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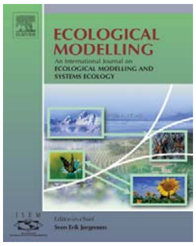

Impact of fugitive dust emissions from cement plants on nearby communities

Sabah A. Abdul-Wahab

Sultan Qaboos University, College of Engineering, Mechanical & Industrial Engineering Department, P.O. Box 33, Al Khoud, P.C. 123, Muscat, Oman

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ABSTRACT

The objective of the study was to assess the impact of fugitive particulate emissions from a cement plant on a nearby community. High volume samplers were used for the determinations of total suspended particulate (TSP) concentrations at representative assessment points situated nearest to the cement site at three existing residential houses. Furthermore, dust impact arising from cement plant on the three existing residential houses was predicted using an air quality model (fugitive dust model, FDM). The emission rates of dust from various activities of the cement plant were estimated by using the emission factors technique. The measured (high sampler) and predicted (FDM) values of dust concentration were compared. The results of the study showed that the agreement between the 24-h average predicted and measured dust concentrations were excellent. Although the model under-predicted slightly the measured dust concentrations, yet the FDM was adequate for application at the cement plant. Furthermore, the spatial isopleths of TSP concentration for cement plant and its surrounding environment indicated that the predicted ground level of dust concentrations, close to the cement plant, exceeded the World Health Organization (WHO) guideline value of 120 μg/m^3. This study was invaluable for locating areas nearby the cement plant that are at risk of approaching or exceeding guideline TSP concentrations.

1. Introduction

Dust generated from open sources is termed fugitive because it is not discharged to the atmosphere in a confined flow stream as usually happens with point-sources (Massacci et al., 2003). During the process of cement manufacture considerable amount of dust is emitted at almost every stage. Dust is generated through emissions, handling, spillage, leakages, starting with the quarrying of the major raw material limestone and ending with the packing and dispatch of cement from the plant. Concentrations of fugitive dust released from cement plant vary greatly from one area to another depending on the nature and intensity of local sources, and on other factors such as topography, general weather conditions, and liability to temperature inversions (Trindade et al., 1981; Abdul-Wahab, 2003).

Cement dust can cause ill health by skin contact, eye contact, or inhalation. Risk of injury depends on duration and level of exposure and individual sensitivity. Moreover, different cements have different ingredients. Many of them contain substances that can be hazardous, like crystalline silica (quartz), lime, gypsum, nickel, cobalt, and chromium compounds (Green N8 Residents Group, 2004). Inhalation of silica dust can cause silicosis or other potentially fatal lung diseases. In addition, inhalation of chromium compounds found in some cement dusts can cause cancer. Hence, cement dust can be an important pathway for potential human exposure. It leads to the aggravation of the problem of environment with

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E-mail address: sabah1@squ.edu.om.

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its impact not only on the employees working in the plant but also the community in the neighborhoods.

A model widely used for estimating atmospheric fugitive dust concentrations is the fugitive dust model (FDM). FDM is a Gaussian plume model specifically designed for computing concentration and deposition impacts from fugitive dust emissions (Sung, 1996). The gravitational settling velocities and deposition velocities are calculated based on the research done by Sehmel and Hodgson (1978). The model was particularly developed to model fugitive dust emissions and is well accepted by USEPA for this purpose (USEPA, 1995). It incorporates transport, dispersion and deposition of pollutants in the atmosphere, using input data for particulate matter (particle radius, density, etc.) and air-flow (mean velocity, wind direction).

The cement plant used in this study was completed in 1983 with an annual integrated cement production capacity of 624,000 tons, which consisted of ordinary Portland cement (OPC) and sulphate resistant cement (SRC). The plant currently produces 1.44 million tons of clinker and 1.5 million tons of cement annually. Clinker is produced by the heat treatment of cement raw materials (mixture of alumina, silica, lime, iron oxide and magnesia) in a kiln working at high temperature (greater than 1200 °C). Clinker is pulverized with gypsum in the manufacture of Portland cement. Therefore, clinker is a product produced in a Portland cement kiln, which is then proportioned with additives and ground into a fine powder called Portland cement.

High concentrations of particles emitted from cement plant may affect the health and property of homeowners living adjacent to the plant. There are numerous complaints about cement plant from nearby residents. They include specific problems about odors, blasting, noise, respiratory problems and corrosive dust on cars.

The main objective of the present study was to assess the impact of the existing cement plant on the nearby community. The dust emissions associated with the cement plant were investigated to ensure that the plant meet the air quality standards. A field sampling was designed and conducted to measure the particles concentration at the homeowner's property. Furthermore, the study was aimed to evaluate the performance of the FDM with respect to measured total suspended particulates (TSP) concentrations at three residential houses adjacent to the cement plant. The evaluation was conducted on a 24-h average concentration basis. In addition, the dust concentration contours were presented in order to determine the spatial distribution of dust over the studied area. This paper will be useful for the cement industry, regulatory agencies, research organizations, consultants and all those concerned with monitoring and control of dust pollution.

2. Fugitive dust model (FDM)

Most existing dispersion models that are well validated are related to gaseous pollutants. Depending on the particle size, these models may or may not be valid well for the dispersion of particulate matter. Therefore, there are limitations of existing models for estimating the concentrations and impacts from fugitive dust sources. Currently, industrial source complex model (ISC), CALPUF, and fugitive dust model are suitable for modeling fugitive emissions. Moreover, there are some particle trajectory models (e.g. PTM) that can be used to account for the dispersion and deposition of coarse particles in the atmosphere (Vesovic et al., 2001).

FDM is a computerized air quality model specifically designed for computing impacts from fugitive dust sources. It can be used to model the emissions of fugitive dust from various sources. For example, it can be used to predict dust concentrations from sources such as quarrying, aggregate crushing, abrasive blasting, unsealed surfaces and material stockpiles. It can also be used for industries that emit particulate dust such as urea, sulfate, cement or others. FDM also can be used to model emissions surrounding a liquid waste disposal facility, odors from sewage treatment plants, dirt roads, and mining operations.

It has been reported that significant different results can be derived for the same input data to the ISC and CALPUFF models for both gaseous and particulate emissions from areas sources, as well as for particulate emissions using the CALPUFF and FDMs. The CALPUFF model is fairly sensitive to the specification of particle size distribution by particle size class (Hrebenyk et al., 2003). It has also been reported that FDM is better than either ISC or CALPUFF for modeling in situations of variable emissions rates (e.g. wind erosion due to variable wind speeds).

Assumptions for solution of the atmospheric dispersion equation in FDM include: (1) the pollutant is composed of different classes of uniformly-sized particles and the diffusion in *x*-direction is small compared to the advection by the wind in that direction and (2) Eddy diffusivities are functions of only the downwind distance and independent of travel time from the source. Based on these assumptions the concentration and the deposition rate at several receptors sites are calculated. However, the FDM contains no plume rise algorithm (Rwsman and Lipsher, 1993). Thus, it has not been designed to find out the impacts of buoyant point sources.

Vesovic et al. (2001) indicated that the shape of the particle is a very important parameter in determining the deposition. They stressed that all of the existing models assume that the released particles are spherical. They pointed out that this assumption is not true of the most emitted particles. Hence, it is believed that the shape of particles play an important role in particle transport away from the source. Details of the FDM, ISC, PTM and other different models are given elsewhere (e.g. Finzi and Guariso, 1992; Vesovic et al., 2001; Malmaeus and Håkanson, 2003; Aloyan, 2004)

3. Methodology

High volume sampler was used to collect total suspended particulate from inside three residential houses. This was used to measure the suspended particles concentration at the homeowner's property located nearby the cement plant (as indicated in Fig. 1). These houses were located adjacent to the cement plant and were selected on the basis of that the collected samples would be representative of the worst pollution conditions in the zone. The high-volume sampler worked like a vacuum cleaner; it drew a volume of air through a filter that

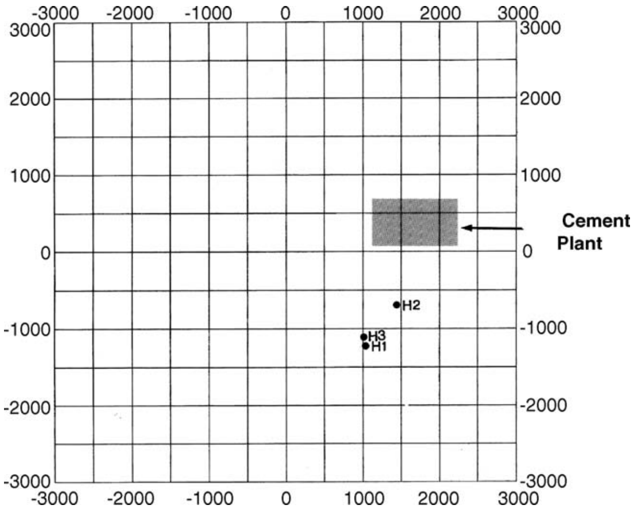

Fig. 1 – The location of the three discrete receptors in relation to the cement plant.

captures the particles suspended in the air (TSP with a diameter of 100 μm or less). The high volume samplers were operated at flow rates of 60 l/min and TSP were collected on Whatman glass microfibre filters. The high volume sampler was placed at a height of about 1.5 m for 24-h periods. The sampler was run continuously for a period of 24-h and was turned off for a period of 24–72 h before it was operated again. At the end of the sampling period, the filter paper was removed, dried and reweighed. The concentration of particulate was measured by the weight gain of the filter divided by the volume of air sampled and was reported in micrograms (or nanograms) per cubic meter. Sampling at each house was duplicated and the average of the two readings was considered for the study.

The performance of the FDM with respect to measured TSP concentrations at three residential houses was investigated. The evaluation was conducted on a 24-h average concentration basis. Since fugitive dust emissions can contribute to TSP concentrations, regulations require an evaluation of the 24-h impact of fugitive dust sources. In this study, the World Health Organization (WHO) guideline (120 $\mu g/m^3$ as a 24-h average) was used in the assessment of TSP data (WHO, 1999; Australia EPA, 2001). Furthermore, the TSP concentration contours were presented in order to determine the spatial distribution of suspended dust over the studied area.

4. Emission rate calculations

This section describes the procedure for estimating emissions from facilities engaged in cement manufacturing activities. The principal sources of dust emissions from the processing sources include the limestone crushes, preheater kilns, clinker processing and finished cement grinding operations. Quarrying operations are also an important source of dust (Marlowe and Mansfield, 2002). Dust emissions also arise as a result of material handling operations (e.g. raw material unloading, raw material charging to crushers, active stockpiles of raw materials due to wind, transfer and conveying, unloading to storage). The emissions activity also includes roadways and parking areas (i.e. transport of raw materials to the site).

The emission factors estimation technique was used to estimate emissions from cement facility. An emission factor is a tool that is used to estimate emissions to the environment. It relates the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are usually expressed as the weight of a substance emitted multiplied by the unit weight, volume, distance, or duration of the activity emitting the substance (NPI, 1999).

Emission factors were used to estimate a facility's emissions by the following equation:

$$E_{\mathrm{kpy},i} = [\mathrm{Ar} \times \mathrm{OpHrs}] \times \mathrm{EF}_i \quad (1)$$

where $E_{\mathrm{kpy},i}$: emission rate of pollutant i, kg/year, Ar: activity rate, t/h, OpHrs: operating hours, h/year, EF_i: uncontrolled emission factor of pollutant i, kg/t.

In this work, the emission rates of dust from various sources were calculated using the emission factors reported in National Pollution Inventory manual (NPI, 1999). This manual provides the procedures and recommended approaches for estimating emissions from facilities engaged in cement manufacturing activities.

4.1. *Calculation of dust emissions from cement manufacturing*

This presents the dust emissions from the processing sources only that include: (1) limestone crushing; (2) Kiln processing; (3) clinker production; and (4) finished cement grinding. Table 1 shows these calculations. It is clear from this Table that for the different processes of the cement operations, there were large variances on the mass concentrations of the fugitive particles. Furthermore, it should be noted that these numbers represent the PM10 emissions from the processing sources only. The emissions from all other sources, e.g. stockpiles, roads, will need to be added to these. Although it was expected that TSP and PM10 emissions were not identical. Nevertheless, comparison against the PM10 emissions was still useful. It was necessary to invoke this assumption because information on the TSP emissions from cement processing was not available. Clearly, the assumption made in order to apply the FDM. The results will be useful in understanding not only how well the model predictions fit the measurements but also in gaining an insight into the model's behaviour.

4.2. *Calculation of dust emissions from active stockpiles*

Particulate matter emissions from active stockpiles due to wind (Table 2) was calculated using the following equation:

$$E_{\mathrm{PM10}} = \mathrm{EF}_{\mathrm{PM10}} \times \mathrm{area} \times \mathrm{ER}_{\mathrm{PM10}} \quad (2)$$

where E_{PM10}: hourly emissions of PM10 (kg/h), $\mathrm{EF}_{\mathrm{PM10}}$: site emission factor of PM10, kg/ha/h (in the absence of available PM10 data, the default value of 0.3 kg/ha/h can be used. Area:

Table 1 – Calculation of dust emissions from cement manufacturing

Cement plant	Emission factor (kg PM10/ton unit)	Conversion factor	Emission factor (kg PM10/ton cement)	Emission rate (kg PM10/year)	Emission rate (E_{PM10}) (g PM10/s)
An uncontrolled limestone crusher	0.017 kg PM10/ton limestone	0.8 ton limestone/ton cement	0.0136	20400	0.78703
A preheater kiln with an electrostatic precipitator	0.1 kg PM10/ton clinker	0.96 ton clinker/ton cement	0.096	144000	6.112
A clinker processing operation fitted with an electrostatic precipitator	0.01 kg PM10/ ton clinker	0.96 ton clinker/ton cement	0.0096	14400	0.556
Finished cement grinding operation (uncontrolled)	0.3 kg PM10/ton cement	1 ton cement/ton cement	0.3	450000	17.361

Number of operating days per year = 300 days/year = 7200 h/year, Annual production rate of cement = 1.5×10^6 ton cement/year, 0.8 ton of limestone and 0.96 ton of clinker are processed per ton of cement.

Table 2 – Calculation of dust emissions from active stockpiles

Area of each stockpile (area) = 2,705.3 m^2 = 0.27053 ha
Site-specific factor (EF_{PM10}) = 1.44 kg/ha/h (default value)
No emission reduction of PM10 (ER_{PM10} = 100%)
Emission rate of PM10 for each stockpile (E_{PM10}) = EF_{PM10} × area × ER_{PM10} = 1.44 × 0.27053 × 1 = 0.38956 kg/h = 0.108 g/s

Number of stockpiles = 8, width of each stockpile = 23.611 m, length of each stockpile = 114.58 m.

Table 3 – Calculation of dust emissions from material handling calculations (limestone conveyor belt)

EF_{PM10}= 0.0036 kg PM10/ton limestone (default value taken from NPI, 1999)
0.8 ton of limestone are processed per ton of cement
Annual production rate of cement = 1.5×10^6 ton cement/year
Number of operating days per year = 300 days/year = 7200 h/year
EF_{PM10} for cement = (0.8 ton limestone/ton cement) × 0.0036 kg PM10/ton limestone = 0.00288 kg PM10/ton cement
Emission rate of PM10 = (0.00288 kg PM10/ton cement) × (1.5×10^6 ton cement/year) = 4320 kg PM10/year = 0.17 g PM10/s

area of base of stockpile, hectare (ha), ER_{PM10}: emission reduction of PM10 (%).

Furthermore, Table 3 shows the calculations related to the dust emissions from lime stone conveyer.

4.3. *Calculation of dust emissions from equipment traffic*

Particulate matter emissions from trucks traveling on-site (Table 4) was calculated using the following equation:

$$E_{PM10} = EF_{PM10} \times VKT \quad (3)$$

where E_{PM10}: emissions of PM10 (kg/year), EF_{PM10}: emission factor for PM10 = 1.5 kg/VKT (default value taken from NPI, 1999), VKT: truck kilometer traveled per year (km/year).

The truck kilometer traveled per year (VKT) was calculated by using the following equation:

$$VKT = D \times NU \quad (4)$$

Table 4 – Calculation of dust emissions from equipment traffic calculations

Amount of limestone required per year = (1.5×10^6 ton cement/year) × (0.8 ton limestone/ton cement) = 1.2×10^6 ton limestone/year
Number of trucks needed per year (NU) = (1.2×10^6 ton limestone/year) × (truck/30 ton limestone) = 40,000 trucks/year
Average distance traveled by each truck (D) = 1 km/truck/year
Truck kilometer traveled per year (VKT) = D × NU = (1 km/truck/year) × (40,000 trucks) = 40,000 km/year
Emission factor for PM10 (EF_{PM10}) = 1.5 kg/VKT (WHO, 1999)
Emission rate (E_{PM10}) = (EF_{PM10}) × (VKT) = (1.5 kg/VKT) × (40,000 VKT/year) = 60,000 kg/year = 2.3148 g/s

Distance from quarry to the crusher = 1 km, capacity of each truck = 30 ton, number of wheels = 8 wheels.

Table 5 –

No.	Source	Type of source	Emission rate (g/s)	X1 (m)	Y1 (m)	X2 (m)	Y2 (m)	X3 (m)	Y3 (m)	X4 (m)	Y4 (m)
(a) Source information											
Limestone crushing operations											
1	Crusher	Point	0.787	1128.8	1100.0	–	–	–	–	–	–
Kiln Operations											
2	Stack1	Point	3.056	1481.9	412.7	–	–	–	–	–	–
3	Stack2	Point	3.056	1481.9	450.7	–	–	–	–	–	–
Cement grinding operations											
4	Finished cement grinding	Point	17.361	1783.3	440.8	–	–	–	–	–	–
Stockpiles sources											
5	A1	Area	0.108	1200.0	607.0	1353.3	607.0	1353.3	725.0	1200.0	725.0
6	A2	Area	0.108	1248.6	607.0	1285.3	607.0	1285.3	725.0	1248.6	725.0
7	A3	Area	0.108	1286.1	607.0	1326.9	607.0	1326.9	725.0	1286.1	725.0
8	A4	Area	0.108	1341.7	607.0	1371.4	607.0	1371.4	725.0	1341.7	725.0
9	A5	Area	0.108	1341.7	729.0	1371.4	729.0	1371.4	846.5	1341.7	846.5
10	A6	Area	0.108	1286.1	729.0	1326.9	729.0	1326.9	846.5	1286.1	846.5
11	A7	Area	0.108	1248.6	729.0	1285.3	729.0	1285.3	846.5	1248.6	846.5
12	A8	Area	0.108	1200.0	729.0	1353.3	729.0	1353.3	846.5	1200.0	846.5
Materials handling											
13	Limestone conveyor belt (width = 0.5 m)	Line	0.17	1200	846.5	1128.8	1100	–	–	–	–
14	Equipment traffic Trucks (Width = 2.5 m)	Line	2.3	1130	1100	130	1100	–	–	–	–

Stack	Diameter (m)	Height (m)	Velocity (m/s)	Temperature (°C)	Flow rate (m^3/s)
(b) Stack information					
1	3.25	83	4.678	90	38.81
2	1.8	120	8.877	150	22.59

Total emission rate (g/s) 27.594.

Table 6 – Diameter and particle fraction for each particle size class

No.	Diameter range (μm)	Particle fraction
1	0–45	0.07916
2	45–53	0.09878
3	53–63	0.12984
4	63–75	0.45106
5	75–90	0.10468
6	90–150	0.12650
7	≥150	0.00998

where *D*: average distance traveled (km/truck/year), NU: number of trucks (trucks).

It can be concluded from Tables 1–4 that that 62.9% of dust emissions arise from cement grinding operations, 21.7% from kiln stacks, 8.3% from trucks, 3.1% from stockpiles, 2.9% from limestone crushing operations and 0.6% from limestone conveyor belt.

5. Data requirements for FDM

The required input parameters to the FDM included dust emission sources at the cement plant and site meteorological conditions. These parameters together with receptor data and other miscellaneous parameters provided a comprehensive set of information that were used to run the FDM and thus simulated the concentrations of fugitive dust.

5.1. *Dust emission sources*

The FDM can process up to 121 sources. The emission sources may be point, line, or area sources. Area sources needed not be square, but rather could be rectangular, up to an aspect ratio of 1–5 (ratio of width to length). Total of 14 dust sources were specified as input for the model: four point stack sources, eight area sources, and two line sources. The general source information needed to be input into the model for the point sources was restricted to the *X* and *Y* coordinates of each point source. However, the general source information needed to be input into the model for the area sources was restricted to the *X* and *Y* coordinates of the four ends ((*X*1, *Y*1), (*X*2, *Y*2), (*X*3, *Y*3) and (*X*4, *Y*4)) of each area source. Furthermore, the general source information needed to be input into the model for the line sources was restricted to the *X* and *Y* coordinates of the two ends ((*X*1, *Y*1) and (*X*2, *Y*2)) of each line source and the width of each line source. Table 5a shows the emission rates, the coordinates and the release heights data for each of the included 14 sources. Table 5b shows the stack information data.

5.2. *Particle fractions and density data*

FDM permits the specification of up to 20 particle size classes. In this study, seven particle size classes were used. Table 6 shows the diameter and particle fraction for each particle size class used to run the model.

Table 7 – Receptors information

Number of discrete receptors = 3

Receptor	House	X (m)	Y (m)	Height with respect to cement plant (m)
Discrete receptors				
1	H1	1010	−1075	22
2	H2	1475	−715	14
3	H3	1000	−1030	22

Parameter	FDM value
Grid receptors	
Grid coordinates	Generate cartesian
Number of points a long the *X*-axis	14
Number of points a long the *Y*-axis	14
Southwest corner *X*-axis location	−3000 m
X-axis receptor spacing	500 m
Southwest corner *Y*-axis location	−3000 m
Y-axis receptor spacing	500 m

5.3. *Receptor location*

The FDM can process up to 1200 receptors. Receptors should be located where the maximum total concentration is likely to occur and where the public is likely to have access (USEPA, 1992). In this study, three discrete receptors (three residential houses located nearby cement plant) were specified in terms of *X*, *Y*, and *Z* coordinates. The discrete receptor coordinates are given in Table 7 and shown in Fig. 1. Furthermore, calculations with the FDM were performed on a rectangular grid, 3 km × 3 km that is shown on Fig. 1. The grid base element was a 0.5 km square. These dimensions were chosen so as to avoid including a large number of receptor points outside the area that was affected by the cement source emissions. The height of the receptors (*Z* coordinate) was set to be 1.5 m, which was supposed to represent a reasonable location where people would be walking and breathing (Hickman, 1976; USEPA, 1992; Lindemann, 1994). The parameters related to the gridded receptors are summarized in Table 7.

5.4. *Meteorological data*

Meteorology is an important factor of any dispersion model. It is the main component in determining the diluting effect of the atmosphere as the released substance is carried along by the wind (Abdul-Wahab and Bouhamra, 2004). The FDM required the site-specific meteorological information as input data to define the conditions for transport, diffusion and deposition. The hourly meteorological data relevant to this study were obtained from Seeb International Airport (Table 8). These data was restricted to the following:

- Hourly wind direction and speed, air temperature together with atmospheric Pasquill stability class (based on total sky cover and cloud amount).
- Daily morning and maximum mixing heights based on the radiosonde ascent at Seeb airport.

Table 8 – Hourly meteorological data required to the FDM

H	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10
27–28 July 2003 (11:00–10:00)																								
WD	358	359	30	47	52	59	62	65	62	54	60	67	88	126	170	307	56	157	296	289	236	242	16	38
WS	3.2	4.1	4.9	4.2	3.5	3.4	3.8	3.5	2.4	2.0	2.3	2.9	3.6	1.3	2.0	1.8	0.5	0.2	0.2	1.0	2.9	2.6	2.7	1.7
T	312	311	311	310	310	310	309	308	307	306	305	304	307	306	308	305	304	304	303	304	306	308	305	307
SC	B	B	B	B	B	B	B	B	E	E	E	E	D	E	E	E	E	E	E	A	B	B	B	A
5–6 August 2003 (11:00–10:00)																								
WD	11	22	35	40	44	39	47	53	59	55	64	80	31	91	91	185	322	186	184	102	249	310	354	17
WS	3.0	4.4	4.8	4.5	4.2	3.9	3.2	2.5	2.0	1.3	1.4	0.2	1.4	2.1	1.7	1.2	1.1	0.2	0.6	1.0	1.1	1.4	1.9	2.4
T	306	306	305	306	305	305	304	304	304	303	303	303	303	303	303	304	302	303	302	302	303	305	306	308
SC	B	B	B	B	B	B	B	A	E	E	E	E	E	E	E	E	E	E	E	A	A	A	A	A
11–12 August 2003 (11:00–10:00)																								
WD	34	36	51	51	48	49	50	62	25	320	291	307	291	261	327	67	63	69	127	253	278	12	347	343
WS	1.8	3.3	3.6	4.2	4.6	4.4	5.3	4.9	2.5	1.1	0.9	1.6	2.2	0.4	0.9	1.8	1.9	1.6	0.9	1.9	3.2	3.7	3.8	3.6
T	305	304	305	304	304	304	303	304	303	301	301	300	300	302	300	300	300	300	300	300	302	303	304	305
SC	A	B	B	B	B	B	C	B	E	E	E	E	E	E	E	E	E	E	E	A	A	B	B	B

H: hour, WD: wind direction, WS: wind speed (m/s), T: temperature (k), SC = Stability class, mixing height = 1200 m.

Table 9 – Miscellaneous input parameters required to the FDM

Parameter	Input FDM values
Number of particle size classes	7
Surface roughness height (cm)	0.003
Particulate matter density (g/cm^3)	1.44
Averaging period selection	24-h
Length of meteorological period (min)	60
Number of hours to be processed (h)	24
Anemometer height above ground (m)	10

5.5. *Miscellaneous data*

The remaining input variables required by FDM include surface roughness height, the averaging time, the wind speed dependence factor, the length of meteorological period and the particulate matter density. These miscellaneous data are summarized in Table 9. The surface roughness coefficient indicates the average downwind flow obstruction and its value will affect the model's determination of friction velocity and wind speed profile. The recommended surface roughness coefficients for various land uses can be found elsewhere (USEPA, 1992). The surface roughness length equals 0.003 cm was used in this. The averaging period selection was 24-h, since predictions (in the model) and sampling (in the field) were performed for a 24-h period. It should be noted that the particle density listed in Table 9 was specific to Oman cement plant that determined experimentally in the labs at the Sultan Qaboos University.

6. Results and discussion

Table 10 shows the results of the measured particulate samples collected from the three residential houses located nearby the cement plant. Measurements in each house were averaged on 24 h and collected on: 27–28 July, 5–6 August, and 11–12 August 2003. Table 10 showed that the dust measured in house1 ranged from 312.08 to 423.83 μg/m^3, in house2 ranged from 196.19 to 358.91 μg/m^3, and in house3 ranged from 203 to 259.6 μg/m^3. Furthermore, the 24-average dust concentrations for each house were compared to the World Health Organization guideline value of 120 μg/m^3 (WHO, 1999). The results indicated that the measured average TSP concentrations at the three houses exceeded the WHO guideline. These results revealed that the cement plant activities had impact on the air quality of the nearby residential houses. Such concentrations would be expected to be higher when worst atmospheric and stability conditions occurred especially if this coincided with the increase of the cement plant production rate.

The FDM was run with the estimated dust emission rates and on-site meteorological conditions. The model predictions were carried out for 24-h averaging time, since the dust measurements were done for 24-h averaging time. The actual measured dust concentrations were compared with FDM predicted data over the same period. The predicted and observed dust concentrations at the three house locations during the period of the study are listed in Table 11. In general, the modeling results tended to under-predict the measured concentrations

Table 10 – Results of the measured total suspended particulate samples collected from the three residential houses

No.	Receptor	Date of sampling	Time on (hh:mm)	Time off (hh:mm)	Sampling time (min)	Flow rate (L/min)	Flow rate (m^3/min)	Volume (m^3)	Weight filter before (g)	Weight filter after (g)	Concentration (g/m^3)	Concentration (μg/m^3)
1	House1	05–06 August 2003	11:45	12:42	1497	64.0	0.0640	95.81	0.1535	0.1834	0.00031208	312.08
2	House1	11–12 August 2003	11:23	12:39	1516	63.5	0.0635	96.27	0.1530	0.1938	0.00042383	423.83
3	House2	27–28 July 2003	11:20	11:40	1460	59.0	0.0590	86.14	0.1536	0.1705	0.00019619	196.19
4	House2	05–06 August 2003	11:40	12:37	1497	59.0	0.0590	88.32	0.1528	0.1845	0.00035891	358.91
5	House3	27–28 July 2003	11:30	11:35	1445	60.0	0.0600	86.70	0.1527	0.1703	0.00020300	203.00
6	House3	05–06 August 2003	11:47	12:44	1497	61.5	0.0615	92.07	0.1528	0.1767	0.00025960	259.60

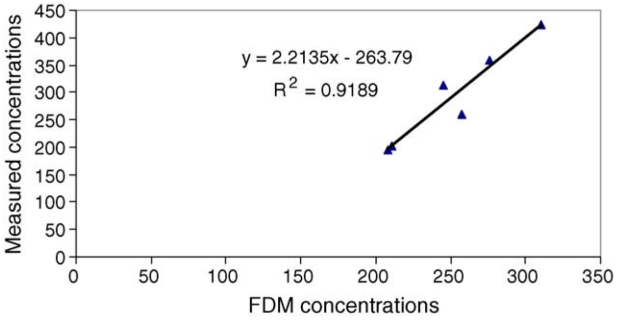

Fig. 2 – Comparison between measured and predicted average dust concentration (μg/m^3), averaged on 24 h.

at all receptors. This under-prediction for dust concentrations was seen on 5–6 August and 11–12 August 2003 data. The variation between measured and predicted values may be due to non-accountable dust emissions from various other sources and activities. Although the model over-predicted slightly the measured dust concentrations on 27–28 July 2003, yet the quantitative agreement between average predicted and measured concentrations was excellent.

Furthermore, the performance of the FDM was evaluated using the correlation coefficients and the regression coefficients (Fig. 2). Correlation coefficients provide an idea how far the measured values are related to predicted values. It is the measurement of the strength of relationship between observed and predicted values. A value of correlation coefficient close to unity implies good model performance. On the other hand, regression coefficients represent the status of the best-fit line between measured and predicted values (Chaulya et al., 2002). The value of the correlation coefficient for FDM was calculated as 0.9189, which showed a good agreement between measured and predicted values. The linear regression

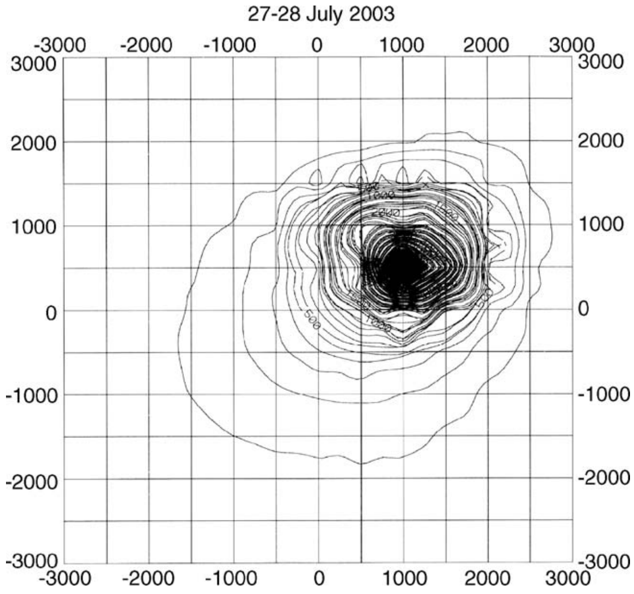

Fig. 3 – Predicted 24-h average concentration contours of fugitive dust (μg/m^3) on 27–28 July 2003.

Table 11 – Comparison between FDM results and air sampler results

Receptor	FDM concentration (μg/m^3)	Air sampler concentration (μg/m^3)	Ratio (measured/FDM)	Difference (%)
27–28 July 2003				
2	208	196	0.94	−6.12
3	211	203	0.96	−3.94
5–6 August 2003				
1	245	312	1.27	+21.47
2	276	359	1.30	+22.91
3	257	260	1.01	+0.77
11–12 August 2003				
1	319	424	1.37	+24.7

coefficients a, and b were calculated to be 2.2135 and 263.79, respectively.

Figs. 3–5 show the contours (isopleths) of predicted 24-h average TSP concentrations. These contours were produced as results of running the FDM for the dates of 27–28 July, 5–6 August, and 11–12 August 2003, respectively. They were plotted using the Breeze Air Graphics Utility of the FDM. These isopleths indicated the dust tendency in the assessment area. Therefore, they were very important in determining the spatial distribution of dust over the modeled area. In addition, they were used to determine the spatial locations for which the guideline value for dust concentration was approached or exceeded the WHO guideline value. Figs. 3–5 showed that the contour pattern changed depending on variations in meteorological conditions. Variations in the atmospheric conditions determined the total area that was affected by the emission sources at cement plant. Close inspection of these figures revealed that the highest dust concentrations were expected to occur relatively close to the sources of emission at cement plant. Moreover, because fugitive dust was generally emitted at or near the surface, ground-level concentrations immediately downwind of the cement plant were expected again to be extremely high. This was observed over the whole days covered by study. For example, the contours of predicted average dust concentration on 27–28 July, 5–6 August, and 11–12 August 2003 showed a maximum average value of 12901, 7671 and 10668 μg/m^3, respectively. These values were located close to the cement plant at the X and Y coordinates of 1000 and 500 m, respectively, from the origin. This suggests that the air quality inside the cement workplace and its surroundings (i.e. nearby community) would be affected in terms of TSP concentrations.

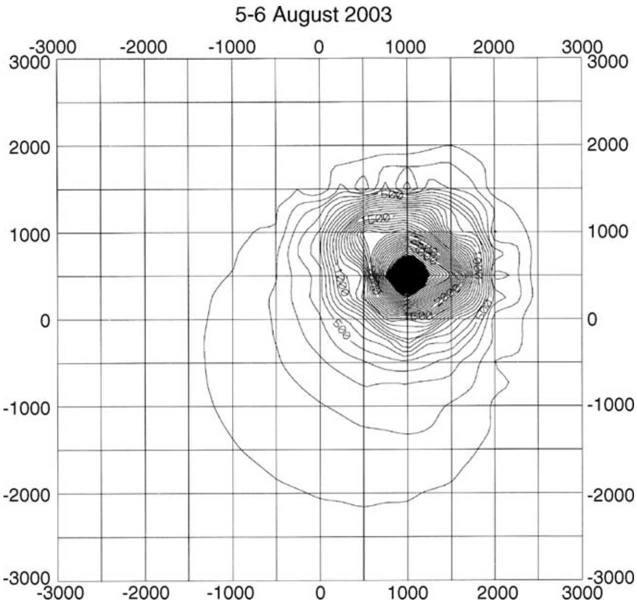

Fig. 4 – Predicted 24-h average concentration contours of fugitive dust (μg/m^3) on 5–6 August 2003.

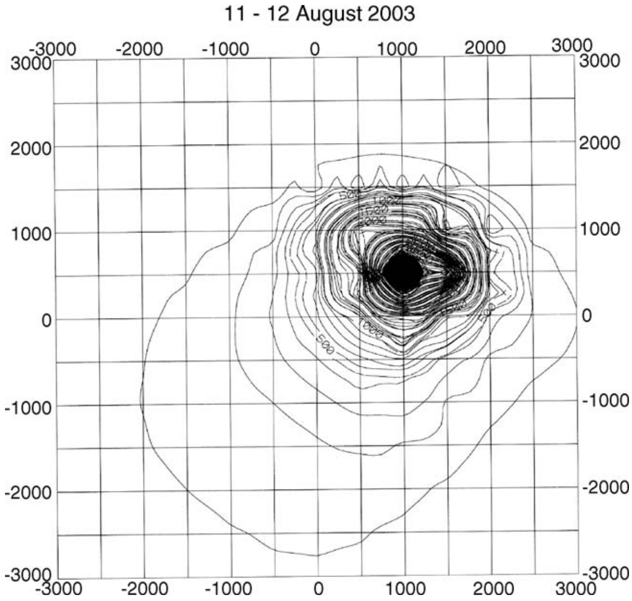

Fig. 5 – Predicted 24-h average concentration contours of fugitive dust (μg/m^3) on 11–12 August 2003.

7. Conclusions

The fugitive particulate emissions generated from the cement plant activities were investigated in this paper. The main objective was to assess the impact of the existing cement plant on the nearby community. High volume samplers were used for the measurements of total suspended particulate concentrations at three existing residential houses at the Misfat Al Safil village. The measurements, averaged on 24 h, showed that the TSP generated from the cement plant may affect the health and property of homeowners living adjacent to the plant.

In addition, dust emission associated with the cement plant was modeled using the fugitive dust model. The ground level dust concentration predicted for each of the three houses was compared with actual values. In general, the FDM results tended to under-predicted the measured concentrations. However, the results of the comparison showed that FDM performed well in predicting dust concentrations and that the model was adequate for application at the cement plant. Accordingly, the FDM was used for the purpose of simulating the spatial distribution of dust in and around the plant. The isopleths of TSP concentration for cement plant and its surrounding environment were plotted. These isopleths indicated that the maximum 24-average predicted ground level of dust concentrations were seen at locations close to the cement plant.

It is recommended that further study be undertaken to assess the impact of SO_2, NO_x, and the heavy metals arising from the cement plant. Another study that is also recommended for investigation is the determination of the worst-case scenarios that lead to the highest concentrations of dust in the area. Other scenarios should be examined that include increased industrial activity in the region. A more comprehensive study should be made on the factors that affect the emission rate calculations at each stage during the production of cement. The existence of thermal inversion phenomena in such areas, especially during the winter months should also be assessed. Such studies will allow scientists to gain a better insight about FDM behavior, and to assess the reliability and accuracy of model predictions. The information obtained in the current study will be invaluable not only for finding locations at risk, but also for assessing the most practicable ways of making improvements to local ground-level dust air quality. In addition, the results of the paper will be a valuable resource to those involved with dust issues.

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