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Influence of sand feed on transport dynamics in wind tunnels

JASEM M. AL-AWADHI

Environmental and Earth Science Division, Kuwait Institute for Scientific Research, P.O. Box 24885, 13109 Safat, Kuwait

ABSTRACT

Wind tunnel experiments were conducted to assess ways in which fed sand can affect the nature of sand transport. A series of sand flux measurements at three preselected different shear velocities using sand fed at three different heights were performed on a 2 cm thick bed of sand (mean grain diameter; 275 μm). The characteristic parameters of the laden bed and the rate of sand transport were then compared. In general, it was found that the total sand flux can be significantly altered by the height at which sand is fed into the wind flow. Trends observed in the experimental tests indicate that the presence of an upstream sediment source has a direct influence on the sand flux and the general wind speed profile.

INTRODUCTION

Several factors can affect the flow conditions and, subsequently, the dynamics of sand-particle transport in a wind tunnel. Willetts & Rice (1985, 1986a, 1986b) have made detailed studies on the influence of variation in the grain size distribution and in grain shape on the saltation mode and on aeolian transport in general. Various authors have dealt with the problem of uncontrolled aeolian variables such as surface texture and ripple formation influencing the wind flow and the sand movement (e.g. Willetts & Rice 1989, Rasmussen & Mikkelsen, 1991).

Iversen *et al.* (1991) indicated that the sand grains have a major effect on the flow and they greatly complicate the role of the stabilised surface. Shear stress is a major contribution in initiating sand movement. Once the sand is in motion the effect of the inter-saltation and splashing of the rested grains is predominant (Willetts & Rice 1988, Willetts *et al.* 1991). However, there is no conclusive evidence that the dislodgement caused by direct wind forces become negligible when the saltation layer becomes fully developed (Willetts *et al.* 1991).

The influence of sand feed in initiating sand transport was seen from a comparison of pairs of data from Belly (1964) and Rasmussen & Mikkelsen (1991) respectively, with and without sand feeding in different wind tunnels. The comparison showed that for shear velocity below about 0.45 m/s the transport rate is consistently smaller with the sand feed turned off.

Sand feed is usually used in wind tunnel experiments to lower the threshold shear velocity by creating an artificial impact on the sand bed; however, some experiments require continuous feeding to maintain a steady sand flux for a long period of time. Such feeding may disturb the general condition of the experiments because the fallen grains significantly alter the flow below feeding. In this regard, Bagnold (1941) stated that "the sand profoundly alters the state of the wind". McEwan (1993) extends the understanding of this statement further by saying "as the sand grains are accelerated by the wind, so must the wind be decelerated by the sand, and this is action and reaction of equilibrium or feed back mechanism, which leads to the development of steady state saltation and the limiting of the quantity of sand being transported" (McEwan 1993, p. 145).

It would appear from the study of Rasmussen & Mikkelsen (1991) that the subject of sand feed influence has not been widely investigated by sand experts. Therefore, this paper aims to focus on those problems related to sand transport rate and the wind flow regime in the case of feeding sand into the wind tunnel.

EXPERIMENTAL SET-UP

A 12 m long wind tunnel with a cross section of 0.5 m by 0.5 m, owned by the University of Aberdeen, was used to conduct the experiments. The wind tunnel is described in full by Rice (1990). A new feeding system, designed by the author, was fitted to the tunnel to carry out experiments related to this study. The system, which was installed at 41 cm downwind of the wind tunnel entrance, is shown schematically in Fig. 1. The rate of sand feed is controlled by a variable speed motor that controls the number of drum rotations and by the number and sizes of grooves cut in the surface of the rotating drum. The reservoir fills these grooves with a sand load. As the drum rotates the grooves drop their load into four chambers, each of which leads to an inlet tube that transports sand to a lower position in the wind tunnel.

The four inlet tubes are shaped aerodynamically (each having a minor axis of 5 mm and a major axis of 22 mm) to minimise the distortion of the wind, and are distributed at equal distances across the width of the wind tunnel. Each tube discharges its load through an adjustable opening between two convex, circular smooth surface plates. The convex nature of these plates assists feeding by accelerating the flow velocity between them. This prevents grain accumulation on the lower plate and spreads grains in a wide range across the wind tunnel. In addition, flow acceleration between them creates a low pressure zone that minimises the effect of back pressure generated in the inlet tubes due to the 'blower' nature of the tunnel.

The chambers were designed so that the two middle inlet tubes received about 80% of the total feed rate. This avoids sand accumulation near the wall that would otherwise arise if the sand were equally discharged from all of the tubes.

To reduce the large erosional capability of the wind flow at the upstream end of the wind tunnel and to ensure the rapid development of a fully rough condition, static roughness was created using cylinders of 11 mm height and 9 mm diameter, spaced evenly and uniformly at a centre-to-centre distance of twice the cylinder diameter. This roughness extended for a distance of 1.5 m downstream from the position of the sand feed tubes. According to Rasmussen & Mikkelsen (1988), an obstacle height of 11 mm gives approximately the same order of magnitude of roughness height ($z_0 = 5\%$ of the height) as can be extrapolated from the wind profile during sand transport.

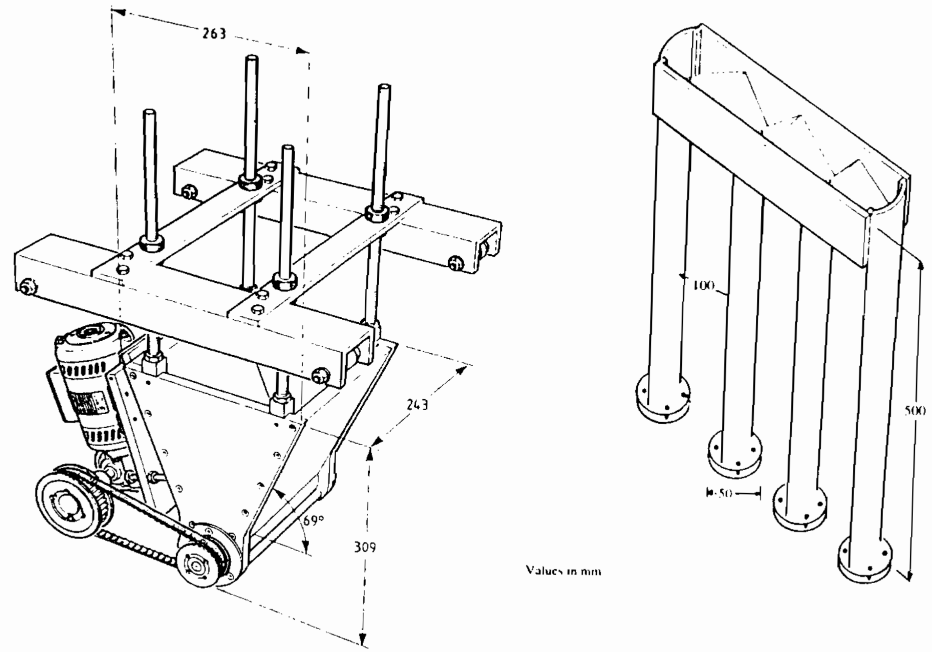

Fig. 1. Schematic view of the sand feeding system. The system was installed 41 cm downwind of the tunnel's entry. The rate of sand feed is controlled by a variable speed motor that controls the rate of rotation of the drum, and by the number and size of grooves cut in the surface of the rotating drum. The four inlet tubes are aerodynamically shaped (each having a minor axis of 5 mm and a major axis of 22 mm), and they are distributed at equal distances across the width of the wind tunnel.

A vertical pitot static tube rack measuring the dynamic and static pressure at three different heights, namely, 7.5, 17.5, and 41.5 mm above the sand bed (Fig. 2), was used to determine the shear velocity above the sand bed layer at a distance of 6.245 m downstream from the position of the sand feed tubes. The range of heights used lies within the range of the lower portion of the wind profile during sand movement that is suitable for shear velocity determination (Spies *et al.* 1995).

A sand trap of inlet width and height of 2 cm and 20 cm, respectively, was used to record sand flux. The sand trap is a modified version of that used by Jones & Willetts (1979) and later described by Al-Sudairawi (1992). Since there is, as yet, no standard trap to measure the sand flux, it is assumed that a zero static pressure difference between the inside of the trap and that inside the wind tunnel gives a reasonably good measurement of sand flux. The static pressure inside the sand trap was measured through two tappings on the lower portion of the trap opposite each other, and the static pressure inside the wind tunnel was measured by a static tube located near the trap inlet. The static pressure inside the trap was controlled by sliding doors on ventilating slots outside the wind tunnel so as to match the static pressure in the mouth of the trap to local static pressure in the wind tunnel. A manometer with the following specifications: (i) range 0 ± 1000 mm H_2O; (ii) accuracy $\pm 1\%$, (iii) linearity $\pm 0.5\%$, was used to obtain a zero difference between the static pressures.

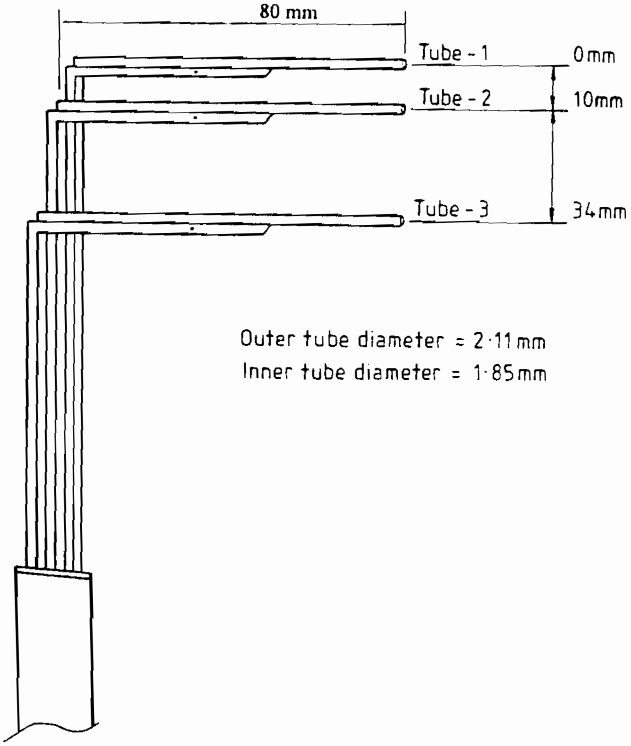

Fig. 2. Schematic diagram of the vertical pitot static tubes rack used in measuring the wind profiles.

The sand trap was tested in the work of Al-Sudairawi (1992) under different static pressure differentials. He presented evidence that the performance of the trap varies with this pressure difference and that zero pressure difference was the most appropriate operating condition. The trap provided a record of accumulated weight of sand as a function of time. The actual recording started 30 s from the beginning of

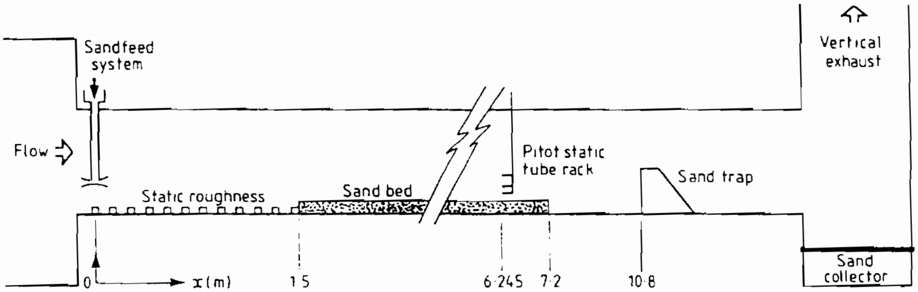

Fig. 3. Schematic side elevation of the wind tunnel. 1-Sand feed at the co-ordinate origin from which x is measured; 2-Static roughness used to ensure an early rough condition extending from $x = 0$ to $x = 1.5$ m; 3-Mobile sand bed having average grain diameter of approximately 275 μm extending from $x = 1.5$ to $x = 7.2$ m; 4-Sand trap located at $x = 10.8$ m; and 5-Vertical pitot-static tube rack used to determine the shear velocity at $x = 6.245$ m.

Table 1. Experimental findings of shear velocities and sand transport rates based on vertical pitot static tube rack and sand trap measurements, respectively.

case	Feeding height (cm)	Shear velocity (cm/s)	Sand transport rate (g/cm.s)
1	No feeding	22.95	.006
	4.5	30.33	.24
	10.5	29.4	.21
	15	28.78	.215
2	No feeding	37.85	.39
	4.5	35.4	.365
	10.5	32.86	.34
	15	32.07	.335
3	No feeding	47.75	.645
	4.5	46.8	.76
	10.5	45.1	.69
	15	43.2	.68

the experimental run. The trap was set at 3.6 m downwind from the downstream edge of the sand bed to avoid direct effect of the continuous changes in the bed characteristics, like texture and relief, on the sand flux measurement.

A series of measurements of the sand flux at three different preselected shear velocities, namely 22.95 (≅threshold), 37.85 and 47.75 cm/s, was performed on a 2 cm thick bed of sand having an average grain diameter of approximately 275 μm. The sand was well-mixed and laid flat over a length of 5.7 m from the downwind

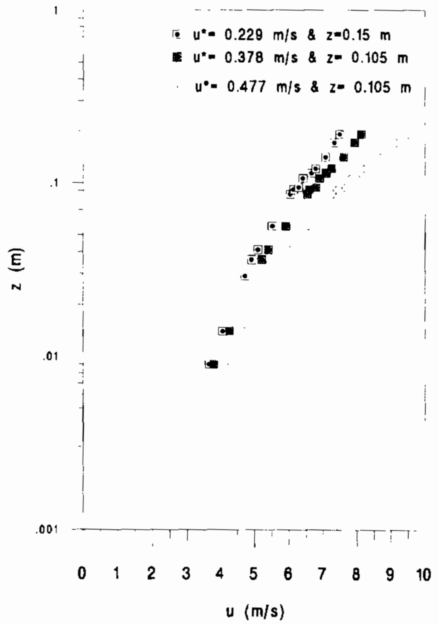

Fig. 4. Wind profiles measured over the laden sand bed at a distance of 6.245 m from the point of feeding in sand feed experiments. Legend shows initial value of shear velocity, u^*, and height of sand feeding, z.

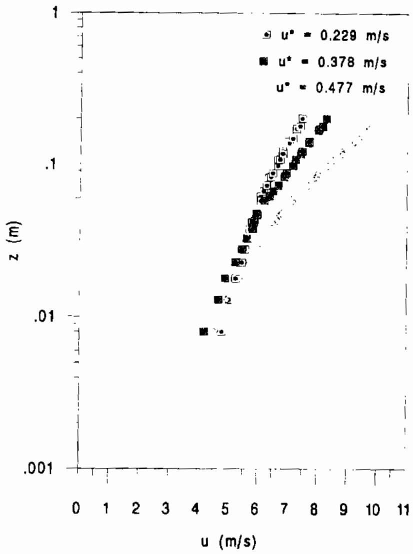

Fig. 5. Wind profiles measured over the laden sand bed at a distance of 6.245 m from the point of feeding in non-feed experiments. Legend shows value of shear velocity, u^*.

edge of the artificial static roughness. Figure 3 shows a schematic diagram of the general experimental set-up.

RESULTS

To establish the rate of sand feed required at each preselected shear velocity, three preliminary experiments were carried out without feeding. In these experiments, measurements of equilibrium sand flux were made. Accordingly, the rate of sand feed required at each preselected shear velocity was chosen to be approximately twenty times the average rate of sand transport in the experiment run at the lowest shear velocity (i.e. $u^* = 22.95$ cm/s) and approximately double the average rate of sand transport rate measured within the same period of run at the two higher shear velocities (i.e $u^* = 37.85$ and 47.75 cm/s). The reasons for this overfeeding are two-fold. First, the sand trap efficiency is probably between 70% and 80% (Rasmussen & Mikkelsen 1988), implying that it catches roughly 25% less sand than it should (the average total catch of a similar but unventilated vertical sand trap developed by Horikawa & Shen (1960) was shown to be 0.63 relative to an isokinetic trap (Cermak *et al.* 1982)). Second, some sand particles are caught between the cylinders, partially filling the space between them. Thus, to achieve an equilibrium population near the upstream edge of the free sand bed, it was found necessary to feed sand at more than the equilibrium transport rate. Accordingly, the chosen rates of feed were: 6 (nearly), 41 and 76 gm/s at preselected shear velocities of 22.95 ($\cong$threshold), 37.85 and 47.75 cm/s, respectively.

For the purpose of this study, identical experiments to those of primary ones were conducted with sand fed at three different heights, namely 4.5, 10.5 and 15 cm from the floor of the wind tunnel. Thus, nine sand feed experiments incorporated three

Table 2. Details of dune formation and sand bed layer thickness change due to feeding.

case	Initial shear velocity (cm/s)	Duration of run (s)	Rate of feeding (gm/s)	Height of feeding (cm)	Dune Height (cm)	Downstream distance of deposited sand from point of feeding (cm)	Depth of the sand bed at $x = 200$ cm	Depth of the sand bed at $x = 400$ cm	Depth of the sand bed at $x = 620$ cm
1	22.95	1800	6						
1.1				4.5	1.5	10	1.5	2	2
1.2				10.5	—	25	1.5	1.8	1.6
1.3				15	1.3	41	1.7	2	2
2	37.85	1200	41						
2.1				4.5	7.5	8	NA*	NA*	NA*
2.2				10.5	4.5	29	3	NA	1.7
2.3				15	3.5	60	3	NA	1.9
3	47.74	960	76						
3.1		+60		4.5	6.5	12	2.5	2.5	1.5
3.2				10.5	2.5	123	2.5	2.2	1.5
3.3				15	4.5	150	4**	3.2	1.5

** The depth of the bed was almost unchanged (visual observation).

** Depth of the sand bed at x = 100 cm.

x indicates distance from the position of the sand feed tubes (Fig. 3).

Measurements were taken at the end of a run of the duration indicated in column 3.

NA means data is not available.

preselected shear velocities with associated rates of sand feed carried out. The results of the sand feed experiments and those with no sand feed are presented in Table 1.

In all experiments, the changes in the surface characteristics of the bed were monitored. The dimensions of dune formation and the bed thickness change in each experiment are presented in Table 2.

The influence of sand feed on the wind speed profile was investigated by a comparison of the wind profiles measured over the laden sand bed in the sand feed experiments, for selected heights of feeding, and in non-fed experiments at a distance of 6.245 m from the point of feeding. The results of these measurements are shown in Figs. 4 and 5, respectively.

VISUAL AND QUANTITATIVE OBSERVATIONS

In the experiments without sand feed, the bed texture gradually started to change shortly after the start of the experiments. This was more obvious in experiments with shear velocity 37.85 cm/s and 47.75 cm/s than in the one with shear velocity near the threshold value. Coarser-grained material collected at the surface and relief (ripples) began to form. The ripples formed uniform patterns and became more sharp-crested toward the end of each experiment. Similar observations were reported by Rasmussen & Mikkelsen (1991).

The erosion of the sand bed began at the downwind edge when the shear velocity was 37.85 cm/s, while it began at the upwind edge of the bed at shear velocity of 47.75 cm/s. This suggests that, at the former shear velocity, more distance is required to develop a steady-state saltation than at the latter one, which in turn, affect the adjustment of the boundary layer to uniform roughness. This effect can also be related to the characteristics of the artificial static roughness bed used to produce equilibrium boundary layer. The bed may fail to give a value of surface roughness that should be equivalent to the roughness height of the saltation layer.

In sand feed experiments, the changes in the surface texture of the bed and the ripple formation were not so marked, with a relatively smooth sand bed observed at the end of each experiment. Sand was deposited a little downstream from the point of feeding as a dune on the floor containing the cylinders (Table 2).

EFFECT OF SAND FEEDING ON SAND FLUX AND WIND PROFILE

In the windblown sand system, two critical items should be considered: the grain cloud, i.e. saltating grains, and surface drag extraction of momentum from the flow (McEwan *et al.* 1993). When sand feed is added to the system, the falling grains absorb some of the momentum from the wind flow between the height of feeding and the top of the grain cloud, resulting in a reduction in the wind strength above the grain cloud. The falling grains may remain in saltation mode, gaining momentum, until they have sufficient energy to eject other bed grains into the flow. In such circumstances, the fed grains may provide the extra momentum needed to initiate the sand movement by direct collision.

Significant sand flux changes were observed in the sand feed experiments. At or near the threshold, where the wind has insufficient near-bed momentum to initiate the grain collision sequences that start the saltation process, sand feed initiated the chain reaction of saltation via the falling grains which carry momentum. The resulting transport rate was, therefore, mainly associated with particle collision rather than fluid entrainment. As a result, the effective roughness of the sand bed responded to a quick development of the saltation layer, causing an increase in the shear velocity as well as in the amount of sand transport. In addition, the reduction in wind strength due to the feeding was thought not to be large because of the small amount of feeding. From Fig. 6a, it can be seen that the rate of sand transport was increased at near threshold shear velocity by approximately 3900%, 3400% and 3483% during sand feeding at heights of 4.5, 10.5 and 15 cm, respectively, whereas the shear velocity was increased by 32.15%, 28.1% and 25.4%, respectively.

Owen (1964) emphasised the feedback between the moving grains and the near-surface wind and introduced the concept of self-regulation of the saltation cloud.

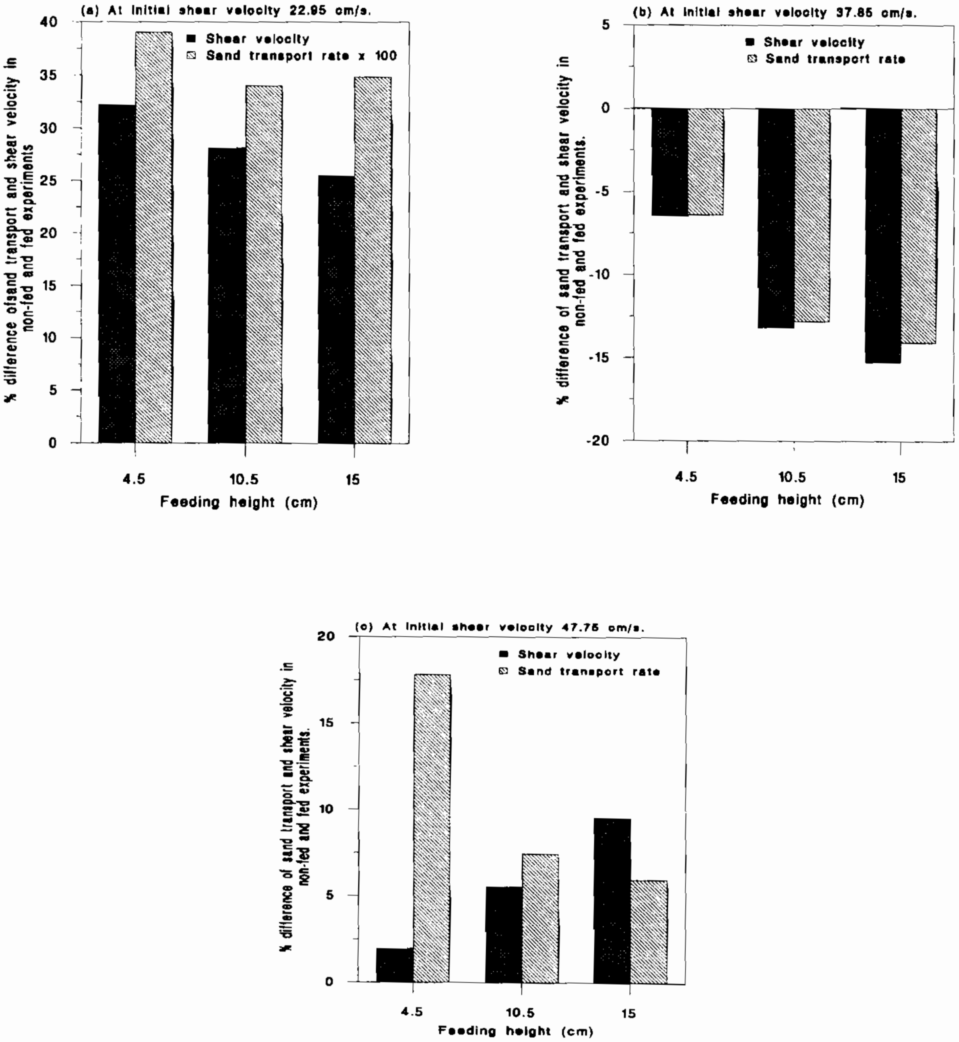

Fig. 6. The ratio (in %) between sand transport rate and shear velocity respectively without sand feeding and with sand feeding in the wind tunnel.

This concept is described as an equilibrium state being reached between the wind and a certain concentration of moving grains. In other words, an increase in sediment concentration reduces the near-bed wind velocity, and saltation is consequently reduced until equilibrium is achieved. Conversely, a decrease in the concentration increases the near-bed wind and, thus, more grains are maintained in saltation.

At medium shear velocities, it appears that the feed rate was poorly judged and overfeeding occurred. A slight increase was produced in the concentration of the saltating grains associated with the near-surface wind already reduced due to the feeding. This increase reduced saltation until an equilibrium state was achieved between the strength of the wind and its capacity to carry sand grains. This was confirmed by experiments conducted at an initial shear velocity of 37.85 cm/s. When the sand was fed at heights of 4.5, 10.5 and 15 cm, the amount of sand transport was reduced by 6.41%, 12.82% and 14.1% and the value of the shear velocity reduced by 6.48, 13.19 and 15.27%, respectively (Fig. 6b).

At the highest shear velocities, the sand feeding had a crucial role in regulating the sand flux. With the sand feed turned on, the grain cloud population increased to an appropriate saturation level (similar to that with the absence of sand feed) despite the reduction in the shear velocity. An increase in transport rate, accompanied by a fall in near-bed velocity, is a possible consequence of sand feeding. This is shown by the findings of the experiments run at the high shear velocity (Fig. 6c). With sand fed at heights of 4.5, 10.5 and 15 cm at an initial shear velocity of 47.75 cm/s, the amount of sand transport increased by 17.83%, 7.44% and 5.96% and the shear velocity reduced by 1.99%, 5.52% and 9.51%, respectively. This confirms that fluid entrainment was not the key process in generating the saltation cloud.

In all sand feed experiments, the effect of the height of feeding on sand transport was recognised. Figure 7 shows a plot of this relation for the two shear velocities above their thresholds. In the cases where the shear velocity was considerably larger than its threshold, the reduction in the percentage change in the sand transport rate with the increase of height of feeding was in phase with the corresponding change in the shear velocities. Each of these cases tends to approach an equilibrium state of reduction in the percentage of change in the sand transport. The results obtained, at lower shear velocity (threshold) almost agrees to some extent with the findings of the above two cases. As the height of feeding increases, the cross-sectional area of the space in which the falling grains are situated increases, and thus more momentum is extracted from the wind flow below the feeding point. Reduction in wind strength is, therefore, expected to be a function of the height of sand feed.

Velocity profiles measured in this study for selected heights of feeding (Fig. 4) confirmed that feeding directly affected the flow. In the experiments without sand feed, the profiles exhibited two distinct regions separated by a kink varying in position (at heights ranging from 3.5 to 4 cm above the sand bed) with the variation in wind speed (Fig. 5). This kink, which Bagnold (1941) recognised, corresponds to "the height reached at which a characteristic or average saltation trajectory acquires the bulk of its forward momentum from the air" (McEwan 1993, p. 145). Below the kink, in the lower segments of the profiles, it is assumed that the grains in saltation significantly alter the wind flow (Gerety 1985). The alteration in the flow in this segment is attributable to the number and speed of saltating grains which absorb momentum from the flow. At high wind speeds, where a large number of grains are

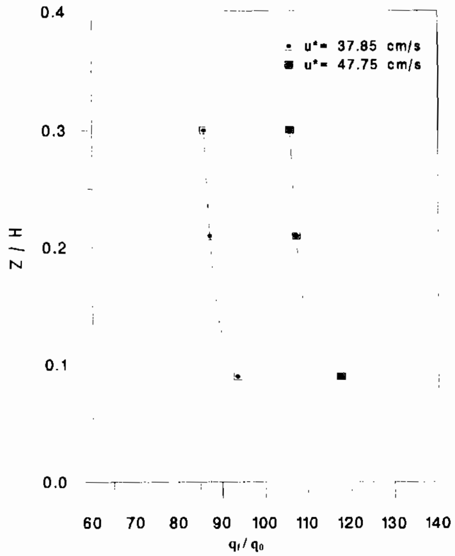

Fig. 7. Relationship between sand flux ratio and height of feeding at shear velocity (u^*) below the threshold. Sand flux ratio is obtained by dividing total sand flux during feeding (q_f) by total sand flux during zero feeding (q_0) while ratio height is obtained by dividing height of feeding (Z) by the height of the wind tunnel (H), which is 0.5 m.

set into motion, more proportional reduction in the wind strength was observed in the lower segment of the profiles than at lower wind speeds. Above the kink, however, where the number of saltating grains was sufficiently low, the force exerted by these grains per unit volume on the wind decayed very rapidly with height, so that wind strength ceased to exhibit momentum loss.

In the experiments with fed sand (sand feeding at a height of 15 cm in the case of low wind speed and at a height of 10.5 cm in the two other cases), the kink is less recognisable than in the experiments without sand feed (Fig. 4). This could be attributed to the presence of a substantial number of fed sand grains above the kink height found in experiments without sand feed. Consequently, the lower segment of the profile at each wind speed exhibited significant differences in fed and unfed cases, especially at the lowest wind speed. These differences are believed to arise from the fact that the fed grains absorb momentum from the air from the feeding point downwards, thus producing an extra reduction in the fluid stress strength near the bed. Such a reduction was observed at all wind speeds, but the upper segments remained relatively unchanged compared with non-feed experiments.

CONCLUSIONS

Experiments have shown that feeding sand in wind tunnel experiments influences the sand transport and the flow regime as follows:

1. The fed sand absorbs some momentum from the wind flow and, at the same time, supplies extra momentum to the sand bed surface. It appears that both the absorbed and the supplied momentum increase with the increasing height of feeding up to a certain limit.

2. At wind shear velocity at or below threshold levels, the sand bed is artificially set into motion by the fed sand, providing the necessary momentum to initiate sand transport. This leads to an increase in the amount of initial shear velocity due to a developing saltation layer, which increases the effective roughness height.
3. Feeding sand at shear velocities above the threshold, both impact and fluid shear velocities play roles in initiating the sand transport rate by developing an equilibrium saltation layer.

RECOMMENDATION

Some wind-tunnel experiments on sand transport require continuous sand feed to maintain a steady sand flux for a long period of time. Such feeding might disturb the general conditions of the experiments because the fed grains significantly alter the flow below the point of feeding. It is also very difficult, if not impossible, to establish a required rate of sand feed at a working shear velocity. To avoid the problems that may arise from feeding sand into a wind tunnel, and to assure a more accurate development of an equilibrium sand flux for a considerable period of time, it is recommended that a longer wind tunnel should be used. A wind tunnel of a length of 30 m or more, such as the boundary-layer wind tunnel of Colorado State University could be more suitable for carrying out experiments with equilibrium sand flux, without feeding sand. Shao & Raupach (1992) reported experimental results from a study of saltation in a wind tunnel with a working section 17 m long, 1.5 m wide, and 0.9 m high. It was found that the sand transport rate increases from zero at the upstream edge of the sand bed to a maximum value at around 7 m downwind, and that the minimum distance required for sand transport to reach equilibrium (about half the maximum value) is approximately 15 m, depending on wind speed. Any measurements of the sand transport rate at a downstream distance of roughly 7 m may therefore overestimate the sand flux value. This is also supported by the numerical experiments of Spies (1995).

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تأثير التغذية الرملية على حركتها الديناميكية في النفق الهوائي

جاسم محمد العوضي

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ص.ب. 24885 الرمز البريدي 13109 الصفاة – الكويت

خلاصة

أجريت عدة تجارب باتباع أسلوب النفق الهوائي من أجل تقييم طرق تأثير التغذية الرملية على طبيعة حركة الرمال. وقد تضمنت التجارب إجراء سلسلة من القياسات لانجراف الرمال وفق ثلاث سرعات احتكار مختارة على ثلاثة ارتفاعات تغذية، وذلك على طبقة رملية بلغت سماكتها 2 سم (بلغ متوسط قطر الحبيبات الرملية 275 ميكرون تقريبا) . وقد تم بعد ذلك مقارنة الخصائص المتغيرة للطبقة الرملية ومعدل الانجراف الرملي في كل تجربة على حدة . وبشكل عام ، أظهرت التجارب أن إجمالي معدل الانجراف الرملي قد تغير على نحو كبير تبعا لارتفاع التغذية الرملية الذي أجريت عليه التجربة. كما أظهرت نتائج الاختبارات التجريبية أن وجود مصدر للرواسب الرملية عند مدخل النفق له أثر مباشر على حركة الرمال وعلى المقطع الجانبي لسرعة الرياح بشكل عام.

INSTRUCTIONS TO AUTHORS

The Kuwait Journal of Science and Engineering is an international journal which publishes papers in all fields of natural, life and applied sciences and engineering. The Journal will publish papers reporting original contribution to scientific knowledge. Review articles on themes of topical interest are welcome.

Communications

1 Manuscripts and correspondence should be addressed to Dr. Martha Thomson, Editor-in-Chief at the following address: Kuwait Journal of Science and Engineering, Academic Publication Council, P.O. Box 5669, Safat 13060, KUWAIT.

2 Authors are encouraged to supply E-mail addresses, and fax and telephone numbers upon submission of manuscripts. These are likely to speed communications.

3 Late changes of address must appear as a numbered footnote.

General

1 An original and two copies of text, tables, figures and captions should be submitted on good quality A4 paper for review. Papers must be in English; either American or English spelling is accepted. An abstract in Arabic is required.

2 Papers accepted for publication will be limited to a maximum printed length of 24 pages. Page charges will apply for papers exceeding 12 pages.

3 Concise well thoughtout and prepared papers adhering to the style of the Journal are likely to be published sooner than those in need of extensive editing and revision. The Journal will enforce its style on papers accepted for publication. It is the responsibility of authors to ensure adherence to guidelines outlined in these 'Instructions to Authors'.

4 Full instructions to authors are appended below. REFER TO THESE AND A RECENT ISSUE OF THE JOURNAL FOR DETAILED GUIDELINES.

Preparation of Manuscript

1 The main text should be paginated, starting with the Title/Abstract page and ending with the References page(s). Sheets of captions to Figures and Tables should establish another paginated list. Page numbers should appear at middle top of pages.

2 Manuscripts must be typewritten with double spacing and wide margins (25mm) at all sides. A font size of 12 points is required.

3 Words to be printed in italics should appear as italics or be underlined in manuscript.

Revision of Manuscripts

1 Manuscripts must be returned to the Editor-in-Chief within 3 months of the authors receipt of referees' reports.

Title/Abstract/Keywords

1 The title page should contain the title of the paper, the name(s) of the author(s), their institutional address(es) and an abstract. Up to 5 keywords should be given below the abstract in alphabetical order and separated by semicolons.

2 Title should be short, specific and informative. Avoid long titles; a running title of no more than 75 characters is encouraged.

3 The abstract, not exceeding 300 words, should be independent of the text. It must not contain bibliographical references or references to figures. Avoid abbreviations in abstracts.

Text Headings

1 The main text should follow the abstract and conform with the current style of the Journal. The following hierarchy for headings should be used:

AREA (bold capitals, centered)
Sector (bold, capital first letter, centered)
Zone (italics, capital first letter, un-indented)
Block (italics, capital first letter, indented)
No numbers or Roman numerals should be used in these headings.

Figures

1 All illustrations are called Figures and should be referred to as 'Figure' at the start of the sentence or as 'Fig.' otherwise. Figure parts are referenced as Fig. 1(a) or (Fig. 1a).

2 Figures should be numbered serially and should appear in text in order.

3 Figure captions should appear on a separate sheet.

4 All composite figures should be mounted together and the parts labelled (a), (b), (c), etc. Page size montages of photographs count as a single figure. Avoid mixed montages of photographs and line drawings.

5 Original diagrams should be prepared at approximately twice the final printed size, using black drawing ink on a good quality tracing medium, or high quality laser printing.

6 The maximum printed size is 170 × 250 mm. Letters and numerals should not be less than 1mm after reduction. Regular Times or Helvetica typeface with a final (printed) size of 6pt to 8pt type, and equivalent line weights, are preferred. (If drawn for intended 50% reduction use 12pt to 16pt fonts). A small range of print size (less than twofold) is recommended.

7 Use distinct tones when shading. However, avoid shading as much as possible, unless it is absolutely necessary.

8 Although original figures are required, good glossy photographs of originals at $1\frac{1}{2}$ times the intended printed size are acceptable. Figure number and authors names should be faintly pencilled on back of all figures and originals.

9 In the final version of the manuscript indicate in pencil in the left hand margin the desired location of Figures and Tables.

Photographs

1 Photographs occupy separate coated pages, normally restricted to two per page. Photographic figures will be printed in sequence, and they should be numbered.

2 Photographs (i.e. half tones) should be sharp black and white glossy printed at 1 to $1\frac{1}{2}$ times the intended printed size and mounted in the desired layout. Both portrait and landscape styles are accepted.

3 Field photographs must contain a scale.

Maps

1 Maps and field sketches must include a metric bar scale. Regional maps must include a north arrow and at least 2 latitude and 2 longitude numbers on each of its respective sides; National Grid numbers may also be used. Map keys should be given on map or figure, not as numbered boxes.

Color Illustrations

1 Color figures, maps and photographs may be accepted at the authors' expense.

Tables

1 References to tables in text should appear as Table 2 or (Table 2).

2 Each table should have a brief descriptive title set above the body of the table.

3 Submit tables on separate sheets. Assign to tables serial numbers which correspond to the sequence of their appearance in the text.

References

1 'Personal communications' should be authorized in writing. Unpublished data should be cited as (unpublished data).

2 Authors are responsible for accuracy of references.

3 References must be on sheets separate from the text.

4 An alphabetical list of all literature cited in the text should follow the text, headed by REFERENCES, and double spaces. Names of periodicals should be given in full.

Example References

Journal:

Al-Awadi, N.A. 1990. Gas Phase pyrolytic reaction. Journal of Chemical Society **2**:2179–2189.

Book:

Jenny, H. 1980. The Soil Resources.
Springer-Verlag, Berlin.

Book Chapter:

Verklij, A.J. & Schat, H. 1990. Mechanisms of metal tolerance in plants. In: **Shaw, A.J. (Ed.).** Heavy Metal Tolerance in Plants. Pp. 179–193. CRC Press, Boca Raton.

Conference or 177 Symposium:

Waked, A. 1980. Energy conversion measures in Kuwaiti buildings. Proceedings of the First Regional Symposium in Thermal Insulation in the Gulf States. Kuwait Institute for Scientific Research, Kuwait.

Dissertation:

Al-Sulaimi, J.S. 1981. Aspects of geology of the northern part of Oman Mountains, United Arab Emirates. **Ph.D. thesis** University College of Wales, Aberystwyth, U.K.

Citations

1 Citations in the text should be in the form (Misfir 1988, Salama *et al.* 1991), or "according to Misfir (1988) and Kepper & Astry (1993)", Papers "in preparation" or "submitted" or "under review" are NOT VALID references. Work in preparation, unpublished abstracts, and personal communications or oral communications may be cited in text, but NOT in the reference list.

Acknowledgments

1 Acknowledgments should follow the main text and be headed **ACKNOWLEDGEMENTS**.

2 Personal acknowledgments should precede those of institutions or agencies.

Appendices

1 Appendices are encouraged for specific details on methodology, mathematics, or voluminous data.

2 Computer program listing, if included, must be camera ready.

Units, Abbreviations, Acronyms

1 Units should be metric, generally SI, and expressed in standard abbreviated form.

2 Acronyms may be acceptable, but must be defined at first usage.

Mathematics

1 Authors must provide instructions on how symbols and equations should be set.

2 Equations should be numbered sequentially in the right-hand side and in parenthesis. They should be referred to in the text as 'Equation 4' or Eq. 4.

Page Proofs

1 One set of proofs will be sent to the corresponding author to be checked for typesetting and editing. Corrections or changes must not be made which constitute departure from the article in its accepted form. Proofs should be returned within 2 weeks from date of receipt.

2 Check proofs thoroughly and return them immediately to the publisher.

Reprints

1 Fifty copies of each published paper will be supplied free of charge to the principle or corresponding author. Additional copies may be requested for cost using the order form provided with the proofs.

2 All manuscripts become property of the Journal and are not returned to authors, even if a manuscript is rejected. Original manuscripts and illustrations are discarded two months after publication, unless a prior arrangement is made with the Editor-in-Chief.

Electronic Text

1 Final version, ONL, may be submitted on disk, along with hard copies of manuscripts.

2 Text from most word processing systems is acceptable. The Journal, however, encourages the use of Microsoft Word and Wordperfect in the MS-DOS or WINDOWS format. Save the file in the word processor proprietary format (not ASCII).

3 Authors must submit $3\frac{1}{2}$ inch floppy disks.Label disk with authors names, operating system and name of wordprocessor. Include in label a shortened version of the paper title and file name. Keep the entire manuscript in one file. Distinguish 0 from o and 1 from l.

4 Illustrations and tables are accepted in any of the common formats used by popular drawing programs for the PC and MAC environments. Use a separate disk for the illustrations and label as in 3 immediately above.

5 Authors are requested to ensure that the content of the diskettes corresponds exactly with the hard copy manuscript.

6 Do not transmit texts or figures electronically (via the Internet).