffusion and inertia-impaction of dust. Maximum deposition rate can reach 11.45% when wind velocity is 5m/s. Therefore, the dust pollution is serious for solar PV system, especially for large wind velocity.

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