Study on the Distribution Law of Sand Dust Particles in Solar Power Stations

Wang Shuai¹ and Zhao Mingzhi¹

¹School of Energy and Power Engineering, Inner Mongolia University of Technology, Hohhot, China, 010051.
¹China General Certification Center, Beijing, China, 100000

zhaomingzhi2020@163.com; 1351587945@qq.com

Abstract: Dust is an important part of the particulate matter in the desert atmosphere environment. It moves to the nearby solar panels by suspension and saltation, which affects solar power. Collecting sand dust with sand sampler and compare with the dust distribution characteristics and parameters on the earth's surface to find out the transport law of dust and variation of dust weight with height in sand sampler. The results showed that the distribution of dust particle size obeyed the exponential distribution law. The dust particle size of surface dust is larger than that of sand sampler and the dust is in poor sorting which was caused by the selection of external factors such as wind. There is a good correlation between the dust in the sand sampler and the specific gravity of dust particle size in the earth's surface. The dust weight increases with height in sand sampler obey the law of power-decreasing. The heigheer the solar panel, the surface dust deposition has less influence on it. The results will provide a theoretical basis for the impact of desert dust on solar power station.

1. Introduction
The desert in the Northwest China region is an important source of sand dust. Hobq Desert, as one of the largest deserts in China, it is possible to have a rough understanding of the dust composition in the northwest in researching its composition of dust particle size law. Many of the solar power plants are built in the desert, and most of the dust is transported at a close range, which provides the conditions for the deposition of dust on the battery panels, the power efficiency of the battery panels have been seriously affected. When the sand falls on the battery panels, the light can not be shining on the battery panels through the sand and the area of the light received by the battery board will be affected. When the battery panel starts to work, the sheltered part rises quickly, it may cause damage to the inside of the battery board may.
Sand dust falls on the battery board, not only with the wind speed, dust particle size and the physical properties of the battery itself, but also with the structure of the sand flow. Sand dust falls on the battery board, Ma Shiwei\(^{[1]}\) and others are studied in the vertical height of the sand flow and found that the sediment transport decreases exponentially with the increase of height. Zhang Jinchun\(^{[2]}\) and others analyzed aerosol concentration in Minqin area. As the desert gradually close to the oasis, the concentration gradually decreased, the concentration decreased with the increase of altitude in the form of power law function. Sand dust in sand source area was more easily affected by underlying surface in near ground within 40m. Kong Dan\(^{[3]}\) and others analyzed dust particle size with laser particle size analyzer in Taklimakan Desert, the average particle size of sand dust is about 100\(\mu m\), the higher the altitude is, the better the sorting, the particle size curve is positive.

This paper analyzes the dust particle size at the source of desert and obtains the law of particle size distribution of sand dust. Designing the shunt-hedging sand sampler and explains the working principle and structure. Arriving that to using index to describe reasonable distribution law in the dust particle size at the Hobq Desert solar power base. The analysis of the dust particle size can provide a better understanding of the movement of sand dust, provide more theoretical basis for the settlement of sand dust and it's helpful to increase the efficiency of solar power generation.

2. Experimental Method

Particle size analysis has a unique advantage in analyzing the particle size distribution of dust. Particle size is not a real particle size. It is not easy or even impossible to get the dust particle size, dust presents an irregular state in reality. So in the analysis, we are equivalent to the particle size and the equivalent particle size, that means to think of dust particles as an equivalent sphere of specific diameter. Different sources of dust particles have different particle size characteristics, we explore their differences from the point of view of mathematical statistics. Average grain diameter, medium diameter and the frequency distribution curve are the main contents of our research.

The average grain diameter is the average level of the particle size distribution, the median diameter is also commonly used particle size index, that is, the particle size of the total content is 50\%, the median diameter is not affected by the larger diameter, so the sensitivity is lower than the average diameter. In the dust study, the average particle size is related to the average kinetic energy of dust. If the average particle size is calculated by graph method, first, cumulative frequency distribution curve of dust, and work out the particle size of 16\%, 50\% and 84\%. Then, figure out the average particle size by the formula (1). If use the moment method, first find the percentage of the median and the range of granularity in each particle size range, then substitution formula (2) to calculate the average particle size. When the dust particle size was normal distribution, it is equal in average grain diameter and median diameter.

\[
M_z = \frac{(F_{16} + F_{50} + F_{84})}{3} \quad (1)
\]

\[
M_z = \sum \left(\frac{f_i m_i}{f_i}\right) \quad (2)
\]

In the formula, \(f_i\) is the percentage of overall ranges of size range \(i\), \(m_i\) is the median of \(i\) size range. \(F_{16}, F_{50}, F_{84}\) are the corresponding value on the cumulative distribution curve.

The separation factor is related to the degree of sorting of dust, and the graphic method is calculated of ratio of grain size with cumulative content of 25\% and 75\%, sometimes expressed in
terms of a root mean square. The separation factor is related to the dynamic conditions of dust handling which reflects the stability of transporting dust. Generalized graphic method for calculating standard deviation can be a good reflection of empennage in sorting property, which has been widely used and calculated by formula (3). Standard deviation of moment method was calculated by formula (4).

\[ s_1 = \frac{(F_{94} - F_{16})}{4} + \frac{(F_{95} - F_{5})}{6.6} \]  
\[ d = \left[ \frac{\sum f_i (m_i - M_z)^2}{\sum f_i} \right]^{1/2} \]  

In the formula, \( f_i \) is the percentage of overall ranges of size range \( i \), \( m_i \) is the median of \( i \) size range. \( M_z \) is the average particle size of sand dust.

The skewness is related to the symmetry of the particle size distribution and represents the relative between the mean particle size and the median particle size. The skewness formula of generalized graphic calculation is (5), and the skewness of moment method is (6). When the skewness is zero, the curve is symmetrical. When it is greater than zero, it is positive skewness and the coarse part is relatively concentrated. When it is less than zero, it is negative skewness and the fine particle size part is more concentrated.

\[ S_k = \frac{F_{95} + F_{16} - 2*F_{50}}{2(F_{94} - F_{16})} + \frac{F_{95} + F_{5} - 2*F_{50}}{2(F_{95} - F_{5})} \]  
\[ S_k = \frac{\sum f_i (m_i - M_z)^3}{\sum f_i} d^3 \]  

In the formula, \( f_i \) is the percentage of overall ranges of size range \( i \), \( m_i \) is the median of \( i \) size range. \( M_z \) is the average particle size of sand dust. \( d \) is standard deviation.

The kurtosis is a measure of the distribution curve center section and shape area of tali, and intuitively indicates the degree of the distribution curve. The larger the peak state, the more obvious the peak, the narrow the peak is, the better is the middle part than the tail part. The formula for calculating the peak state of the graph is (7) and the kurtosis formula of the moment method is (8).

\[ K_G = \frac{F_{95} - F_{5}}{2(F_{75} - F_{25})} \]  
\[ K_G = \frac{\sum f_i (m_i - M_z)^4}{\sum f_i} d^4 \]  

The sieving method usually obtains the percentage of mass fraction of dust particles in an interval. We take the right end endpoint value of each granularity range as the particle size of each granularity range, thus normalizing the particle size within each particle size range to create conditions for data analysis.

3. Dust Sample Collection

The dust samples used are randomly which taken from the solar power station in the heart of the Hobq Desert, there are no factories around, away from roads and towns, and animals are rarely infested and are not affected by human factors. Standard sieve selected was produced from Zhejiang Shangyu City Road Zhang Xing yarn sieve plant, the aperture of 0.01mm ~ 0.09mm, 0.1mm ~ 1mm. JY series of multi-functional electronic balance by the Shanghai Pu Chun Measurement Instrument Co. Ltd. production, the accuracy of 0.01g[4-5]. Sift the dry sand particles through 30min in the airless indoor environment and then weigh it on the paper that has been measured. The weight of the paper is removed from the measured weight to give the weight of the dust in the different particle size ranges.
Sand sampler is located in the center of the solar power station of the Hobq Desert. In order to facilitate transport and demolition, sand sampler is generally bolted, fixed on the ground, the sand separator is fixed on the support of the sand sampler through bolts, so the air inlet on the sand separator can rotated in different directions. The height of the inlet of sand separator is 65, 110, 150, 192, 235, 272 cm, and the number of layers is 6. In order to avoid the influence of wind direction and wind speed on the sediment concentration, except for the height of the sand separator, the conditions of sand separator size, exit direction and entrance direction are the same\[6\].

4. Results and Discussion

4.1. Sand particle size analysis
The analytical method of sediment grain size (d is sand particle size, mm) is a conventional method for sediment particle size analysis.

![Figure 1](relationship_between_gravity_and_sand_grain_size_0-01mm.png)

**Figure 1.** Relationship between Gravity and Sand Grain Size (0-0.1mm)

![Figure 2](relationship_between_gravity_and_sand_particle_size_0-01mm.png)

**Figure 2** Relationship between Gravity and Sand Particle Size (0-0.1mm)

According to Figure 1 and 2, we can see from the correlation coefficient, regardless of the dust particle size is less than 0.1mm, or greater than 0.1mm, the best relationship between specific gravity and dust particle size is exponential relationship. When the dust is less than 0.1mm, the proportion gradually increased, and then gradually reduced until zero. The reason, when dust is collected, there
are tiny dust particles that are easily carried by the wind because of levitation, dust particles with larger grain sizes produce saltation energy by impacting.

4.2. Distribution characteristics, Parameter comparison and Correlation analysis between Sand sampler (High 65cm) and Dust particle size on the ground surface

4.2.1. Comparison of distribution characteristics between sand sampler and dust particle size on the ground surface

| Media size/n/mm | mean value/mm | Separation coefficient | Skewness | Kurtosis Kg | < 0.01 mm | ~ 0.02 mm | ~ 0.03mm | ~ 0.04 mm |
|----------------|---------------|------------------------|----------|-------------|------------|------------|-----------|-----------|
| Near ground    | 0.112         | 0.124                  | 0.042    | 0.340       | 0.797      | 0          | 0         | 0         |
| Ground         | 0.142         | 0.142                  | 0.037    | 0.019       | 0.724      | 0          | 0         | 0.01%     | 0.04%     |

It can be seen from Table 1 that the dust in the surface is dominated by fine sand (0.1 ~ 0.25mm), accounting for 83.47%, dust (0 ~ 0.1mm) accounted for 15.32%, coarse sand accounted for 1.21%, which medium sand (0.25 ~ 0.5mm) accounting for 1.13%, coarse sand (0.5 ~ 1mm) accounted for 0.08%. The dust separation coefficient of the surface is 0.037, the sorting is excellent, the skewness is 0.019, almost symmetric, kurtosis is about 0.724, which belongs to the narrow kurtosis type. The dust separation coefficient in sand sampler (high 65cm) is 0.042, good in sorting and skewness is 0.340, positive skewness, kurtosis is about 0.797, which belongs to the narrow kurtosis type. In addition to the skewness, dust particle size parameters in sand sampler and the earth's surface are relatively close to each other. The dust particles on the earth's surface are larger and poor sorting than the dust particles in the sand sampler which is caused by the selection of external factors such as wind.

4.2.2. Correlation analysis of dust particle size distribution on the earth's surface and sand sampler (high 65cm)
Table 2. Correlation between sand sampler and dust particle size distribution on the earth’s surface

| Specific gravity of surface dust | Sand dust ratio of sand sampler | PearsonRelevance | Significance (bilateral) | N |
|----------------------------------|---------------------------------|------------------|--------------------------|---|
| Specific gravity of surface dust | 1                               | .953**           | .000                     | 19 19 |
| Sand dust ratio of sand sampler  | .953**                          | 1                | .000                     | 19 19 |

**. Significantly correlated at .01 level (bilateral)

It can be seen from Table 2 that Available from the table, the Pearson correlation coefficient between the two variables is 0.953, the two-tailed test probability p is 0.000 <0.05,and the variables are significantly correlated. The dust particle size distribution in the sand sampler is similar to that in the earth’s surface. The dust particle size analysis of earth’s surface can well reflect the dust distribution characteristics in the sand sampler and it is of great practical significance to analyze the dust particle size on the earth’s surface. It also shows that near ground wind carries dust mainly from the vicinity, only a small part is transported from a long distance.

4.3. Variation law of sediment discharge rate with height

![Figure 3. Relationship between dust weight and height](image)

It can be seen from Figure 3 that the sand dust weight decreases with height in the sand sampler,
and the best relationship is the power function, which is also the relationship between the sediment transport rate and the height. Dust in the air movement is mainly determined by their own gravity and air resistance, if there is not enough updraft, dust can only rise to a certain height and fall. The weight collected by the sand sampler at the entrance height of 1.1m is much different than that collected by the sand sampler of 0.65m height which shows that most of the dust has fallen below the height of 1.1m. This is consistent with the theory of aeolian sand boundary layer. From here it can be concluded that if the height of solar panels is higher than 1.1m, the amount of dust will be relatively small, the impact of solar power will be small.

5. Conclusion

(1) It is reasonable to describe the dust particle size distribution of the solar power station in Hobq Desert and it is not easy to control the suspended dust drift of dust due to the acquisition and subdivision, some experimental errors may occur.

(2) The surface dust is dominated by fine sand, followed by dust and coarse sand; the dust particles in the surface and sand dust particles in the sand sampler are close to each other. The dust particles in the sand sampler are smaller than the dust particles on the earth’s surface, it is concluded that dust particles with smaller size are more likely to take off from the ground surface; sand sampler (65cm) has a great correlation with dust particle size on the ground surface, indicating that most of the sand dust is transported at close range.

(3) The dust weight increases with height in sand sampler obey the law of decreasing power function, indicating the existence of wind-sand boundary layer. The higher the solar panel height, the smaller the impact of dust settling on it.

References
[1] Ma Shiwei. Study on the structure of wind and sand flow [J]. China Desert, 1988, 8 (3): 8-22.
[2] Institute of Environmental Science and Engineering, Central South University, Changsha 410083, China; Study on aerosol concentration variation of dust storms in Minqin near ground [J]. Chinese Journal of Environmental Science, 2009, 29 (3): 496-504.
[3] Dong Zhibao, Sun Hongyi, Zhao Aiguo. WITSEG sandstorm instrument: multi-channel sandstorm in wind tunnel [J]. China Desert, 2003, 23 (6): 714-720.
[4] ZHAO Man-quan, WANG Jin-lian, LIU Han-tao, et al. Effects of structural parameters of sand-bearing apparatus on sand-collecting efficiency [J]. Journal of Engineering, 2010, 26 (3): 140-145.
[5] Li Ying, Shi Yongji, Jiang Fu Qiang. Development of full wind direction gradient sand sampler [J]. Technical supervision of railway, 2012, 40 (2): 41-43.
[6] Li Zhenshan, Ni Jinren, Liu Xianwan. Study on sand storage efficiency of vertical lattice sand collecting sand instrument [J]. Sediment Research, 2003, 1: 24-31.