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Dust Emission from Unpaved Roads in Luleå, Sweden

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Abstract

The dust emission from unpaved roads, if not controlled, can cause enormous problems. Though a few real-world measurements of road dust have been done by automated samplers in Sweden, measurement by BSNE (Big Spring Number Eight) and the estimation of total dust generation from vehicle driving is rare. This study measured and analyzed dust emission by BSNE at two unpaved roads in Luleå, Sweden, at the driving speed of 20, 30, 40, and 50 km/h different heights. Even though US EPA excluded vehicle speed as a parameter in estimating dust emission factors for unpaved roads, this study confirmed a strong dependence of dust emission on vehicle speed. This is in agreement with several recent studies which concluded dust emission increases with driving speed exponentially or linearly, however the power law is the best description for the data from this study.
The comparison with estimated dust emission by US EPA's equation showed the equation underestimates the dust emission more than 50 percent when vehicle speed and silt content is higher than 25.40km/h and 2.17 percent respectively. There might be some interrelationship between driving speed and silt content in road surface.
Earlier researchers have reported increased dust emission with increasing silt content and this is confirmed by this study.

Keywords: Dust emission, Unpaved road, BSNE, Vehicle speed, Silt content.

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1 Introduction

Since early 1990s, the environmental impact of dust emission, transportation and deposition has become a major concern [1]. Unpaved road often contributes a significant amount of atmospheric dust formed due to re-suspension of road material by trucks, and observed as a dust cloud behind the driving vehicle. Unpaved road accounts for 90 percent of road networks worldwide [2]. It was reported that in Sweden, 20 percent of the 100,000 km national roads are gravel roads [3]. The length of the Swedish gravel roads are roughly estimated to be 300,000 km which corresponds to 75 percent of the total roads network in Sweden [4]. The dust emissions can cause safety problems by reducing operator's visibility, discomfort for road-users, and health risks due to human exposures to heavy metals, metalloid, and mineral matter [5, 6]. In addition, gravel road without proper dust control can increase fuel costs; travelling time, riding discomfort, and vehicle wear [7].

The dust emission from an unpaved road consists of three parts: emissions in the form of exhaust or tailpipe emission, emissions from re-suspension of surface material due to truck travelling, and emissions due to wind erosion of road surface. In most developed countries, exhaust emissions are expected to decrease drastically because of legislation control. Generally wind erosion will not happen unless the wind speed is greater than 8m/s at 2 meters height. Therefore, road dust is often referred to as re-suspension [8]. During vehicles travelling, the rolling wheels exert a force to the surface which pulverizes the roadbed material and eject particles with the shearing force as well as by the turbulent vehicle wakes [9]. Many researchers have studied the phenomenon of road dust re-suspension and concluded that the dust emission rate primarily depends on the vehicle weight [10, 11, 12], silt content of the surface material [13, 11], the soil moisture content [14], and the vehicle speed [9, 15, 16]. However, in the later version of US EPA's dust emission factor for unpaved road, the effect of vehicle speed was no longer included as an independent variable because of the validation showed almost no additional predictive accuracy with inclusion of vehicle speed [17].

To study the phenomenon of road dust generation and its influencing parameters, proper design for measurement of dust emission is an important factor. Though the importance of road dust has been well recognized, there are not so many field measurements outside the United States. Real-world measurements are usually very difficult because of different influencing factors. Mobile and stationary systems are two methods for measurements of road dust. Mobile system uses real-time monitors mounted in front and behind of the travelling vehicle in the well mixed wake to record dust concentration. Fitz et al. [18] used SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways) mobile platform to measure PM10 concentration. Kuhns et al. [19] developed TRAKER (Testing Re-entrained Aerosol Kinetic Emissions from Roads) system to measure road dust. In Sweden TRAKER system has been used to study the relationship among dust concentration, vehicle speed, and tyre types, to find hot spots of dust emission and to exam the efficiency of dust control [20, 21, 22]. However, to estimate total dust emission and develop dust emission factor from a road, US EPA has recommended upwind and downwind measurement by high volume dust samplers [10], which is called herein above stationary system. Despite some advantages, both high volume samplers and real-time monitors used in mobile systems are automated samplers and very costly. In some situations a large number of samplers are required. Instead of high volume dust sampler, Goossens and Buck [23] tried to use BSNE (Big Spring

Number Eight dust sampler), which is much cheaper and can quantify dust emission by off-road driving. They concluded that BSNE behaves similar to several automated samplers and may provide a reasonable alternative [1]. Though few real-world measurements of road dust have been done by automated samplers in Sweden, measurement by BSNE and the estimation of total dust generation from vehicle driving is rare.

The purpose of this research is to estimate total dust generation at two unpaved roads in Luleå, Sweden by using BSNE samplers. Dust generation related to the effect of vehicle speed is to be evaluated at the first road. The measurements from the second road shall be compared with that from first road to evaluate the effect of road surface condition. The measured dust emission is to be compared with estimated value using US EPA's equation.

2 Material and Methods

The measurements were carried out on two unpaved roads in Lulea, Sweden. The first road is located in Hertsö area in the west of the city center of Lulea (Fig. 1). The road surface is natural soil with some boulders and there are vegetation covers along both sides of the road, which can hinder dust spreading (Fig. 2). The road leads to a picnic area, Hertsöträsket. The dust problem mainly takes place during weekends when people are free to drive to Hertsöträsket for picnics. The second road is at a construction site located in Björsby north of Luleå city center (Fig. 1). The road surface is composed of fine materials and no vegetation exists in the construction site (Fig. 3). The site is blocked and no cars are allowed to go through apart from those connected with construction activities. Dust is generated during large type excavator or other machine working and spreads to the surrounding areas. Both roads have no surface crust.

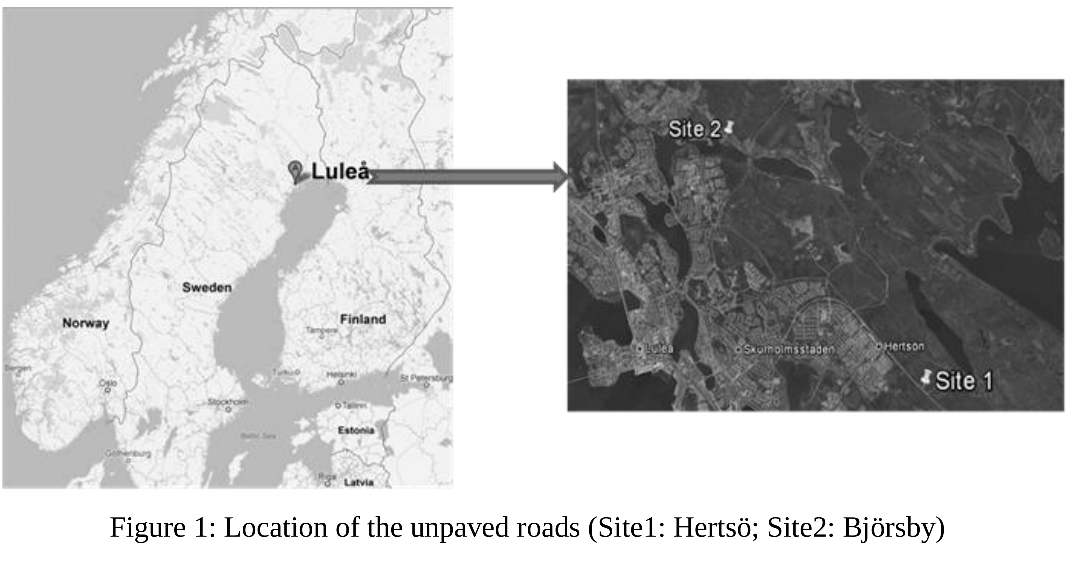

Figure 1: Location of the unpaved roads (Site1: Hertsö; Site2: Björsby)


a

b

Figure 2: a: The unpaved road in Hertsö, b: The road surface


a

b

Figure 3: a: The unpaved road in Björsby, b: The road surface

The car used for dust generation is Ford Mondeo with an approximate weight of 1730 kg and 4 wheels (Fig. 4). The car drove 15 runs for each of the following speeds: 20km/m, 30km/h, 40km/h and 50km/h (Fig. 5). The measurements were undertaken using BSNE samplers [24]. BSNE sampler has a relative large inlet area of 10 cm^2, and its efficiency has been tested for various grain sizes [25, 26, 27]. For the first road, BSNE samplers were installed at the heights of 0.25m, 0.50m, 0.75m and 1.00m down wind direction of the road. Two sets of BSNE samplers were installed at the same side of the road in order to collect adequate dust quantity (Fig. 5). No samplers needed at the up wind direction of the road because the wind velocity was insufficient to activate wind erosion of surface material and the background dust was assumed to be 0. The same setup was used for the other road, but the heights of the samplers were at 0.58m, 0.83m, 1.08m and 1.33m, and the measurements were only undertaken for the driving speed of 20km/h. According observations during measurements, the height of the dust plume was always between 1m to 1.5m.

The weather during the measurement was rather dry and sunny. Besides the BSNE samplers, two weather stations were installed at the height of 1m and 2m. The average wind velocity at the height of 1 m and 2 m were 2.40m/s and 3m/s which can not cause wind erosion. The wind direction was mostly from southwest. The measurements were done on the road sections which were perpendicular to the wind direction to ensure the largest amount of dust to be obtained in the samplers. Measurements on the two roads were done in the same day so that the weather factors were almost the same.

The dust in the samplers was collected by a brush with a great care to avoid sample loss. All the samples were weighed in the lab by a balance with the precision of 0.0001g. The amount of the dust collected was too little to do size analysis. All particles are assumed to be below 60µm which corresponds to the maximum size of grain that can be transported in short-term suspension under average wind speed and turbulence [28]. The samples of surface materials from the two roads were sent to the soil mechanics laboratory in Luleå University of Technology for moisture content and particle size analysis. Moisture content was measured by oven drying material at 105˚C to constant weight. The difference of the weight before and after the drying process is the amount of the water existed in the sample.

Figure 4: The dust generation by vehicle traveling

Figure 5: The experimental setup

3 Calculations and Results

The amount of dust collected from BSNE samplers at the first road were plotted against the height for four driving speeds (Fig. 6). The results for the second road compared with the first road with the same driving speed of 20km/h are shown in Fig.7. All the figures show that the dust mass is highest at the lowest height and decreases with increasing height reaching zero at the top of the dust plume. It is reasonable to assume the zero dust mass at the ground surface level, which means the dust emission increasing sharply to the maximum value at a small height near the surface. However, it is difficult to pinpoint the height of the maximum dust mass by these tests. It could be only inferred that the maximum point is located between ground level and the height of the lowest measurement.

The second road produced much more dust due to different road surface conditions (Fig.7). It is not easy to use vertical dust profile in Fig.6 to make the interpretation of relationship between dust production and driving speed. To visualize the relationship total dust production should be calculated.

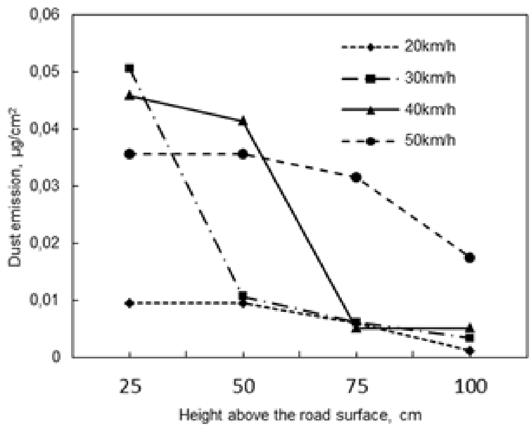

Figure 6: Vertical dust flux profile for road 1 for the driving speed of 20, 30, 40, and 50 km/h.

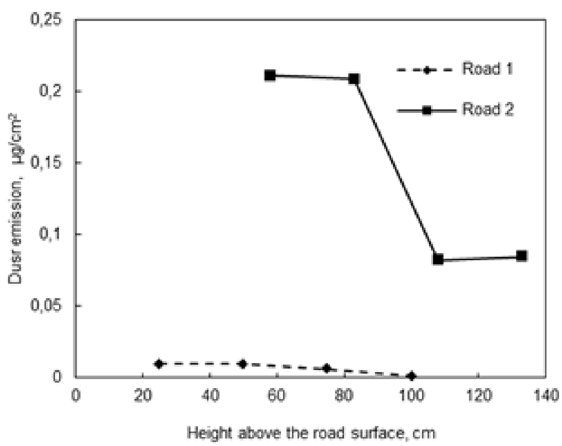

Figure 7: Vertical dust flux profile for road 1 and road 2 for the driving speed of 20 km/h

Usually, dust production in a vacant area is calculated by using mass per unit area and the total area. Since a road is a line source, a better option to calculate dust production is to use mass per unit length travelled and the travelling length. The dust emission per unit length is calculated by integrating dust mass along the height of the dust plume. First the amount of dust collected from different heights must be corrected for the efficiency of BSNE. Here the overall efficiency of 90% was used. The corrected dust mass was then divided by the inlet area of BSNE samplers (2*10 cm^2) to calculate the dust amount per square meter at the four measuring heights. Integrating dust amount from the road surface to the top of the dust plume we can get the total dust produced (µg/cm) in every centimeter travelled by the car. The integrations were done with 4th order polynomials which fitted quite well with vertical dust profiles in Fig. 6. Figure 8 shows the calculated total dust production per centimeter travelled against driving speed for the first road and indicated a proportional relationship. Figure 9 shows a significant difference between the two roads in calculated total dust production per centimeter travelled. Besides the driving speed, surface condition of the road may also have an impact on dust production.

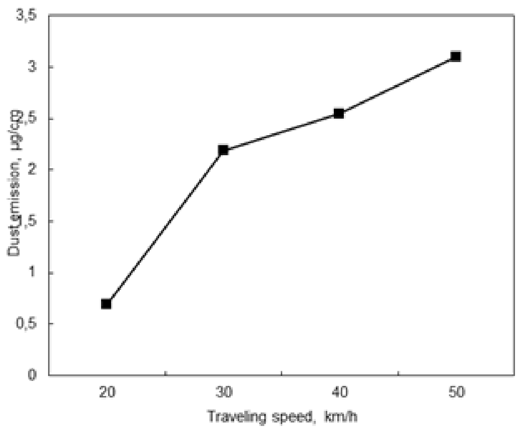

Figure 8: Total dust emission per centimeter the car drove at the speed of 20, 30, 40, and 50km/h for the road 1

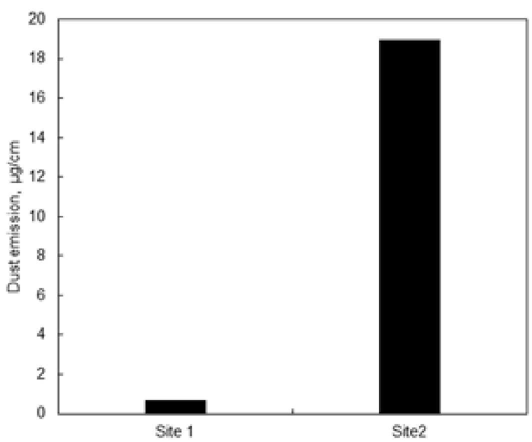

Figure 9: Total dust emission per centimeter the car drove at the speed of 20 km/h for the road 1 and road 2.

Soil texture and the moisture content of the surface materials from the two roads are tabulated in Table 1. The second road has higher amount of fine grains with size below 63µm than that of the first road. Soil texture is the most important soil factor influencing dust production. With more fine fraction existing the more dust can be generated. The second road contains a bit more rock content compared with that of the first one. But this could increase the abrasion between the tire and the road surface which results in additional dust production. Both surface samples showed very low moisture content, and no surface crust observed at the sites. Vegetation covers are present along the two sides of the first road, which would reduce dust spreading rather than dust production. The second road has not vegetation protection at all and the dust could spread to the surrounding areas.

Table 1: Soil texture and surface characteristics of the road surface

Sample location	Soil texture %						Rock content in upper 15mm >2mm, %	Moisture content %	Surface crust	Vegetation
	<63 µm	63-125 µm	125-250 µm	250-500 µm	500-1000 µm	1000-2000 µm			Presence	
Site 1	1.89	11.72	12.44	13.15	14.34	18.34	28.13	0.24	No	Along both sides of the road
Site 2	7.57	12.49	16.10	10.73	8.90	9.75	34.44	0.39	No	None

4 Discussion

4.1 Effect of Vehicle Speed

The linear dependence of dust emission on vehicle speed seems to be a better fit for the result from the experiment for the first road in current study than exponential dependence (Fig. 10). The R2 value of linear relationship is 10 percent higher than that of exponential relationship. R2 value is increased by 2 percent when the data was fitted with a power law. Based on R2 value in Fig.10 the relationship between dust emission and vehicle speed is best described by a power law for the road in Hertsö area (road 1, R^2=0.92), though the linear dependence showed just slight lower performance (R^2=0.9). It should be mentioned however that US EPA [17] excluded vehicle speed as a parameter in estimating dust emission factors for unpaved roads but other researchers confirmed this relationship [14, 23, 29, 16, 20].

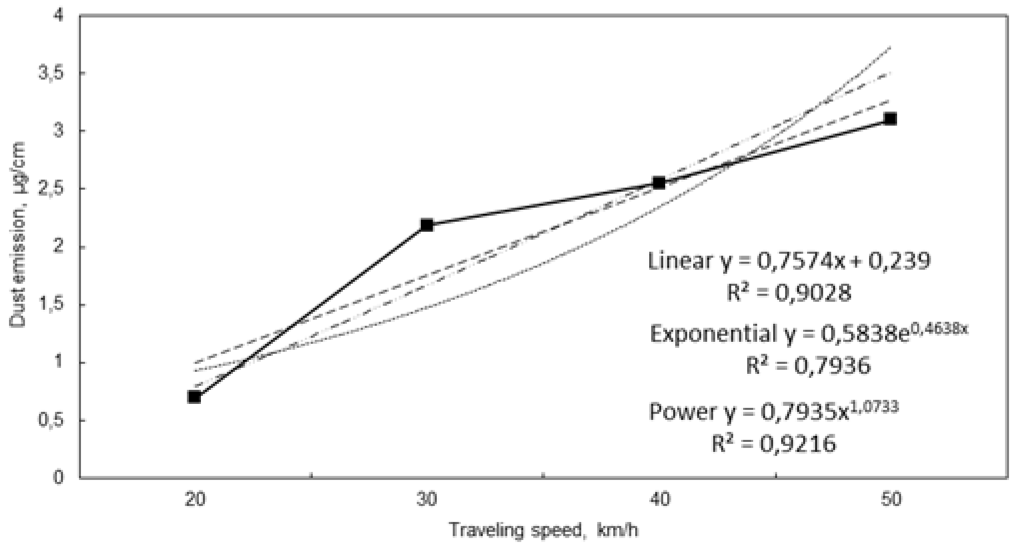

Figure 10: Dust emission versus driving speed for road 1 and curve fitting

4.2 Effect of Road Surface Material

The moisture content and the soil texture of the surface material are important factors for road dust generation. Both roads in this study have low content of moisture in the surface material during measurement (Table 1). Silt content as a factor influencing dust generation has been confirmed by several studies [23, 10, 30], which showed an increased dust level with increasing silt content. To visualize the silt content as an influencing factor, more data points are required. Two data points from Goossens and Buck [23] were plotted together with the data from this study (Fig. 11). All the data were measured at the same driving speed of 20km/h. All the data were corrected for the vehicle weight before plotting. Figure 11 shows a linear relationship which is in consistence with earlier findings that dust generation increases with silt content.

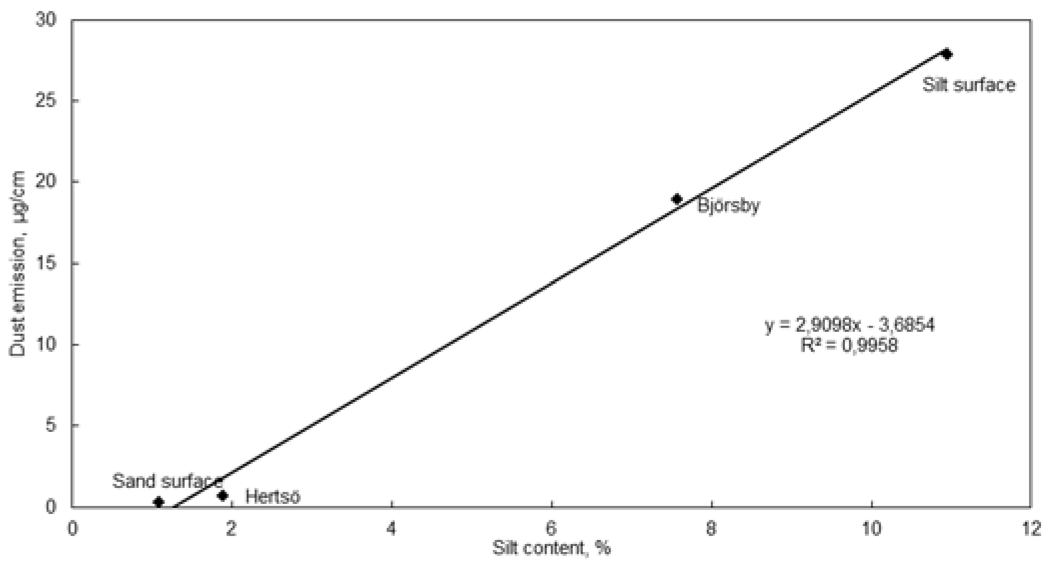

Figure 11: Dust emission versus silt content at the driving speed of 20km/h

4.3 Comparison with Calculated Dust Emission

A dust emission factor represents the value relating the amount of dust released to the atmosphere with the activity associated with the dust generation [10]. The equation of dust emission factor for unpaved road for dry conditions has the following form [10]:

EF=5.9k (s/12) (S/30) (W/3)0.7 (w/4)0.5 (1)

Where:
EF = the dust emission factor (pounds per vehicle-mile-traveled),
k = the particle size multiplier (0.8 for PM30),
s = the silt content of the road surface material (%),
S = the mean vehicle speed (miles per hour), W is the mean vehicle weight (ton),
w = the mean number of the wheels.

The equation shows that the dust emission is linearly dependent both on vehicle speed and silt content. This is in partial agreement with the results obtained in this study where the dust emission is in linear relationship with silt content, and in power relationship with vehicle speed.
Fig. 12 and Fig.13 illustrates the measured and calculated dust emission using US EPA's equation versus vehicle speed and silt content, respectively. Both figures show that the equation underestimates the dust production when vehicle speed and silt content increases, though they fit quite well at the low speed and silt content. The difference between measured values and calculated values increases with vehicle speed and silt content. The equation underestimates the dust emission more than 50 percent when the vehicle speed and silt content is higher than 25.40km/h and 2.17 percent respectively (Fig.12, Fig.13). Two reasons could explain the difference. Firstly, the equation intends to estimate the average dust emission over a long period [12], while the present emission measurement was done in only one day. Secondly the equation is the estimation for particulate matter under 30µm, while the particles collected in present experiment are assumed with max of 60µm with the small fraction between 30-60µm.

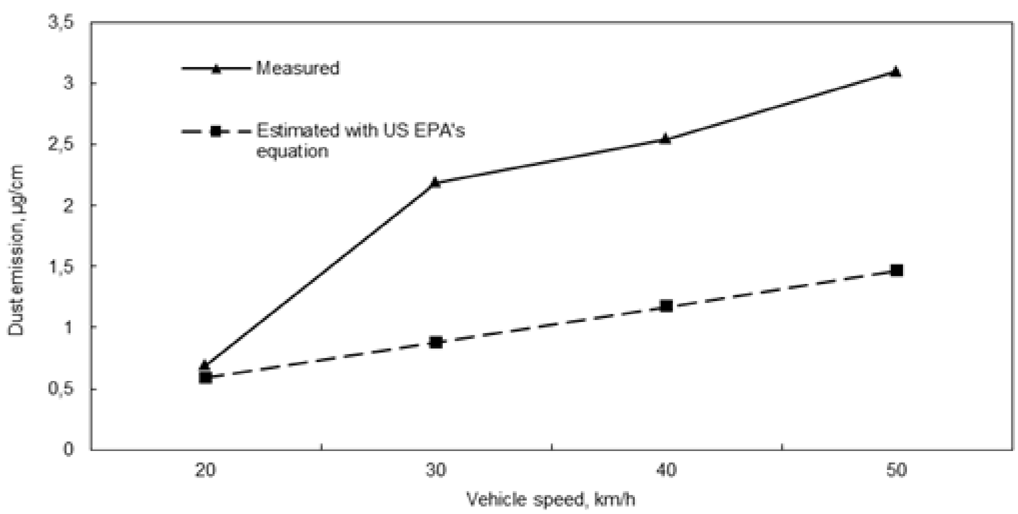

Figure 12: Measured and estimated dust emission versus driving speed

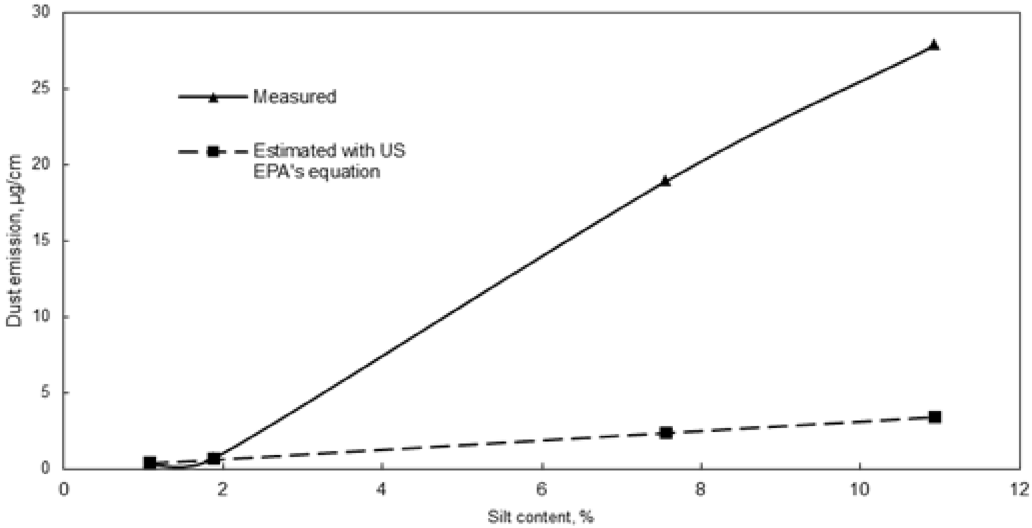

Fig. 13: Measured and estimated dust emission versus silt content

5 Conclusion

The results indicated that there is a strong relationship between vehicle speed and dust emission. This is in agreement with several recent studies. Dust emission has been reported to increase with driving speed exponentially or linearly, however the power law is the best description for the data from this study. Earlier researchers have reported increased dust emission with increasing silt content and this is confirmed by this study. The comparison with estimated dust emission by US EPA's equation showed the equation always underestimates the value. Two reasons could explain the difference. Firstly, the equation intends to estimate the average dust emission over a long period, while the present emission measurement was done in only one day. Secondly the equation is the estimation for particulate matter under 30µm, while the particles collected in present experiment are assumed with maximum size 60µm with the small fraction between 30-60µm. There might be some interrelationship between driving speed and silt content in road surface. However, it is very difficult to be evaluated from the present experiments.

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