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DUST EMISSIONS FROM UNPAVED GROUND SURFACES

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ABSTRACT

Soil erosion occurs through the process of wearing away of the earth's land surface through rain, wind or other agents. Dust storms cause air pollution as the dust particles are carried by the wind. Dust emissions from unpaved ground can cause enormous problems such as dust storms that may lead to accidents and also respiratory tract diseases. The main objective of this study was to investigate fugitive dust resulting from unpaved ground caused by wind. Two types of clay soil (type A and B) was obtained from two different locations in Johor, Malaysia. Dust emission assessment equipment consisting of a purpose built wind tunnel was developed and modified to determine the assessment of the soil erosion index for simulated natural ground surfaces and was used also in laboratory testing. The assessment was carried out to preset values of the wind speed which were 2.9 m/s, 3.8 m/s and 7.2 m/s in environmental temperatures of 26° C, 40 °C and 60° C in the various tests. The test soil specimens were prepared in a mould with dimensions of 60 (L) x 60 (W) x variable height (maximum 5mm). A total of 90 tests were carried out on 2 different samples (type A and type B). The binding properties of fines and stabilizers within the gravel particles of a road surface may be reduced in the dry season due to moisture loss. The foremost industry need is to develop new and appropriate instrumentation for the evaluation of a reliable soil erosion index.

Keywords: clay soil, dust assessment**,** dust storms, erosion index, soil erosion, unpaved road.

INTRODUCTION

In geomorphology, erosion refers to the consequences of exogenic processes (such as water flow or wind) which remove soil and rock from one location on the Earth's crust, then transport it to another location where it is deposited. Eroded sediment may be transported just a few millimeters, or for thousands of kilometers. Soil particles picked up during wind erosion are a major source of air pollution, in the form of airborne particulates of fine sand size (dust). Dust from erosion acts to suppress rainfall and changes the sky color from blue to white, which leads to an increase in red sunsets. The images shown in Figure-1 are examples of the severity of this problem in hot and arid climates, such as that in Dubai and the surrounding Middle Eastern countries dust storms are prevalent. When dust storms hit built-up areas they reduce the visibility leading to disruption of essential services. Such dust storms are also common in other areas such as Arizona during dry and windy conditions, when walls of dust are known to blanket an area in a matter of seconds. Volcanic ash storms may be construed to be similar but the particle size distribution is significantly different and so is its origin. Either of these storms cause havoc in the environment with road safety implications of a relatively sudden and significant reduction in the visibility and hazard to drivers on highways (Figure-2) escalating the labour costs for the maintenance of clear surfaces of the highways.

Wind erosion is a natural process of wind forced movement of soil particles from unpaved ground surfaces. This process has the distinct phases of particle entrainment, transport and deposition. The process is somewhat complex as it is affected by many factors which include environmental conditions (such as wind speed, precipitation, temperature) ground surface conditions (such as topography, properties of ground cover and that of the soil (texture, shape, composition, moisture and aggregation. During wind erosion, these factors interact with each other and, as the erosion progresses, the properties of the eroded surface is modified significantly. (Shao *et al,* 2008).

Unpaved ground / road (or also commonly referred to as gravel road) is a type of unimproved roads with no surface road sealing material added. The gravel used consists of crushed stone, sand and fines. These then form a source for soil erosion in any weather especially in dry conditions. In many developing countries, roads through villages remain unpaved and vehicle-generated dust is a constant part of the lives of many villagers for much of the year. Dust is one of the main reasons given by rural dwellers for the necessity of sealing rural roads, particularly roads through villages (The World Bank, 2011). It is known that vehicle generated dust has adverse impacts on the health of individuals (especially children) transmission of disease, respiratory afflictions, the safety of road users, agricultural production, the local environment and the cost-effectiveness of the gravel road material. Traffic-generated dust is a transport related problem in villages. There is also anecdotal evidence in South Africa of the increased mortality rates among young livestock from traffic-generated dust.

Figure-1. Dust storms over built up areas (http:// www.google.com/search?q=dust+storm).

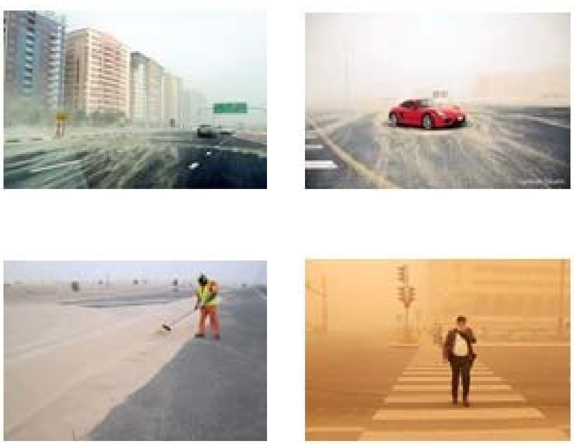

Figure-2. Disruptions to highways due to dust storms and the associated environmental health hazard (http:// www.google.com/search?q=dust+storm).

The loss of road fines (<0.075 mm sieve) as dust from the wearing surface exposes the coarse aggregates that readily become dislodged with the abrasive action of the traffic. If such material is lost in vast quantity, it needs to be replaced. If these are not treated with a dust palliative, aggregate replacement will become necessary over shorter time periods, and frequent unpaved road maintenance will be required.

LITERATURE REVIEW

Air pollution in cities is a very complex issue, showing strong seasonality and dependence on meteorological factors, sometimes culminatingin severe and dangerous smog episodes which require intervention by local authorities (Jancsek-Turoczi *et al*, 2013)

Soil particles vary greatly in size, and soil scientists classify soil particles into sand, silt, and clay. Starting with the finest, (clay particles are smaller than 0.002 mm in diameter). Some clay particles are so small that ordinary microscopes do not show them. Silt particles are from 0.002 to 0.05 mm in diameter. Sand ranges from 0.05 to 2.0 mm. Particles larger than 2.0 mm are called gravel or stones. Most soils contain a mixture of sand, silt and clay in different proportions.

Unpaved roads are the largest source of particulate air pollution in the country. According to the Environmental Protection Agency, unpaved roads produce almost five times as much particulate matter as construction activities and wind erosion which is the next two largest sources combined. Dust emissions from unpaved surfaces are caused by the same factors as for paved surfaces, but the potential emissions are usually much greater. A dust emission factor represents the value relating the amount of dust released to the atmosphere with the activity of dust generation.

Efforts to study fugitive dust (FD) on unpaved road in the laboratory are hampered by the lack of an effective instrument to measure the broad range of particle sizes that make up FD. To meet this need, an attempt was made to develop and evaluate a novel instrument capable of measuring dust generated from soils having particles size less than 2.0 mm. (Sokolik *et al.,* 2001; Epps & Ehsan, 2002)

Shao (2008) defined soil erosion / erodibility index I as the potential soil loss in t/ha/yr (g/m^2/s). This therefore represents a feeling as to how erodible the ground surface is at a site.

LABORATORY DUST ASSESSMENT

Figure-3 illustrates an innovative dust assessment technique that was developed for this study. The specimen preparation for the experiments presented herein were for dried soil passing 2mm sieve. Samples collected and prepared were sieved to remove particles retained on 425 µm prior to testing. A total of 336 number of soil specimens were prepared in 60 mm x 60 mm x 2mm adjustable height mould for all the four series of tests to determine the amount of dust generated (Soil erosion index, I in unit g/m2). Table-1 presents the four series of tests and the total number of soil specimen prepared and tested for the dust assessment experiments carried out in the laboratory. The dimensions of the test specimens were such that there was a two millimetres protrusion of exposed surface prior to testing as shown in Figure-4**.**

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Figure-3. Dust assessment equipment.

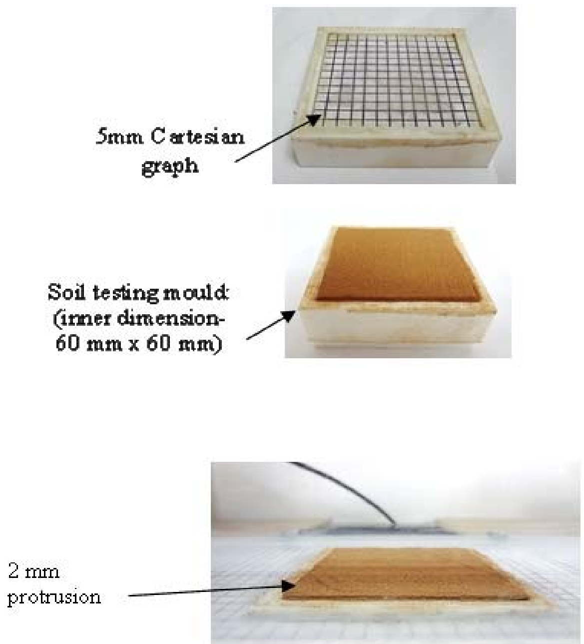

Figure-4. Mould for test specimen with 2mm protrusion.

Table-1. Dust assessment tests reported.

Test Series	Details of specimens tested
1	Uncompacted loose air dried sample Wind speed 7.2 m/s Wind temperature = 25 +/- 2 ^{0}C
2	Compacted Unstructured and Structured samples Wind speed 7.2 m/s Wind temperature = 25 +/- 2 ^{0}C
3	Road Dust sample – loose air dried Wind speed 7.2 m/s Wind temperature = 25 +/- 2 ^{0}C
4	Wet road dust sample Wind speed 7.2 m/s Wind temperature = 40 +/- 2 ^{0}C & 60 +/- 2 ^{0}C

RESULTS & ANALYSIS

Test series 1; Soils tested were of different particle sizes (passing sieve 425, 300, 212, 75 and 63 µm) tested at 6 testing periods ranging from 30s to 300s. Figure-5 illustrates the soil erosion index obtained from the experiment results. Particle size passing 212 µm generate highest soil erosion index tested on all testing periods (500 to 844.44 g/m2) for soil type A (CH). Similar phenomena were observed for soil type B (CI) as shown in Figure-6. Particle size of 212 µm contributes the highest amount of soil dust compared to smaller particle size (75 and 63 µm). From this observation, it is found that soil type A generally give higher soil erosion index compare to soil type C (450.00 g/m2 for soil type A and 844.4 g/m2 for soil type B).

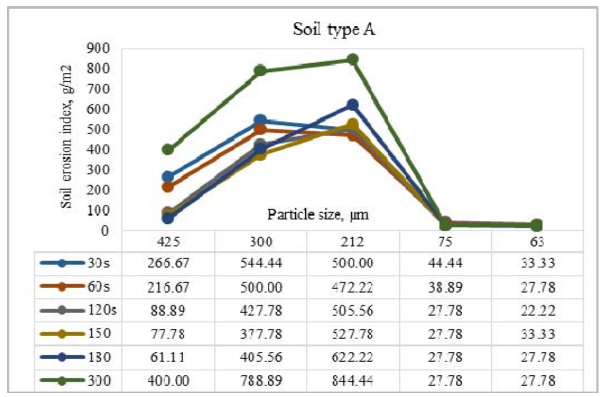

Figure-5. Soil erosion index of soil type A tested at various particle sizes and testing periods.

The area of scour rates was also determined at 150 second intervals to investigate the soils that pick up dust from the soil surface through wind erosion testing. The laboratory experimental results show that particle size passing 212 µm gives highest scour rate for both soil type A and C (see Figure-7). Furthermore, the soil erosion index was observed to correlate linearly with scour rate with high coefficient of determination of 0.83 (soil A) and 0.98 (Soil C) as shown in Figure-8.

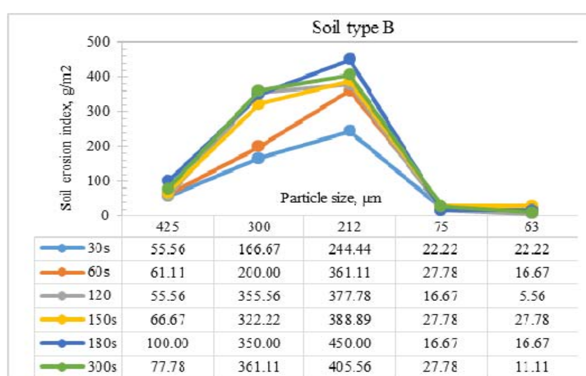

Figure-6. Soil erosion index of soil type C tested at various particle sizes and testing periods.

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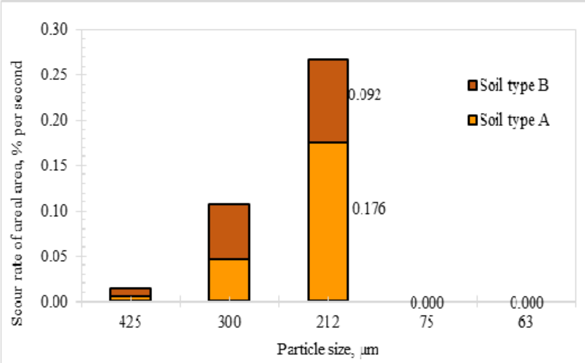

Figure-7. Scour rate of areal area for soil type A and C tested after 150 seconds intervals.

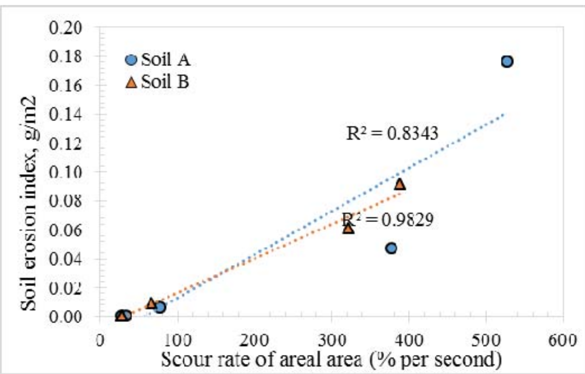

Figure-8. Relationship of soil erosion index and scour rate of areal area.

Test Series 2; Analysis of the observations showed that soil type A (CH) generally gave higher soil erosion index for all the particle size tested compared to soil type B (CI). Hence, soil type A sample was used for Test Series 2 to research the effects of the soil erosion index for both compacted but unstructured and compacted structured samples. Soil samples prepared for the analysis in this section were compacted at its maximum dry density and optimum moisture content. The results showed that the compacted sample did not generate dust once the samples were compacted. This is way below the expectations of obtaining a small amount of dust as the moisture content for all the structured and compacted soils are relatively low (< 0.5%). However, Figure-9 shows the erosion index rose to 7.5 g/m2 when the tested sample A used was in loose and uncompacted condition. The moisture content of the loose sample is 0.011%. The relatively low moisture content of loose soil bear no significant difference compared to moisture content of both structured and compacted samples. Nevertheless, loose sample produces significant amount of dust compared to the compacted structured and unstructured sample (all the samples' moisture content are almost 100% dried). Hence, the analysis shows that once the soil sample is being compacted, no dust will be generated at a certain period. A personal communication with a soil road expert (Yek, 2014) revealed that in order to reduce the maintenance cost of an unpaved road, the compacted soils of a newly constructed road is necessary to be sealed with sealant at an application of 1 to 2 layers on the surface of the compacted sample to expand the life span of the road.

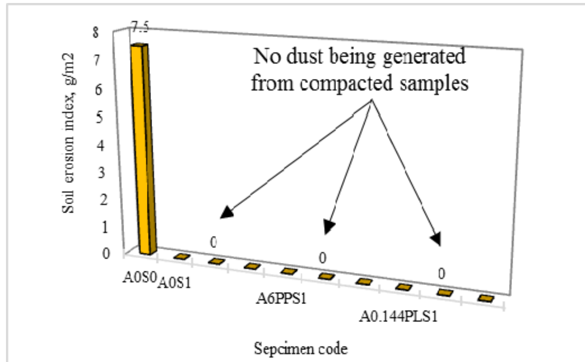

Figure-9. Soil erosion index for structured soils and loose samples.

Test Series 3; Three repetitive samples were carried out using soil samples collected from road surface and tested at three different wind velocity. Figure-10 shows the soil erosion indices which are generally increasing with the increase of testing period. It can be seen that larger variation of the soil erosion index can be observed on the three repetitive sample when the samples were tested at the maximum wind speed of 7.2 m/s. Mean data for soil erosion index was reported. There were significant increases in soil erosion index when dust sample were tested at 7.2m/s and as testing period increased. The average wind velocity in Malaysia, 3.8 m/s was chosen and tested on dust sample and was found that soil erosion index has significantly reduced to 6.02 g/m2 when tested for a period of 30 mins. In comparison, the lowest wind velocity (2.9 m/s) adopted for the testing in this research produces marginal erosion index which increases from 0.09 g/m2 to 1.20 g/m2 tested for a period of 30 mins. The results suggested that wind velocity has significant influence in generating dust particle on road surface.

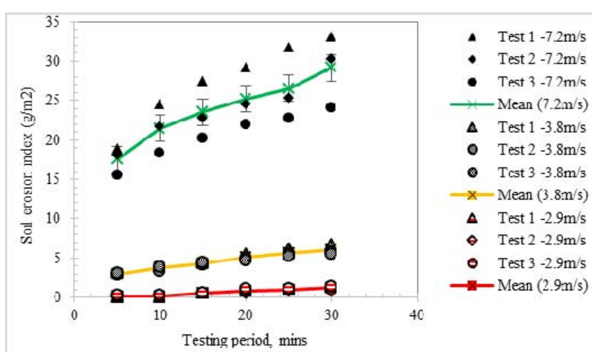

Figure-10. Effect of different wind speeds on dust sample tested.

Test Series 4 Three different wind temperatures were used to research the soil erosion index for loose soil sprayed with 10% of water. The application of water on the loose soil surface show minimal soil erosion index obtained (1.11 g/m2) when tested over a period of 15 mins at wind temperature of 32±2°C. The moisture content of the sample (0.163%) was measured after the experiment. The improved performance can be explained by the hygroscopic and deliquescent properties of water that keep the surface wet and aid in dust control. However, when the wind temperature is increased to 40±2°C, the soil erosion index increased linearly at 17.5%. to 7.22 g/m2. Nonetheless, for dust sample tested at wind temperature of 60±2°C, the soil erosion index rose to 3.33g/m2 at an increment of 222% (see Table-4.19). These values were compared to the soil erosion index obtained from Section 4.11.1.3 for sample tested at testing period of 15 mins, constant wind temperature of 32±2 °C and at its dried condition. The soil erosion index was observed to have reduced significantly from 23.52 g/m2 to 1.11 g/m2 (reduction of 22.41 g/m2) when the dust sample surface is sprayed with water. When the wet sample surface is exposed to a high temperature at 40 °C and 60 °C, the reduction in soil erosion index further went down to 21.58 g/m2 and 20.19 g/m2, respectively. A correlation between soil erosion index and wind temperature with high coefficient of determination (R2 = 0.99) is established (see Figure-11)

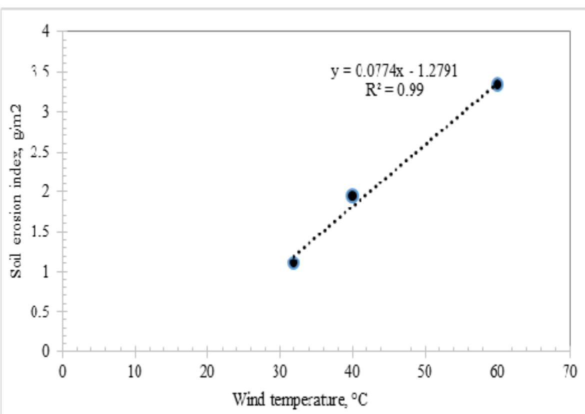

Figure-11. Influence of wind temperature on soil erosion index.

Further test observations showed that there was less dust produced when the sample was compacted and no dust produced when the sample were compacted and structureded with the research stabilizer. The tests on uncompacted sample with the lowest wind velocity of 2.9 m/s generated the lowest dust emission which was in the range of 0.093 g/m² to 1.204 g/m². For a typical daily mean wind velocity in Malaysia of 3.8 m/s dust emission produced was in the range 0.556 g/m² to 2.037 g/m². For the highest wind speed of 7.2 m/s it produced 19.259 g/m² to 31.296 g/m² of dust emission.

The dust emission increase was followed by the testing period of time with three values of wind speeds; 2.9 m/s, 3.8 m/s and 7.2 m/s. These showed that pick-up of dust depends on the magnitude of wind speed and the duration of the wind.

Moisture content of 10% of water was added in another investigation on the uncompacted samples as stabilizer for certain constant temperature; 26°C, 40°C and 60°C with constant velocity of 7.2 m/s. The different temperatures used to simulate the real temperature on the roadside; higher the temperature, larger was the dust emission produced.

CONCLUSIONS

A laboratory testing equipment was developed and demonstrated through trial experimentation. This was develop to assess the dust emission in the laboratory in order to stimulate the real situation at site. From the results obtained, the wind velocity, temperature and the presence of stabilizers affect the dust emission and the amount of dust generated. Laboratory evidence helps to conclude that with the increase in wind velocity, more dust was being generated from the surface of soil and also when the temperature was higher. The presence of stabilizer helped minimize amount of dust generated.

Results suggested that the soil erosion index's performance is a function of the soil type and the stabilization method. The observations from the laboratory test corroborated these evaluation criteria established at the outset of this research. General conclusions are summarized in light of the constraints that this research involved only the laboratory testing based on fine grain soils type used and no filed testing was carried out for the completion in verifying the laboratory results.

REFERENCES

[1] Chiou, S.-F.,and Tsai, C.-J. (2001). Measurement of emission factor of road dust in a wind tunnel. Powder Technology, 118(1-2), 10–15. doi:10.1016/S0032-5910(01)00289-3.

[2] Epps, A., and Ehsan, M. (2002). Laboratory Study of Dust Palliative Effectiveness, ASCE, Journal of materials in civil engineering Vol. 14: (October), 427–435. doi: 10.1061/(ASCE)0899-1561(2001)

[3] Huang, C., Lee, C., & Tsai, C. (2005). Reduction of Particle Reentrainment Using Porous Fence in Front of Dust Samples, ASCE, Journal Environmentqal Engineering 131(12), 1644–1648.

[4] Jancsek-Turoczi, B., Hoffer, A., Nyiro-kosa, I., Gelencser, A., (2013) Samping and characxterisation of resuspended and respirable road dust, Journal of Aerosol Science, 65, p69-76

[5] Pelt, R. S. Van, & Zobeck, T. M. (2013). Portable Wind Tunnels for Field Testing of Soils and Natural Surfaces.

[6] Shao, Y.P., Raupach, M.R., Leys, J.F. (1996), A model for predicting Aeolian sand drift and dust entrainment on scales from paddock to region. Aust. J. Soil Res. 34, 309-342.

[7] .

[8] Sokolik, I. N., Winker, D. M., Bergametti, G., Gillette, D. A., Carmichael, G., Kaufman, Y. J., Gomes, L., *et al*. (2001). Introduction to special section: Outstanding problems in quantifying the radiative impacts of mineral dust. Journal of Geophysical Research, 106(D16), 18015. doi:10.1029/2000JD900498

[9] The World Bank (2011). Rural Roads: A Lifeline for Villages in India. Retrieved September 19, 2011, from http://siteresources.worldbank.org/INTSARREGTOPTRANSPORT/1349788-1130967866881/21755701/Rural-Roads-India.pdf