Variation law of particle size of desert sand in solar power stations

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Abstract. As an important constituent part of the particles in the atmospheric environment of desert, sand affects the solar power by falling on the solar panels nearby by means of suspension and saltation. The present study applied the sieving method to conduct a particle size analysis of the surface sand particles with particle size less than 1mm in the solar power station in the Kubuqi Desert. As indicated by the results, the particle size distribution of sand accords with the exponential distribution law; the particle size of the ground sand is larger than that of the sand in the sand collectors and its sorting is poorer as compared with that of the sand in the sand collectors, which is caused by external factors such as the wind etc.; there is a good correlation between the particle size proportions of the sand in the sand collectors and the ground sand; the weight of sand in the sand collectors follows the law of a power function that decreases progressively as the height increases; the higher the solar panel, the less it will be affected by the sedimentation of the ground sand. The above research findings will provide certain theoretical basis for exploring the influences of sand on solar power stations in the desert.

1. Introduction

Desertification is one of the environmental problems faced by human beings. Sand has caused huge losses to mankind's production activities and its impact on solar panels is one of them. Mohamed et al [1] studied the problem solar power generation in the Sahara Desert, indicating that sand is the main factor affecting the efficiency of photovoltaic power generation in dusty areas. It is generally believed that sand falls to the surface of the solar panel to form a shadow shade to block the solar panel's absorption of the photon, which is the main factor that decreases the generated energy of the solar panel [2, 3]. According to Kaldellis [4], this is mainly caused by the characteristics of sand. For example, the composition, particle size, color, shape, etc. of sand will all affect photoelectric conversion efficiency and thereby affect the efficiency of photovoltaic power generation. The deserts in Northwest China are an important source of sand. The Kubuqi Desert is one of the largest deserts in China. By studying the formation law of its sand, we can gain a general understanding of the composition of dust particles in Northwest China. Bagnold is universally acknowledged as a master of the physics of blown sand. He divided the motion of sand into three types, namely suspension, saltation and slow moving. The present study mainly explores the sand with particle size less than 1mm, which includes the majority of sand in suspension and saltation. The particles of suspension are usually smaller than $70\mu m$ and they can suspend in the atmosphere. The diameter of saltation particles is approximately between 70 to $1000\mu m$. Saltation sand particles do the bouncing movement and they can bounce as high as 1.5 meters [5, 6, 7]. They are the main constituent part of sand that falls on the solar panels.

To study the distribution of the sand transport rate at a vertical height, whirl type separation sand collectors were installed at different vertical heights to collect saltation and suspension particles. On the one hand, its correlation with the particle size distribution of the ground sand can be studied; on

the other hand, the distribution law of the sand transport rate at a vertical height can be analyzed as well. Zhao Manquan et al [8] used whirl type separation sand collectors to study the distribution of the sand transport rate at a vertical height under various wind speeds in wind tunnels. As shown in their study results, under various wind speeds, the sand transport rate decreases exponentially as the height increases. Dong Zhibao et al [9] applied the WITSEG sand collectors to study the distribution of the sand transport rate in wind tunnels and gained the conclusion that the sand transport rate decreases exponentially as the height increases under various wind speeds.

2. Experimental Methods and Collection of Sand Samples

2.1 Experimental Methods

Particle size analysis has unique advantages when it comes to the analysis of the particle size distribution law of sand. The particle size does not refer to the real diameter of particles and it is not easy or even impossible to obtain the particle diameter of sand. Sand is in an irregular state in reality, so we regarded the particle size as equivalent to the equivalent particle diameter, namely the sand particles were regarded as an equivalent sphere with a specific diameter. Sand particles from different sources have different performance characteristics in particle size and we tried to find differences among them from the perspective of mathematical statistics. Average particle size, median particle diameter, frequency distribution curve, etc. were the main contents we studied.

The sieving method usually obtains the mass percentage of particles in one specific interval. The value of particle size at the right end of each particle size range was taken as the particle size of each particle size range. In this way, the particle sizes within each particle size range were standardized so as to create conditions for the data analysis.

2.2 Collection of Sand Samples

The sand samples used in the study were randomly collected in the solar power station in the central Kubuqi Desert. There were no factories, no roads and towns, and no human factors were involved. Since there are no factories around the solar power station and the station is far away from the road and towns, it is not affected by human factors. The standard sieve to select the sand was manufactured by Zhangxing Sand Screening Machine Factory in Daoxu Town, Shangyu City. The pore diameters are 0.01mm~0.09mm and 0.1mm~1mm. The JY Multi-functional Electronic Balance was manufactured by Shanghai Puchun Metrical Instrument Co., Ltd. and its measuring precision is 0.01g. The dry sand particles were screened for 30 min in a windless indoor environment and then weighed on paper that had already been measured. The weights of the sand within different particle size ranges were obtained by the measured weight with the weight of the paper subtracted.

The experiment of the sand collectors was carried out beside the solar panel in the solar power station. The sand collecting height (center height) was 65, 110, 150, 192, 235 and 272cm, and there were altogether 6 layers. To avoid the effect of wind direction and wind speed on the sand collection efficiency, except for the height of the sand collectors, the size, outlet direction, inlet direction, etc. of the sand collectors were the same.

3. Results and Discussion

3.1 Particle Size Distribution of the Sand

The granulometric class (d is the sand diameter, mm) analysis method of sediments is a conventional method used to analyze the particle size of sediments.
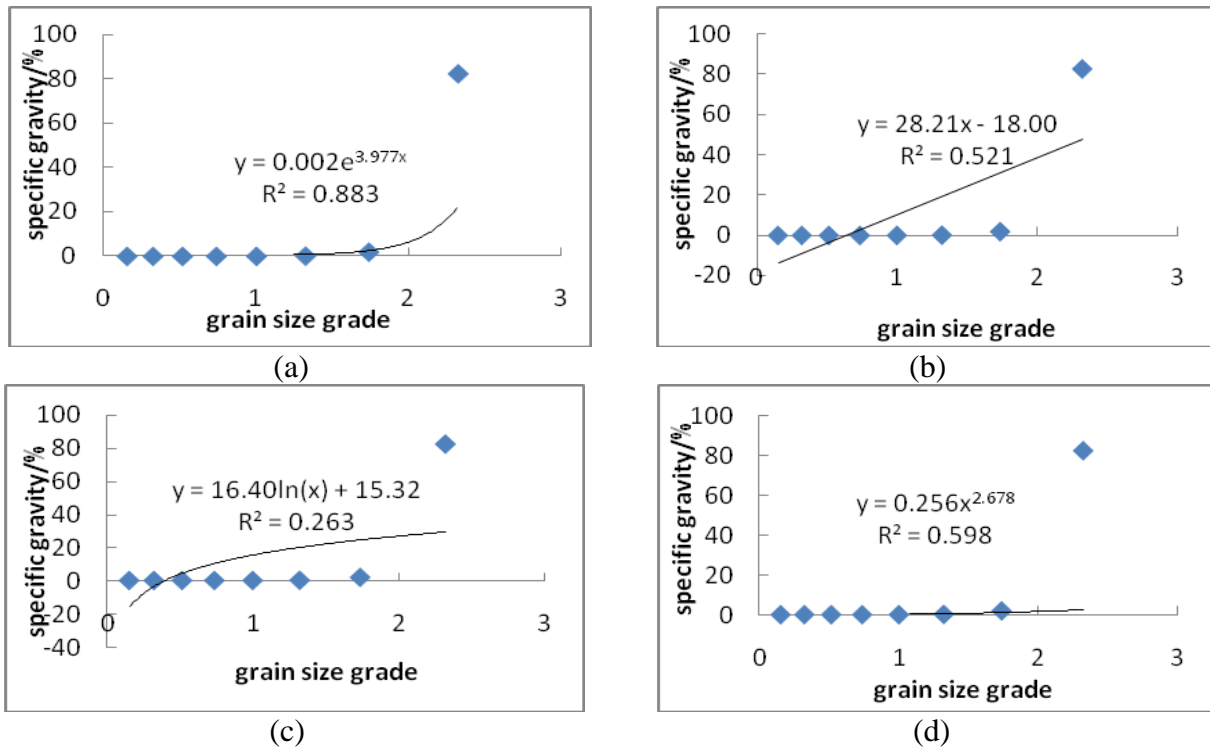
Fig. 1 The relation between specific gravity and the grain size grade of the sand dust (0-0.1mm)
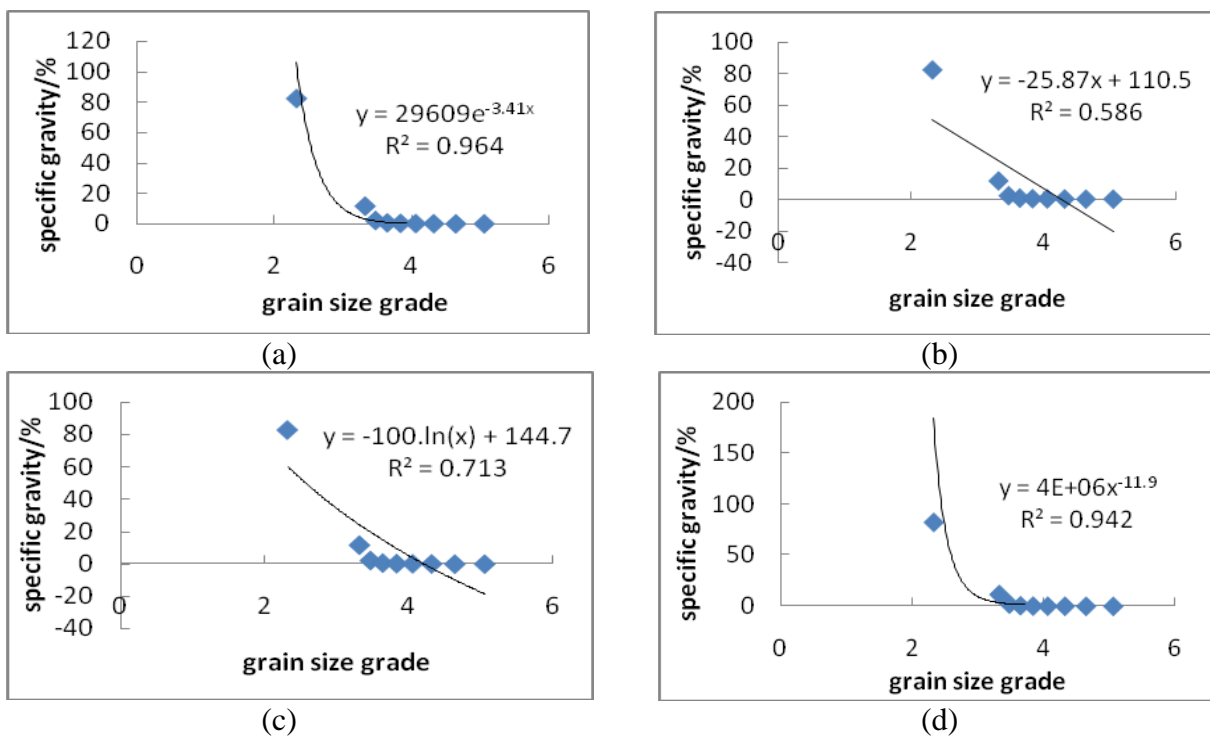

Fig. 2 The relation between specific gravity and the grain size grade of the sand dust (0.1-1mm)

In terms of the correlation coefficient, no matter the particle diameter of the sand is smaller than 0.1mm or greater than 0.1mm, an exponential relationship is the optimal relationship between the proportion and particle size of sand. When the particle diameter of the sand is smaller than 0.1mm, its proportion gradually increases first and then gradually decreases to zero. However, according to scientists occupied in mathematical statistics, it is more rational to describe the particle size distribution law of sediments using the logarithm-hyperbola [10]. The reason is that when the sand is collected, some fine sand is very likely to be carried away by the wind while sand with relatively larger particle diameter will generate saltation after gaining energy through bumping against the

ground surface; while the sand is being subdivided, apart from suspension and saltation, the sand may also stick to the sieve; while the sand is weighed, the metrical instrument can only be accurate to 0.01g. All this might cause errors. In order to explain the necessity of sand particle size analysis on the ground surface, particle sizes of sand in the sand collectors and sand on the ground were compared.

3.2 Distribution Characteristics, Parameter Comparison and Correlation Analysis of Particle Size of Sand in the Sand Collector (Height: 65cm) and Sand on the Ground Surface

3.2.1 Comparison of Particle Size Distribution Characteristics of Sand in the Sand Collector and Sand on the Ground Surface.

Table 1 Major grain size parameters of sand dusts in the sand collector and on the ground

Sand dust	median value /mm	mean value /mm	sorting coefficient	skewness SK	kurtosis K_G	< 0.01mm	0.01~0.02mm
near ground	0.112	0.124	0.042	0.340	0.797	0	0
ground	0.142	0.142	0.037	0.019	0.724	0	0

(a)

0.02~0.03mm	0.03~0.04mm	0.04~0.05mm	0.05~0.06mm	0.06~0.07mm	0.07~0.08mm	0.08~0.09mm	0.09~0.1mm	0.1~0.2mm
0	0	0	2.17%	4.35%	6.52%	6.52%	23.92%	54.35%
0.01%	0.04%	0.13%	0.23%	0.33%	0.68%	2.23%	11.67%	82.51%

(b)

0.2~0.3mm	0.3~0.4mm	0.4~0.5mm	0.5~0.6mm	0.6~0.7mm	0.7~0.8mm	0.8~0.9mm	0.9~1mm
2.17%	0	0	0	0	0	0	0
1.92%	0.15%	0.02%	0.02%	0.02%	0.02%	0.01%	0.01%

(c)

The sand on the ground surface mainly consists of fine sand (0.1~0.25mm) which takes up a proportion of 83.47%, dust (0~0.1mm) which occupies 15.32% and relatively coarse sand which accounts for 1.21%, among which medium sand (0.25~0.5mm) takes up 1.13% and coarse sand (0.5~1mm) accounts for 0.08%. With a sorting coefficient of 0.037, the sand on the ground surface is featured by excellent sorting. With the measure of skewness being 0.019, it is nearly symmetrical. With the kurtosis being 0.724, it belongs to a narrow kurtosis. The sorting coefficient of sand in the sand collector (height: 65cm) is 0.042, indicating an excellent sorting. The measure of skewness is 0.340, which implies a very positive skewness. With the kurtosis being 0.797, it belongs to a narrow kurtosis. Except the measure of skewness, the other particles size parameters of sand on the ground surface and sand in the sand collector are relatively close. The particle size of the ground sand is larger than that of sand in the sand collector and its sorting is poorer as compared with that of sand in the sand collector, which is caused by external factors such as the wind etc. To better discuss the variation law of the particle size of the sand, the study drew a comparison diagram about different particle size proportions of sand on the ground surface and sand in the sand collector.
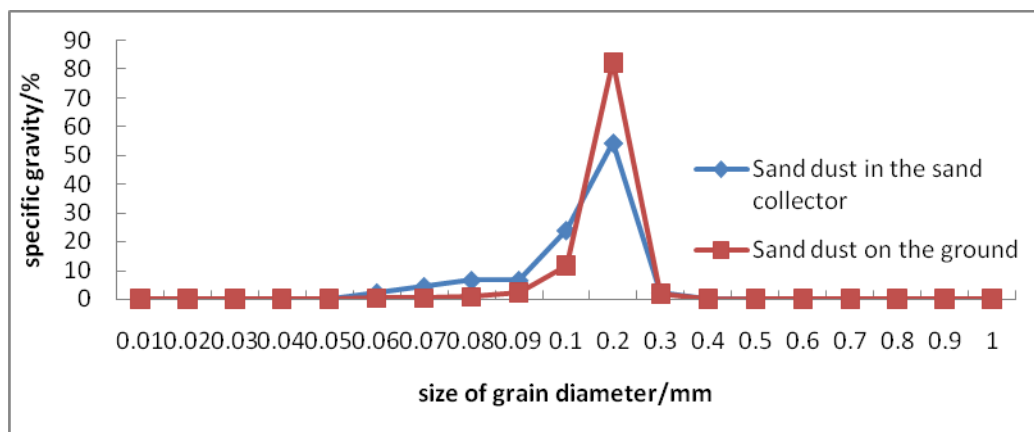
Fig. 3 Comparison of the grain diameter and specific gravity between sand dust0in the sand collector and on the ground

As shown in Figure 3, the particle size distribution curves of sand in the sand collector and sand on the ground surface change slowly from the modal value to the side of fine particles while change rapidly from the modal value to the side of coarse particles, which indicates that fine particles occupy a relatively large proportion while coarse particles take up a small proportion. Compared with sand on the ground surface, the particle size of sand in the sand collector is smaller, which indicates that sand with a smaller particle size is more likely to leap from the ground surface. With various particle sizes and different wind speeds causing sand-blowing, Bagnold only considered the balance between effective gravity and drag force to determine the classic sand-blowing formula and provide the law that friction velocity is proportional to the square root of the particle diameter, which correctly explains the obtained conclusion. With factors like the wind speed remain the same in one place and the roughness of the same underlying surface is the same ignored, the larger the particle size, the more unlikely will the sand suspend or saltate. Dust with $d < 20\mu m$ was not sifted both in the sand collector and on the ground surface, for they can be lifted up by small updrafts to generate long-distance suspension [7]. To illustrate the effect of ground surface sand on the particle size of sand in the sand collector and the consistency between them, the study carried out a correlation analysis of their particle size distribution.

3.2.2 Correlation Analysis of Particle Size Distribution of Sand in the Sand Collector (Height: 65cm) and Sand on the Ground Surface.

Table 2. Correlation between the grain diameter distribution of sand dust in the sand collector and on the ground

		Specific gravity of sand dust on the ground	Specif gravity of sand dust in the sand collector
Specific gravity of sand dust on the ground	Pearson correlation	1	.953[**]
	Significance (double sides)		.000
	N	19	19
Specif gravity of sand dust in the sand collector	Pearson correlation	.953[**]	1
	Significance (double sides)	.000	
	N	19	19

[**]. Significant correlation at the level of 0.1 (double sides)

As indicated by the table, the Pearson correlation coefficient between the two variables is 0.953. As the two-tailed test probability is $0.000 < 0.05$, there's a significant correlation between the two variables. The particle size distribution of sand in the sand collector and that of sand on the ground

surface are greatly similar to each other. The particle size analysis of sand on the ground surface can well reveal the particle size distribution of sand in the sand collector, which is of great practical significance to the particle size analysis of sand on the ground surface. It also indicates that sand carried by the wind near the ground surface mainly comes from places nearby and only a small part of it is transported from remote places. To learn how the sedimentation of sand of different heights affects the solar panels, sand in sand collectors of different heights was weighed to find out the variation law of the sand transport rate along with the change of the height.

3.3 Variation Law of the Sand Transport Rate along with the Change of the Height
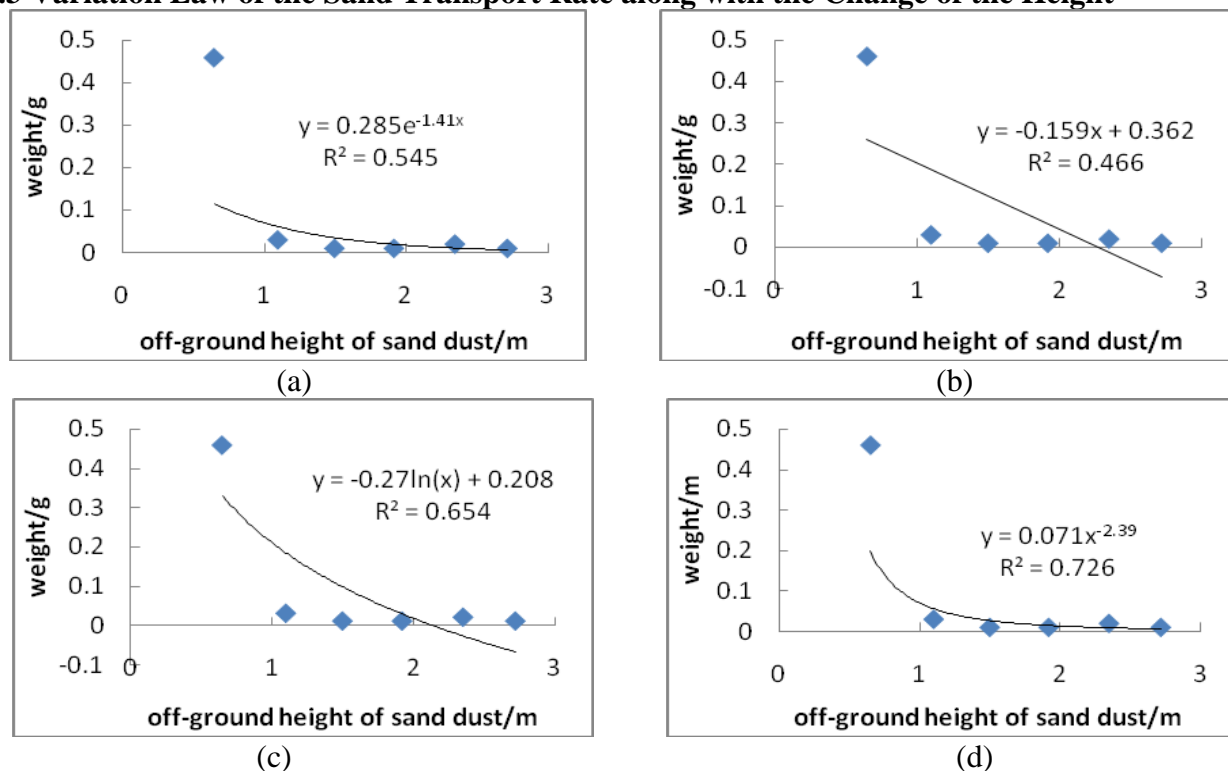

(a)

(b)

(c)

(d)

Fig. 4 Relation between the weight and height of the sand dust

The weight of sand in the sand collector decreases as the height increases, and the optimal relationship between them can be expressed by a power function. This is also the relationship between the sand transport rate and the height. The motion of sand in the air is mainly determined by its own gravity and airflow resistance. If there is not enough upward airflow, sand can only rise to a certain height and then fall. There is a great difference between the weight of sand collected by the sand collector with an entrance height of 1.1m and that of sand collected by the sand collector with an entrance height of 0.65m, which implies that most sand falls before it reaches the height of 1.1m. It agrees with the blowing sand boundary layer theory. It can thus be concluded that if the solar panel is higher than 1.1m, the amount of sand and dust that falls on the solar panel will be relatively small and the solar power generation efficiency will be less affected as well. Of course, since the sand collectors have different heights and the fitting formula is not accurate enough, the experiment precision is greatly affected.

4. Conclusions

It is relatively rational to describe the particle size distribution law of sand in the solar power station in the Kubuqi Desert as an exponential distribution. Since it was hard to control the suspension and saltation of sand during the collection and subdivision stage, some errors occurred in the experiment.

Sand on the ground surface mainly consists of fine sand, with dust taking up the second largest proportion and coarse sand accounting for the smallest proportion. The particle size parameters of sand on the ground surface and that in the sand collectors are relatively close. Compared with sand on

the ground surface, the particle size of sand in the sand collector is smaller, which indicates that sand with a smaller particle size is more likely to leap from the ground surface. There is a significant correlation between the particle size of sand in the sand collector (height: 65cm) and that of sand on the ground surface, implying that most sand is transported within a close range.

The weight of sand in the sand collectors follows the law of a power function that decreases progressively as the height increases, which indicates the existence of the blowing sand boundary layer. The higher the solar panel, the less it will be affected by the sedimentation of the ground sand.

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