Relative efficiency of passive dust samplers: progress towards coarse dust dispersion modelling

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Abstract

The collection efficiency of the DustScan DS100 directional sticky pad dust gauge has been analysed in order to estimate airborne dust concentrations for use in atmospheric dispersion models. A DS100 directional sticky pad dust monitor was tested for 10 months at a quarry boundary with respect to a Wilson and Cook (WAC) sampler, with comparisons primarily made with regard to directional wind speeds over the relevant monitoring periods, as recorded by an on-site meteorological station. The mass of dust collected using the DS100 monitor fluctuated between 3.1% and 21.3% of that caught by the WAC sampler over each period. Variations in collection efficiency were modelled using the count of wind speeds per half hour period and two distinct periods were observed. The main trend showed that higher wind speeds decreased relative DS100 efficiency, with low wind speed (< 3 m/s) and high wind speed (> 5 m/s) periods showing modelled efficiency above 10% and below 5% respectively in comparison to the WAC sampler. However, a central period of 9 weeks during the monitoring study showed a reverse of this pattern, with significant wind speeds over 5 m/s correlating with higher DS100 efficiency. Although dust catch on each sampler varied significantly over the study period, an average DS100 efficiency of approximately 7% in comparison to the WAC is suggested for use in estimating airborne dust concentrations for use in atmospheric dispersion models.

Keywords

Dust; Dust gauge; DustScan; Collection efficiency; Dust monitoring; Dust modelling

1 Introduction

Dust is conventionally defined as airborne particulate matter <75 µm diameter¹ and is most commonly categorised by size fraction. Coarse particles (>10 µm) are typically perceived with 'disamenity' or 'nuisance'² effects and are not subject to any official standards, with non-statutory guidance such as that provided by the IAQM³ used to assess potential and ongoing impacts. Fine particulate matter essentially refers to particles with an aerodynamic diameter less than 10 µm (PM₁₀) or 2.5 µm (PM_{2.5}) and is clearly defined and regulated through Air Quality Objectives (AQO) and the overriding National Air Quality Strategy (NAQS).

Dust can be generated from a broad range of sources, both natural and anthropogenic, and is therefore a widespread environmental occurrence. Anthropogenic sources of dust tend to occur due to mechanical action on materials (e.g. through industry) or the resuspension of existing particulate matter (e.g. through transport). Natural sources of dust include sea spray and dust generated from exposed surfaces or desert areas (e.g. Saharan dust).

This study focuses on coarse dust for which there are no statutory standard sampling methods or limit values and no standardised dust dispersion methodologies. Negative impacts from coarse dust usually relate to the visual effect of short-lived dust clouds and the long-term soiling of surfaces, which can be caused by large dust emissions from a variety of processes including heavy industry, agriculture and minerals workings. Results from well-designed dust monitoring schemes can therefore be used to measure dust sources and pathways in an area and the subsequent risks of disamenity at receptor locations. Coarse dust is typically monitored using passive sampling.

Passive dust sampling uses non-powered instruments to collect dust samples and is consequently inexpensive compared to electronic 'real-time' monitoring. A further advantage is that sample material is collected and can be later analysed for particle size and composition⁴. Passive samples are typically collected over long monitoring periods (e.g. weekly or monthly) and collection efficiencies can be difficult to quantify precisely. Passive sampling of dust is carried out using two methods; directional and depositional dust monitoring. Directional dust monitoring samples dust in flux and moving past a point, usually driven by wind, and is often measured using sticky pads which are subsequently analysed optically for dust soiling and dust coverage. Depositional dust monitoring measures the mass or soiling of dust deposited onto an area and may be sampled using sticky pads (and optical analysis) or using Frisbee-type dust monitors that give results in mass per unit area per day (e.g. mg/m²/day).

The assessment of coarse dust impacts for planning developments ordinarily uses a risk-based approach taken from established guidance (e.g. IAQM³) that accounts for site activities, average weather conditions and distances and directions to receptor locations. For mineral sites, pre-determined risk matrices are used to calculate the 'pathway effectiveness' from source to receptor, based on distance and average wind conditions. This is combined with an estimate of the 'residual source emissions' of each activity, which are estimates of the emission size after mitigation (small, medium or large) and are largely based on 'professional judgement'. These are combined with receptor sensitivity to give an overall estimated risk of impact (low, medium or high) and magnitude of adverse effects (negligible, slight, moderate or substantial) for each identified dust source area.

An alternative, very rarely used method that is commonly applied for fine particles utilises atmospheric dispersion models to predict coarse dust dispersion in a similar method to that frequently used for gaseous pollutants such as NO₂. Software such as the Atmospheric Dispersion Modelling System (ADMS) by CERC⁵ uses Gaussian plume air dispersion modelling to simulate the movement of pollutants in the atmosphere and allows concentrations to be predicted downwind of pollutant sources. Detailed source inputs are needed for coarse dust modelling including hourly meteorological and site activity data, and hourly emission factors (EFs) for dust are also needed which are challenging to predict accurately or obtain. Emission factors are needed to quantify the release of a pollutant in relation to an activity associated with the release of that pollutant. Published EFs for individual dust sources are mostly unavailable due to the complexity in accurately measuring them, and so generalised emission rates are often used. Those can be based simply on the size of the site⁶ or the quantity of materials being moved⁷. Examples of emission factor calculations are shown in Table 1, which demonstrates both the large quantity of data required for complex emission calculations such as emissions from unpaved roads and the broad estimations of emissions using the EEA inventory. Current guidance therefore recommends that detailed dust

dispersion modelling is not undertaken for mineral planning due to the lack of available dust emission data (IAQM, 2016).

Table 1 – Examples of existing emission factors

Dust source	Emission factor source	Data required	Calculation for TSP emissions
Storage, handling and transport of mineral products (uncontrolled or controlled)	European Environment Agency EMEP/EEA air pollutant emission inventory guidebook 2016 – 2.A.5.c	Size of site Level of dust controls in place	16.4 tonnes per hectare per year (uncontrolled) 1.64 tonnes per hectare per year (controlled)
Travel on unpaved roads at industrial sites	United States Environmental Protection Agency AP42: Compilation of Air Emissions Factors – 13.2.2	Surface material silt content Vehicle weights Surface material moisture content Vehicle speeds Vehicle routes and miles travelled	lb TSP per vehicle mile travelled $= k \left(\frac{s}{12} \right)^a \left(\frac{W}{3} \right)^b$ Where: k, a & b are constants based on particle size. $k = 4.9$ $a = 0.7$ $b = 0.45$ s = surface material silt content (%) W = mean vehicle weight (tons)
Aggregate handling and storage piles	United States Environmental Protection Agency AP42: Compilation of Air Emissions Factors – 13.2.4	Wind speed Material moisture content Quantity of material handled	kg of TSP per tonne of material transferred = $k(0.0016) \frac{U^{1.3}}{M^{1.4}}$ Where: $k = 0.74$ (constant based on particle size) U = mean wind speed (m/s) M = material moisture content (%)

Clearly, therefore, it would be beneficial to develop a method that could circumvent the problems and allow the powerful modelling software currently available to be applied to coarse industrial dusts.

One method of obtaining dust emission factors for dispersion modelling is ‘back calculating’ emissions based on dust monitoring results. This is undertaken by modelling dust dispersion and adjusting emission factors based on dust monitoring results for the dispersion area. Passive sticky pad dust monitoring is ideal for this purpose due its cost-effectiveness, ease of installation and simple analytical processes⁸ in comparison with more complex real-time dust monitors. Numerous passive dust monitors can be placed around a site with sample results used to test dust dispersion

predictions. A drawback, however, is that directional dust results collected on a cylindrical two dimensional surface (in mg/m^2) need to be converted to airborne dust concentrations (in mg/m^3) for use in dispersion models. Estimates are therefore needed of the volume of air that has been driven past the monitor and, most importantly, sampler efficiency. Hourly wind data from a local weather station can be used to give an adequate estimate of temporal wind conditions but efficiency estimates for sticky pad dust monitors are mostly lacking. A previous study has measured total collection efficiencies for the DustScan DS100 of 8 – 35% in wind tunnel trials at 2, 4, 7 and 10 m/s against a Wilson and Cook (WAC) dust catcher⁹, although this was in a controlled environment with a known dust source. To the authors' knowledge, no other significant testing has been undertaken. Consequently, further evaluation of the efficiency of directional sticky pad monitors is needed in site-specific studies to allow measurements of dust caught using the sampler to be converted to mass per unit volume (mg/m^3), for development of coarse dust dispersion modelling.

The principal aim of this study was therefore to measure the efficiency of the directional sticky pad dust monitor to produce a method for calculating airborne dust concentrations for use in atmospheric dispersion models and the development of coarse dust dispersion modelling techniques.

2 Materials and methods

2.1 Sampler descriptions

Real time light-scatter dust monitors were considered for use in the evaluation and would also give hourly concentration results for direct comparison. However, they are expensive, require a secure area and constant power source and, most significantly, are known to have low detection efficiencies for particles larger than 20 μm (e.g. Turnkey Osiris, Topas and Dustmate particulate monitors¹⁰, TSI Dusttrak DRX Model 8533 and 8534¹¹). A passive sampler was therefore chosen for comparison with the sticky pad monitor and the most widely used and studied are the Big Spring Number Eight (BSNE, Fryrear, 1986¹²) and the WAC sampler (Wilson and Cooke, 1980¹³; Kuntze et al., 1990¹⁴) which are both frequently used for wind erosion studies (Zobeck et al, 2003¹⁵). Previous studies have shown variable efficiency curves for both samplers dependant on particle size, wind speeds and material properties (Goosens and Offer, 2000¹⁶; Goosens, Offer and London, 2000¹⁷; Youssef et al., 2007¹⁸; Mendez, Funk and Buschiazzi, 2011¹⁹; Mendez, Funk and Buschiazzi, 2016²⁰). Table 2 sets out previous efficiency measurements for the WAC sampler. This study therefore used the WAC sampler as a baseline for efficiency evaluation of directional sticky pad monitors based on its existing published efficiency data, shown in Table 2, and its availability and ease of use, with the most appropriate previous study showing sampler efficiency over 90%. Studies have also shown that the efficiency of the WAC is constant when particle size and wind speed increases, compared to other monitors (Goosens and Offer, 2000).

129 Table 2 – Examples of WAC efficiency

Paper	Particle size range	Wind speed	Efficiency	Comment
Goosens and Offer, 2000	Median 30 μm	2 – 5 m/s	> 90%	Most appropriate particle size range and wind speeds for this study
	95% silt (2 – 63 μm) 5% clay (< 2 μm)	1 m/s	75%	
Goosens, Offer and London, 2000	Median 132 μm	6.5 – 14 m/s	90 – 100%	Demonstrates high efficiency at high wind speeds for large particles.
	Median 194 μm		100 – 120%	
	Median 287 μm		100 – 120%	
Youssef et al., 2007	< 75 μm	13.4 m/s	$\leq 0.5\%$	High wind speed makes results unsuitable for this study.
	50–75 μm		14.5%	
	200–400 μm		37.8%	
	400–500 μm		24.8%	
Mendez et al., 2011	Mean grain diameter 121 μm	9.2 m/s	Up to 120%*	*Focus of study was comparisons against BSNE sampler and not absolute efficiency.
Mendez et al., 2016	PM ₁₀	3 m/s	0.6%	Results presented from suspension zone only. Focused on PM ₁₀ and below and showed that the monitor is poor at collecting fine particulate matter.
	PM _{2.5}		0%	
	PM ₁		2.1%	
	PM ₁₀	6 m/s	9.3%	
	PM _{2.5}		0%	
	PM ₁		0%	

130 2.2 Sampler descriptions

131 The DustScan DS100 directional sticky pad sampler uses an A4 size sticky pad mounted on a north-
132 aligned vertical cylinder, itself mounted on a post of approximately 1.8 m height to sample dust in
133 flux from 360°. A photograph of the sampler at the study site is shown in Figure 1, and includes the
134 depositional component (the ‘DustDisc’) which slots in above the directional sampling head. Samples
135 are generally taken over weekly or fortnightly intervals and once complete are exchanged for a new
136 sampling head (with fresh sticky pad) and returned to DustScan for processing. Samples are
137 subsequently sealed using a transparent film and scanned using a flatbed scanner for analysis
138 (Datson and Birch, 2007²¹).

Figure 1: A DS100-D directional and depositional dust monitor at the study site

The analysis protocol behind the monitor was originally devised at the University of Leeds Department of Mining and Mineral Engineering for monitoring dust levels at opencast coal sites and quarries (Farnfield and Birch, 1997). The advance in technique used computer scanning of sealed dust samples and bespoke software to automate the analysis of samples for dust coverage, and a new unit of measurement was devised, known as Absolute Area Coverage (AAC), which was reported as a percentage of the total surface content covered with dust. Prior to this, sticky pads were commonly used for dust monitoring but were analysed using techniques such as a smoke stain reflectometer (Beaman and Kingsbury, 1981 and 1984) or shade card (Farnfield and Birch, 1997). Samples were reported with reference to their loss of reflectance, either in Effective Area Coverage (EAC) or soiling units (s.u.)²², and were compared against potential nuisance criteria based on surveys of public perception²³. The DustScan software has since developed over time (Datson and Birch, 2007) and now combines automated directional AAC and EAC measurements at 15 degree intervals and masking of non-dust materials (Datson, 2010⁹; Datson, Hall & Birch, 2012⁸). Dust may also be removed from the sticky pad for gravimetric analysis and reporting in mg/m² and subsequent geochemical analyses (Fowler et al, 2010²⁴).

The WAC sampler was originally developed by S.J. Wilson and R.U. Cooke in 1980¹³ and was later modified by Kuntze et al. in 1990. The sampler is comprised of a plastic bottle, an inlet tube and an

outlet tube, with the inlet oriented towards the wind, the bottle acting as a settling chamber and the outlet discharging clean air. Dust entering the settling chamber is deposited due to the pressure drop resulting from the difference in diameter between the inlet and outlet tubes and the bottle. A photograph and schematic of the sampler can be seen in Goosens and Offer (2000).

The sampler has historically been used as a sediment sampler for field studies of saltation. Kuntze et al modified the bottle attachments from vertical in the original design to horizontal and also added a wind vane so that the inlet tube would always be facing the prevailing wind. This modified design, known as Modified Wilson and Cook sampler (MWAC), was not used in this study so that dust from a specific direction could be sampled.

2.3 Sampling site

This study was undertaken at a small mineral stockyard and quarry in southern England of approximately 3.5 ha. The site is in a rural area, surrounded by agricultural fields, and stockpiles a mixture of aggregates including locally extracted sand and gravel and has mineral extraction campaign periods of two to four weeks each summer. The terrain is generally flat and prevailing winds are typically from the south west. Activity at the site for most of the year is limited to material screening, sales and transport of stockpiled aggregates and associated site vehicle movements around the weighbridge and main working area. A schematic site map is shown in Figure 2.

Figure 2: Site plan showing main working areas, weather station and location of co-located dust monitor. The terrain is generally flat with the main working area approximately 15m below the surrounding agricultural fields to the north and east.

Directional and depositional sticky pad dust monitoring prior to this study had been undertaken at the site for 18 months at 8 monitoring locations. A WAC sampler assembly comprising 3 horizontal bottles mounted onto a post was installed immediately adjacent to an existing directional dust monitor (approximately 40 cm away) on the north eastern boundary of the main working area. This location was chosen as it was downwind of the main site area and sheltered from the fields to the north and east. The WAC sample inlet tubes were positioned facing the main working areas of the quarry to the south west and therefore collected dust from this direction only. Dust may also enter through the outlet tube, which faced north east, although this side of the monitor was well screened by foliage approximately 3 m distance away, and directional measurements from the sticky pad

gauge could be used to correct for any dust moving in this direction by assigning a representative proportion of dust contributed from each direction.

Both monitors operated simultaneously for 37 weeks with samples collected and exchanged every 7 to 20 days, with longer monitoring periods in winter during less dusty conditions. An electronic weather station was used to collect half hourly local meteorological data and was located approximately 100 m south east of the monitors on the boundary of the site.

2.4 Sample treatment

WAC sample bottles were processed gravimetrically by filtering the contents of each sample bottle onto a pre-weighed and pre-conditioned 47mm mixed cellulose ester (MCE) filter paper before conditioning (to ensure stable humidity and temperature) and post-weighing²⁵. The mass on the filter paper and area of the inlet tube (132.7 mm²) were used to calculate dust concentrations in mg/m²/day. Directional sticky pad samples were measured for dust soiling (EAC%) and coverage (AAC%) (Datson and Birch, 2007) and dust was removed from the sticky pad by soaking overnight in an organic solvent before gravimetric filtration²⁶ from the two 15° arcs facing towards the site (south west, 200 - 230°) to calculate mg/m²/day.

3 Calculation

Empirical models were developed to measure the influence of environmental variability on sample efficiency of the DS100. The application of the models would allow for changes in DS100 efficiency to be accounted for during different environmental conditions so that an appropriate monitor efficiency value could be used for individual future coarse dust dispersion modelling studies. Each model was designed so that it predicted efficiency of the sticky pad gauge based on the proportion of wind speeds in 1 m/s bins (e.g. 0-1 m/s, 1-2 m/s and so forth) from the direction of the site only (180° - 270°), as the most significant dust source in the area. This allowed for collection efficiency variation to be modelled based on the number of wind speeds in each bin during the sampling period.

Collection efficiency (η) was modelled using *Equation 1* for each half hourly wind speed and averaged across the sampling week to give an estimated efficiency of the DS100 throughout the monitoring period. Values for x and z were calculated using the generalised reduced gradient (GRG) nonlinear method to set an objective value (sum of squares for measured and modelled efficiency) by changing a given number of variables.

$$\text{Equation 1: } \eta (\text{ds100}) = \frac{\sum_{n_w=1}^{n_w!} (c^{w_x})}{\text{count}(n_w)z} \text{ where } w_x = wb^x$$

Where wb is the median value of the wind speed bin, c is a count of half-hourly wind speeds per bin (e.g. 0.5 for 1-2 m/s), n_w is the wind speed bins for that sampling period, w_x is a coefficient of decreasing efficiency for that wind speed bin using x which is calculated using the GRG method and z is a coefficient also calculated using the GRG method.

3.1 Further testing and other variables

The above method assumes that wind speed is the main significant influence on variations in collection efficiency. Further testing of model parameters was therefore undertaken, including:

- Modelling wind speeds during site working hours only (Mon – Fri and Sat morning), when dust emissions were assumed to be highest.
- Assessment of any impact from rainfall, humidity or temperature.
- Modelling wind speeds from a narrower arc (191.25° - 258.75°).
- Modelling wind speeds from a broader arc (146.25° - 303.75°).
- Assessment of wind speeds from all directions on monitor efficiencies, on the assumption that high wind speeds from alternative directions could cause localised turbulence; and
- Adjusting x to increase the impact of higher winds speeds on the model, in the assumption that they would be associated with higher dust emissions and therefore higher dust concentrations at the monitoring locations.

The model tests were compared against monitoring results to see if model accuracy was improved.

4 Results

4.1 Direct comparisons

Table 3 and Figure 3 show the variation in sample measurements between the WAC and DS100 and the relative efficiency throughout the study period. Results between the two monitors varied considerably, with the DS100 collecting between 3.1% and 21.3% of the total mass of the WAC sampler for each monitoring period after accounting for the sample collection area, with an average relative efficiency of 6.7% and standard deviation of 5.3%.

Table 3: Comparison of dust catch on the WAC and DS100 samplers

Start date	End date	WAC mg/m ²	DS100 mg/m ²	DS100 relative efficiency	Proportion of winds from SW > 3 m/s
29-Apr-14	06-May-14	9,769	1,647	16.9%	9.9%
06-May-14	13-May-14	657,288	26,835	4.1%	84.0%
13-May-14	20-May-14	8,991	1,134	12.6%	13.7%
20-May-14	27-May-14	6,253	724	11.6%	15.2%
24-Jun-14	01-Jul-14	5,299	689	13.0%	22.1%
01-Jul-14	08-Jul-14	151,282	7,328	4.8%	33.2%
08-Jul-14	16-Jul-14	23,933	1,134	4.7%	32.0%
16-Jul-14	23-Jul-14	7,961	710	8.9%	19.0%
23-Jul-14	30-Jul-14	7,785	488	6.3%	0.0%
30-Jul-14	07-Aug-14	29,709	1,120	3.8%	29.6%
07-Aug-14	14-Aug-14	95,254	20,266	21.3%	65.1%
14-Aug-14	21-Aug-14	30,161	6,092	20.2%	N/A*
21-Aug-14	28-Aug-14	13,436	578	4.3%	
28-Aug-14	04-Sep-14	62,632	6,446	10.3%	54.5%
04-Sep-14	11-Sep-14	3,014	BDL	N/A	N/A

11-Sep-14	18-Sep-14	3,441	BDL	N/A	N/A
18-Sep-14	25-Sep-14	24,586	765	3.1%	31.7%
25-Sep-14	02-Oct-14	9,066	425	4.7%	45.0%
02-Oct-14	22-Oct-14	162,206	12,446	7.7%	48.6%
22-Oct-14	05-Nov-14	9,493	627	6.6%	57.4%
05-Nov-14	24-Nov-14	3,993	397	10.0%	0.0%
24-Nov-14	11-Dec-14	6,153	BDL	N/A	N/A
09-Jan-15	26-Jan-15	71,422	3,349	4.7%	77.9%
26-Jan-15	09-Feb-15	9,518	571	6.0%	67.8%
Average (excluding BDLs)		66,668	4,465	6.7%	
Standard deviation		139,690	6,972		

*BDL – Below Detection Limit for DS100

*N/A – Local meteorological data not available for this full period

Figure 3: Comparison of dust catch on the WAC and DS100 samplers

4.2 Efficiency investigations

Weekly variations between the two monitors were compared against wind conditions to investigate the cause of the variations in collection efficiency and therefore to understand dust catch efficiency on the DS100 in mg/m^2 . The collection efficiency of the DS100 relative to the WAC sampler varied throughout the year, with two distinct patterns emerging over the study period. The first 8 weeks and last 5 weeks of the monitoring period showed that higher wind speeds ($> 3 \text{ m/s}$) had a strong correlation with decreases in DS100 relative collection efficiency ($r^2 0.58$, $p < 0.01$). The middle 7

weeks of the monitoring study however conversely showed that higher wind speeds had a strong correlation with increases in relative DS100 collection efficiency ($r^2 = 0.78$, $p < 0.05$).

4.3 Model results

Model results are presented in Table 5 and in Figure 4 for the first 9 and last 5 weeks of monitoring and show a strong correlation between modelled and actual efficiency ($r^2 = 0.75$, $p < 0.05$). Table 4 gives an example of the model calculation for the period 29 April – 06 May 2014.

Table 4: Model calculation for the period 29 April – 06 May 2014, where $x = -1.58$ and $z = 353$.

Wind speed bin	0-1 m/s	1-2 m/s	2-3 m/s	3-4 m/s	4-5 m/s
Wind speed bin median (wb)	0.5	1.5	2.5	3.5	4.5
Wind speed bin coefficient (wb ^x)	2.98	0.53	0.24	0.14	0.09
Count of half-hour wind speeds (c)	68	38	39	9	7
c ^{wx}	202.75	20.06	9.20	1.25	0.65
Sum of bin coefficients	233.91				
Predicted efficiency	13.3%				

Due to the change in observed efficiency, with higher wind speeds resulting in higher DS100 efficiency, a separate model value for x was used for the 6 weeks of data from 30 July to 02 October 2014 ($x = 3.24$). Results for this period are also presented in Table 5 and Figure 5 and also show an excellent correlation ($r^2 = 0.95$, $p < 0.01$).

Table 5: Measured versus modelled efficiency of DS100

Start date	End date	Relative DS100 efficiency		
		Model 1	Model 2	Measured
29-Apr-14	06-May-14	13.3%		16.9%
06-May-14	13-May-14	1.2%		4.1%
13-May-14	20-May-14	11.6%		12.6%
20-May-14	27-May-14	9.8%		11.6%
24-Jun-14	01-Jul-14	7.7%		13.0%
01-Jul-14	08-Jul-14	5.7%		4.8%
08-Jul-14	16-Jul-14	5.4%		4.7%
16-Jul-14	23-Jul-14	7.3%		8.9%
23-Jul-14	30-Jul-14	4.0%		6.3%
30-Jul-14	07-Aug-14		5.0%	3.8%
07-Aug-14	14-Aug-14		15.4%	21.3%
21-Aug-14	28-Aug-14		3.3%	4.3%
28-Aug-14	04-Sep-14		8.5%	10.3%
18-Sep-14	25-Sep-14		1.3%	3.1%
25-Sep-14	02-Oct-14		5.2%	4.7%
02-Oct-14	22-Oct-14	11.3%		7.7%
22-Oct-14	05-Nov-14	7.8%		6.6%
05-Nov-14	24-Nov-14	10.1%		10.0%
09-Jan-15	26-Jan-15	3.3%		4.7%
26-Jan-15	09-Feb-15	1.9%		6.0%

Figure 4: Measured versus modelled efficiency of DS100, 29 April 2014 – 06 May 2014 and 02 October 2014 – 09 February 2015 only, with trend line and equation.

Figure 5: Measured versus modelled efficiency of DS100, 30 July 2014 – 02 October 2014, with trend line and equation.

4.4 Further testing

Although the model shows strong promise in predicting changes in DS100 efficiency, the variation between the two distinct periods was investigated and further testing of the model was undertaken to investigate if changes to model parameters significantly altered model results.

Sensitivity testing included options shown in Table 6, with no significant improvement to model results. Meteorological data collected from the on-site weather station is shown in Table 7, with reference to the measured efficiency during each period and the model that was used. Relative humidity was consistent throughout the study period at an average of 83%, and average temperatures varied according to seasonality. Rainfall was consistent throughout the study period, and although both the driest (28 August – 2 October) and one of the wettest periods (30 July – 28 August) coincided with results from Model 2, there were no significant patterns with the efficiency data.

Table 6 – Sensitivity testing results

Sensitivity test	Result
Modelling wind speeds during site working hours only	No significant improvement
Assessment of rainfall, humidity or temperature	No significant improvement
Modelling wind speeds from a narrower arc	No significant improvement
Modelling wind speeds from a broader arc	No significant improvement
Assessment of wind speeds from other directions	No significant improvement
Adjusting x to increase the impact of higher winds speeds	No significant improvement

Table 7: Other meteorological parameters during the modelling period

Start date	End date	Total rainfall (mm)	Average temperature (°C)	Relative humidity (%)	Measured efficiency	Model used
29-Apr-14	06-May-14	20.0	10.0	81.9	16.9%	1
06-May-14	13-May-14	10.6	11.0	82.3	4.1%	1
13-May-14	20-May-14	0.4	14.9	73.4	12.6%	1
20-May-14	27-May-14	45.8	11.7	86.9	11.6%	1
24-Jun-14	01-Jul-14	10.6	14.3	81.5	13.0%	1
01-Jul-14	08-Jul-14	10.6	15.8	78.9	4.8%	1
08-Jul-14	16-Jul-14	5.2	16.7	77.8	4.7%	1
16-Jul-14	23-Jul-14	12.0	19.8	79.9	8.9%	1
23-Jul-14	30-Jul-14	0.0	19.3	71.3	6.3%	1
30-Jul-14	07-Aug-14	25.8	16.9	80.9	3.8%	2
07-Aug-14	14-Aug-14	34.0	15.4	80.9	21.3%	2
21-Aug-14	28-Aug-14	30.6	13.4	83.7	4.3%	2
28-Aug-14	04-Sep-14	1.2	15.4	83.4	10.3%	2
18-Sep-14	25-Sep-14	2.4	13.8	84.0	3.1%	2
25-Sep-14	02-Oct-14	0.2	15.7	83.8	4.7%	2
02-Oct-14	22-Oct-14	59.2	11.6	88.3	7.7%	1

22-Oct-14	05-Nov-14	23.0	11.4	89.6	6.6%	1
05-Nov-14	24-Nov-14	17.2	7.3	93.8	10.0%	1
09-Jan-15	26-Jan-15	25.2	3.7	89.4	4.7%	1
26-Jan-15	09-Feb-15	4.4	2.1	86.6	6.0%	1

Sensitivity testing of the model therefore suggested that only wind speed had a significant consistent impact on the collection efficiency variation between the two monitors and reinforced that the methodology that was used was appropriate for this study.

Uncertainty analysis of the sampling methods was also undertaken by comparing the standard deviation between dust mass measurements between the three WAC bottle samples, which were vertically positioned 120 mm apart. SD was on average 10.9% between the bottles and up to 31.3% in individual monitoring periods, with mass differences between adjacent sampler bottles of up to 206%.

5 Discussion

The model results demonstrate that wind speed is the primary influencing factor on efficiency of the DS100 monitor and show that with careful consideration it is possible to predict the efficiency of the monitor over extended periods of time. However, the variations in efficiency results throughout the study, and difference between model parameter x between the two distinct periods, demonstrates the difficulty of field-testing efficiency calculations and the number of possible influencing factors. Calculating an average efficiency over a weekly period will not reflect the fact that dust concentrations over the monitoring interval will fluctuate due to wind speed and site activities, and other factors such as particle sizing and particle composition variations. Averaging efficiency calculations over the total study period gives a mean dust catch of 7% for the DS100 compared to the WAC, which can be compared positively to the lower limits of previous indoor wind tunnel studies (i.e. 9% at 2 m/s⁹) and is therefore suggested for use in future modelling studies to enable site specific modelling studies of coarse dust to be completed.

Significantly shorter sampling periods (e.g. 24 hours) could potentially alleviate issues of diverse weather conditions during individual sample periods and provide greater clarity to wind speed-based efficiencies, but also pose new issues including dust concentrations below sample detection limits.

Although the two monitors were less than 0.5 m apart, micro-conditions may also have had a large influence on results, and this was shown in the uncertainty analysis of the sampling methods. When compared with wind tunnel studies that were conducted in controlled environments with consistent wind speeds and defined particle sizes (e.g. Datson, 2010⁹ Mendez et al, 2016²⁷), the variance between samplers in this study is not surprising and demonstrates that high uncertainty is possible for both the DS100 and WAC monitors using field rather than laboratory measurements. This demonstrates that micro-conditions between monitors were often highly variable and can explain some of the larger variances between the two samplers.

It was established that activities on site such as sales of material and vehicle movements decreased during the winter period, but no links could be found that would suggest any change in materials on site. Long sampling periods mean that attributing reliable efficiency calculations to different

conditions is difficult, although reducing sampling lengths would also increase the potential influence of short term, unidentified influencers. Factors such as higher dust emissions during different wind speeds can have large influences on the model that are difficult to account for, and boundary layer conditions can be extremely variable from night to day and over the monitoring intervals. The close distance to the potential dust emission sources may also mean that dust is not evenly dispersed into the surrounding areas.

Further work is therefore required to investigate dust impacts using a time and risk-based averaging approach of dispersion patterns, rather than solely focusing on predicting weekly concentrations with high accuracy. Using air quality modelling as an example, predictions are typically undertaken using up to 5 years of meteorological data and verified using at least one year of monitoring data²⁸, with average yearly concentrations used to verify results.

6 Conclusions

The aim of this study was to estimate the efficiency of the DS100 directional sticky pad gauge for use in dust prediction studies utilising atmospheric dispersion models. Results showed that the variation in dust catch over time between the two gauges was modelled accurately, with wind speed the primary influencing factor. However, two distinct periods of monitoring were observed, with contrasting results which could not be consistently linked to any known factors. Although no definitive model could therefore be produced that consistently predicted the efficiency of the DS100 monitor in comparison to the WAC over short monitoring periods (i.e. 2 weeks or less), an average dust catch of 7% is suggested for use in calculating airborne dust concentrations over longer periods. Using this value will allow DS100 monitors to be utilised in dust modelling studies for testing dust emission factors and for use in coarse 'nuisance' dust model adjustment and verification.

Further research is needed to understand monitor efficiency with comparison to real time light-scatter dust monitors, and future efforts are also planned using a time and risk based approach to assessing dust dispersion patterns.

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