A laboratory test of the electrification phenomenon in wind-blown sand flux

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Abstract **The measured data in the wind-tunnel tests show that the wind-blown sand particles acquired a negative charge when their diameters are smaller than 250 μm and positive charge when their diameters are larger than 500 μm, which confirms Latham's assumption that the large particles in wind-blown sand flux acquired positive charge while negative charge developed on small ones. In the meanwhile, the measured data also show that the average charge-to-mass ratio for wind-blown sand particles decreases with the increase of the particle diameter and the wind velocity, and increases with the rise of height. The electric field in wind-blown sand flux is mainly formed by the moving charged sand particles. Its direction is vertical to the Earth's surface and upward, which is opposite to that of the fair-weather field. The electric field increases with wind velocity and height increasing. These experimental results will lay the foundation for developing the theoretical analysis of the electrification phenomenon in wind-blown sand flux.**

Keywords: wind-blown sand flux, charged sand particles, average charge, electric field strength, laboratory test.

Associated with sandstorms, strong electric field and spark phenomena were found in wind-blown sand flux[1−3]. By field observation, Schmidt et al.[4] indicated that the direction of the electric field in wind-blown sand flux is upward and vertical to the Earth's surface, and opposite to that of the fair-weather atmosphere electric field. The magnitude of the electric field strength at 1.7-cm height is upto 166 kV/m. Schmidt et al. expected that the charge on sand particles was negative, but the positive charge was measured at 1.7-cm height. Besides, they considered that the electric field in drifting sand was formed by the static charged particles on the Earth's surface[5]. Latham[3] assumed that the electrification of sand particles was generated by asymmetric rubbing between larger particles and smaller particles. Because of the difference between surface areas of larger sand particles and smaller ones, the contact between smaller particles (warmer) and larger ones (cooler) would transfer positive ions on smaller particles to larger ones. Then the small particles become negatively charged and large ones positively charged. Greeley and Leath[6] gave that 60 μm is a critical diameter for sand particles whether they were negatively charged or positively charged. In the study of blown sand physics, the trajectories of saltating particles are especially concerned[7]. It was found that the sign and magnitude of the charges on sand particles had evident effects on the trajectories of saltating particles and the near surface wind profiles[8]. In the meanwhile, the electric field in drifting sand will interfere with radio-communication, and do harm to the communication equipments and the safety of human beings[9]. Therefore, it is necessary to make a good understanding of the electric properties and rules of moving sand particles in wind-blown sand flux. Based on laboratory measurements in wind tunnel, the reasonableness of Latham's assumption about the mechanism of the electrification of sand particles is further confirmed in this note. The results of measurements also show that the electric field in drifting sand is mainly formed by moving charged particles. This result is different from Schmidt et al.'s conclusion that the electric field is generated by static sand particles on the Earth's surface. The electric field measured by the average atmospheric electric field meter[10] is negative, which states that the direction of the electric field in wind-blown flux is opposite to that of the fair-weather field downward and perpendicular to the Earth's surface. Therefore, the direction of the electric field in the wind-blown sand flux is upward and vertical to the Earth's surface. Usually, the average charge on per kilogram moving sand particles is negative. It decreases in magnitude with the wind velocity and the diameters of particles increasing, and increases with height increasing. Only when the moving particles are very near to the Earth's surface and the velocity of wind is comparatively large, can the average charge on per kilogram moving sand particles be positive. According to the experimental results given in this note, it is not difficult to know why Schmidt et al.'s measured results are in conflict with their expected ones.

1 Experimental

The experiments were performed in the field environmental wind tunnel of the Cold and Arid Region Environmental Engineering Institute of the Chinese Academy of Sciences. The wind tunnel is a movable and direct-blown closed jet one. It can also be used indoor and outdoor. Besides that, the simulation on the wind-blown sand flux given by this tunnel is consistent with the one in the field. The test section is 21 m long and both of its height and width are 1.2 m. The shell of the wind tunnel is made of aluminium alloy, and an electrical grounding treatment is given in the experiment. A sketch on the experiment set-up is shown in fig. 1.

The charge on sand particles was measured by using a steplike sand collector, which is 20 cm high and 2 cm wide, with 10 openings (each area is 2 cm × 2 cm). The average charge on per kilogram sand particle, that is, charge-to-mass ratio, was got by measuring both the weight and the charge of moving sand particles passed through the sand collector and collected in the sand chamber. When measuring the average charge on sand particles moving in the height of 2—22 cm, the sand chamber which was connected with the sand collector was buried in sand, and the lowest opening of the sand trap is 2 cm above the sand surface. To measure the charge on particles at some higher height, for example, the charge on sand particles moving at 50—54-cm height, we fixed the sand collector on a wooden stick through the screw-bolt on the back of the sand collector. The stick's diameter is about 1.5 cm and its lower part was buried in sand, then all openings were sealed except the two lowest ones. By adjusting the height of the sand collector, one can obtain the sand samples at 50—54-cm height. In order to insulate the sand sample from outside, the sand collector and sand chamber, which are made of iron, were sealed with the masking belt. The sand chamber was connected with a D-Q3 digital current meter of impact. The experimental datum was exhibited by 3.5 digit of LED charactron and could be automatically reserved until it was replaced by a new datum. The electric field strengths at various heights in the wind-blown sand flux were measured by a DPD average atmospheric electric field meter. The electric field sensor was suspended upside down from the top of the wind tunnel and could be shifted up and down. After the wind tunnel was opened for about 1 min and the wind-blown sand flux would be in the steady state, the paper belt recorder connected to the DPD field meter was opened and the electric field strengths at different heights could be automatically recorded at a given wind velocity. In order to avoid the electric field sensor interfering with the sand collector, they were staggered 30-cm broadwise.

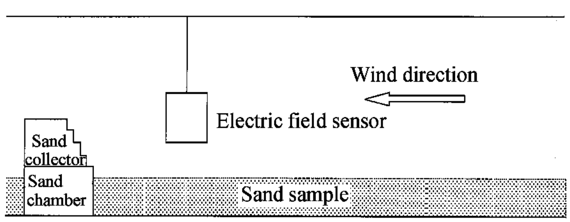

Fig. 1. The test sketch.

The experimental sand samples were taken respectively as mixed sand and "uniform" sand (whose diameters are in a given range). For the experiments of mixed sand, the bottom of wind tunnel was covered with a mixed sand layer which is 19 m long and 15 cm deep. The sand sample was taken from sand dune at the south eastern edge of the Tengger Desert. The diameters of the sand particles range from 40 to 600 μm. The electric field sensor and sand collector were set at the points of 15 and 18 m from the starting point of the experimental section respectively. For experiments of "uniform sand" with various diameter ranges, the bottom of the wind tunnel was covered with steel plates, and a 9-m-long and 1-cm-deep layer of "uniform sand" was put on the steel plates. The electric field sensor and the sand collector were set at the points of 8 and 9 m from the starting point of the experimental section, respectively. The lengths from the starting point of the experimental section to the sensor and the collector are larger than the "saturated fetch" (which is about 4—7 m given by Bagnold[11]).

2 Results and analysis

(i) Average charge on sand particles. Table 1 shows some measured values of the average charge, that is, the charge on per kilogram sand particles or the charge-to-mass ratio, for several "uniform sands", which were blown up over 2—22 cm height off the sand surface at various wind velocities. The measurement results indicated that the charge was negative for sand particle diameters are smaller than 250 μm, and was positive for the diameters are larger than 500 μm, which is qualitatively coincident with Lathem's prediction by the asymmetric rubbing theory[3]. From the experimental results, one can find that the average charge on large sand particles are less than on small ones when the wind velocity is given. This confirms Lathem's prediction on the relationship between the charge and the diameter based on his asymmetric rubbing theory. That is, when the electrification of two sand particles with different diameters occurs, the charges on the particles are equal to each other in magnitude, and opposite in the sign. However, the average charge on per kilogram for large particles is less than that for smaller ones since the large particles are heavier than the small ones. The measurement data of average charge on per kilogram for mixed sand particles are listed in tables 2 and 3. Table 2 is for the average charges on mixed sand particles moving at 2—22 cm height with four different wind velocities and table 3 gives the average charges in several different ranges of height with two kinds of wind velocity. According to tables 1—3, one can find that the average charge on particles decreases with increasing velocity of wind. In the meantime, from table 3, one can find that the average charge increases with the rise of height, which can be explained by the relationship between moving sand particles and the wind velocity. As the wind velocity grows up, the number of blown sand particles with large diameters will increase gradually so that the average charge on per kilogram sand particles decreases, and with the rise of the height, the number of large sand particles gradually decreases so that the average charge on per kilogram sand particles will increase. It should be noted that the average charge on sand particles becomes positive at 2—26 cm height with the wind velocity of 20 m/s (shown in table 3). This phenomenon may be possible because when the wind is strong, the large sand particles with positive charge may be dominant at some height, such as, near the Earth's surface. Based on these experimental data, it can be explained why the average charge on blown sand particles measured by Schimdt et al. is positive. When the field measurement is taken near the Earth's surface, it is possible that the average charge on moving particles be positive and even the average charge is mainly negative.

Table 1 Measured values of average charge on "uniform sand" with three diameter ranges at several wind velocities

Diameter/μm	Wind velocity/m • s^{-1}	Charge/μC • kg^{-1}
0—75	7	−124.5
0—75	15	−40.2
100—250	7	−64.2
100—250	15	−3.6
500—1000	10	0.95
500—1000	15	0.13

Table 2 Measured values of average charge on mixed sand

Wind velocity/m • s^{-1}	7	10	15	20
Charge/μC • kg^{-1}	−23.4	−19.3	−15.9	−9.8

Table 3 Measured values of the distribution of average charge on mixed sand along the height at several wind velocities

Height/cm	Wind velocity/ m • s^{-1}	Charge/ μC • kg^{-1}
2—6	10	−24.5
2—6	20	13.8
6—10	10	−125.0
6—10	20	-31.9
26—30	10	−330.0
26—30	20	−198.0
50—54	10	−1120.7
50—54	20	−890.2

(ii) Measurements of the distribution of electric field with height. The electric field generated in wind-blown sand flux was measured at different heights for several kinds of wind velocity, which are respectively depicted in fig. 2 for "uniform sand" with three kinds of diameter range and fig. 3 for mixed sand (d means the diameter of sand particles, v wind velocity). The measured data show that the electric field is negative, and increases in magnitude as the height grows up. Because the direction of the fair-weather electric field over a comparatively plain ground vertically points at the ground, the negative field displayed on the average atmospheric field meter means that the direction of the field in wind-blown sand-flux is perpendicular to the ground and upward. For "uniform sand", it is obvious that the electric field strength increases as the height rises for small particles, and is stronger for small particles than for large ones when the wind velocity is given. Besides that, the field increases in magnitude with increasing wind velocity for sand particles in the same diameter range. These characteristics are consistent with the fact that the number of small sand particles increases as the height and wind velocity grows up. For the mixed sand, the similar distribution characteristics are found for the field above 20-cm height (see fig. 3). It should be noted that the electric field ranged as large as 6 kV/m at 40-cm height when the wind velocity is 20 m/s. However, the distribution of the field at height below 20 cm, especially below 6 cm, is not entirely in accordance with that above 20-cm height. This may result from the fact that the diameter of mixed sand particles is comparatively in a large range. The lower the height, the more possible the large sand particles are blown up for strong wind. Thus, the net charge decreases in magnitude or sometimes the large particles with positive charge are dominant (see fig. 3). In this case, the electric field strength may decrease and even become positive with the wind velocity increasing. Based on the measured data given in this note, we can conclude that the electric field is mainly formed by moving charged sand particles. Schmidt et al.'s opinion that the electric field is formed by static charged sand particles is not supported by the experiments in this work.

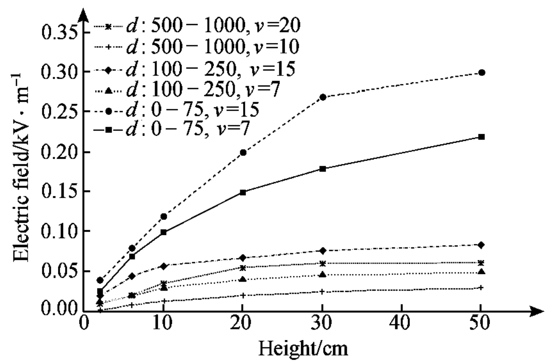

Fig. 2. The curves of electric field versus height in wind blown sand flux with "uniform" diameter at several wind velocities.

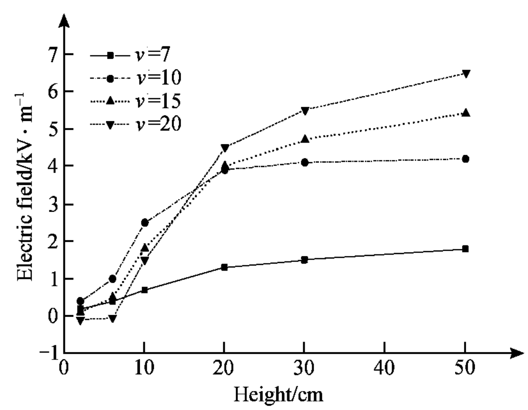

Fig. 3. The curves of electric field versus height in wind blown sand flux with mixed diameters at four wind velocities.

Having compared the measured data given by this note with Greeley and Leach's ones[6] in wind tunnel experiments, one can find that there are some differences in quantity. For example, Greeley and Leach showed that 60 μm is a critical diameter whether the charged sand particles are positive or negative; whereas only the diameter ranges whether the sand particles are positive or negative, are given in this note. That is, sand particles of smaller than 250 μm are negatively charged, and those of larger than 500 μm are positively charged. This difference may be caused, on the one hand, by sand samples in different areas; on the other hand, it is necessary to expound and prove whether there exists a critical diameter so that the sand particles whose diameter is smaller/larger than this value should acquire negative/positive charges.

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