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Developing Emission Factors of Fugitive Particulate Matter Emissions for Construction Sites in the Middle East Area

Hala A. Hassan, Vasiliki K. Tsiouri, Konstantinos E. Konstantinos

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***Abstract*—**Fugitive particulate matter (PM) is a major source of airborne pollution in the Middle East countries. The meteorological conditions and topography of the area makes it highly susceptible to wind-blown particles which raise many air quality concerns. Air quality tools such as field monitoring, emission factors and dispersion modeling have been used in previous research studies to analyze the release and impacts of fugitive PM in the region. However, these tools have been originally developed based on experiments made for European and North American regions. In this work, an experimental campaign was conducted on April-May 2014 in a construction site in Doha city, Qatar. The ultimate goal is to evaluate the applicability of the existing emission factors for construction sites in dry and arid areas like the Middle East.

***Keywords*—**Air pollution, construction, emissions, middle east, fugitive particulate matter.

I. INTRODUCTION

THE main source of airborne pollution in the arid Middle East countries is the fugitive particulate matter (PM) [1], a frequent product of wind erosion. The meteorological conditions and topography of this region makes it highly susceptible to wind-blown particles which raise many air quality concerns. Many hazardous contaminants such as minerals are associated with and transported by dust, and have severe impacts on human health and environment [2]-[5]. The severity of PM effects on human health mainly depends on the concentration levels and the length of the exposure [6]. Several studies during the last decade, have reported adverse health effects of PM related to both long and short term exposure [6], [7].

Fugitive dust particles that are discharged to the atmosphere in an unconfined flow are caused by either one of two phenomena: pulverization/abrasion of surface material by applying a mechanical force, or entrainment of dust particles by air currents such as wind erosion [8]. The latter is a result of two types of forces: “aerodynamic forces” that cause the removal of particles from the surface, and is determined by the “wind friction velocity”, a measure of wind shear at the surface, and forces that resist particles removal such as “gravitational and inter-particle cohesion forces” [2]. The dust particles get entrained into the atmosphere when wind speed exceeds a critical value, that is called the “threshold friction velocity” [9], [10]. The threshold friction velocity is the minimum velocity required to initiate particle motion. The ability of particles to disperse and deposit depend on their shape and size [11], and other factors such as soil texture, moisture and chemical composition affect the quantity of emitted dust particles [12].

Important tools for estimating the dispersion and deposition of dust particles, and help in designing dust control procedures are the Air quality (AQ) models [13]. The United States Environmental Protection Agency (USEPA) has approved a wide range of atmospheric dispersion models [14]. These Models can predict concentrations of various pollutants on both local and regional scale; however, most of the well validated models have limitations in estimating concentrations from fugitive dust sources [15]. One of the most commonly used models to compute concentration and deposition impacts of fugitive dust sources is the “Fugitive Dust Model” (FDM), a Computerized Gaussian air quality model developed by USEPA [16].

The accuracy of an AQ model depends on the accuracy of the input pollutant emission rates [9]. Emission rates can be estimated using data from air quality monitors, or by using empirical emission factors developed by governmental agencies such as USEPA. “Emissions Factor” is a representative value or algorithm (for complex cases) that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant [8].

For example, in the work of Abdul-Wahab, the impact of fugitive dust emissions from a cement plant was assessed [15]. Further, dust emission rates from various sources (cement manufacturing activities, storage piles & equipment traffic) were estimated using the emission factors reported in the National Pollutant Inventory manual [17]. The calculated emission rates along with meteorological and receptor data were entered into the FDM to compute the dust emission concentrations. In order to validate the model predictions, high-volume samplers were placed at residential areas adjacent to a cement plant to collect TSP particles, and the concentrations were calculated using the sample volume. The predicted and observed values were evaluated based on 24-h average concentrations. Although the FDM model showed an under-prediction of TSP concentrations, it proved to be

H. Hassan and V. Tsiouri are with the Chemical Engineering Program, Texas A&M University at Qatar, Qatar (e-mail: hala.hassan@qatar.tamu.edu, vasiliki.tsiouri@qatar.tamu.edu).

K. E. Kakosimos is with the Chemical Engineering Department and Mary Kay ‘O Connor Process Safety, Texas A&M University at Qatar, Qatar (corresponding author; phone: +974 44230678; e-mail: k.kakosimos@qatar.tamu.edu).

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adequate based on the performance evaluation performed using correlation and regression coefficients.

An extensive study was conducted by [12] to quantify windblown dust at Mono Lake, California. This work presents a different method patterned after Owens Lake Dust Identification Program (Dust ID). This method benefits from the theoretically & experimentally evidenced proportionality between the vertical PM10 flux and the horizontal sand flux. The methodology in this study was based on measuring 1-h horizontal sand fluxes and relates them to the 1-h PM10 concentrations and the "AERMOD" dispersion model was used to back-calculate seasonal K-factors (i.e. the ratio of vertical PM10 flux to horizontal sand flux). Next, the seasonal K-factors were used to re-calculate the 1-h PM10 emissions and compare them to the monitored PM10 concentrations. The results obtained in this study concluded that the wind erosion is not a simple function of wind speed, as assumed by the AP-42 wind-tunnel emission algorithms, and that the estimation of PM10 concentrations using the sand flux measurements and K-factors provides better modeling results since they account for the change in surface conditions. In a more recent study by [18], dust emissions from smelter slag were calculated using an experimental-based approach. A physical difference was introduced in this study; that is fugitive dust entrained from smelter slag doesn't depend on a defined threshold friction velocity unlike that of the development of saltation cloud. The mass emission rate "E" was calculated using the control volume method and data from wind experiment. Vertical dust flux "F" was also calculated using finite difference approximation and gave a good agreement with the predicted emission rate. The obtained values were validated though direct field measurements using non-isokinetic TSI DustTrack aerosol monitors, which confirmed a good agreement between the measured and predicted emissions. In the work of Kinsey et al, 2014, a research program was described that directly determined both PM10 and PM2.5 (particles ≤10 and 2.5 µm in classical aerodynamic diameter, respectively) emission factors for mud/dirt carryout from a major construction project located in metropolitan Kansas City, MO [19].

For the Middle East area, the release of airborne PM from major building activities such as earthworks and construction is largely unknown and emissions inventories for different situations are needed. In the present study, fugitive PM releases from a construction site in Middle East area will be examined to provide the missing information to fill this gap. The PM concentrations from wind erosion will be determined and the analysis from the experimental campaign along with the FDM model results will be used to correlate meteorological variables, concentrations and emission rates to understand the behavior of the fugitive dust emissions. This study is done considering the fugitive dust emission factors reported in USEPA AP-42 "Compilation of Air Pollutant Emission Factors" [8]. The ultimate goal of the present study is to improve the accuracy of the existing "factors" to apply for Middle Eastern conditions.

II. METHODOLOGY

The measured concentrations from an experimental field campaign and the predicted concentrations using the FDM model were used to develop emission factors of fugitive PM emissions for construction sites in the Middle East Area. The correlations between meteorological variables, measured concentrations and emission rates were examined to understand the behavior of the fugitive PM emissions and to test the effect of the meteorology on the emission factors for each meteorological variable.

A. Experimental Field Campaign

An experimental field campaign was conducted on April-May 2014 in a construction site in Doha city, Qatar. Particles concentrations were measured directly using an on-site monitoring tool. PM concentrations and meteorological data were measured on site using an air quality monitoring station manufactured by Grimm Aerosol Technik GmbH & Co. KG. The station measures particles over a size range of 0.25 up to 32 µm in 31 size channels, and uses a laser diode of 655 nm wavelength as a light source.

Two monitoring stations were used for this study. One station was installed at a rested (i.e. not active during the study) construction site located at Qatar Foundation Education City within the city of Doha, Qatar. This site was chosen as it represents an open bare land, highly susceptible to wind activity and close to an educational campus & residential areas (Fig. 1). The second station was placed at a building roof top 1.5km away NE (38 degrees heading) from the first station to measure background PM concentrations (Fig. 2). PM emissions rates were monitored for a period of 9 days (from 30th April to 8th May 2014). Meteorological data such as wind speed, wind direction, temperature and humidity were also measured through a climate sensor attached on the top of the station.

Fig. 1 The first Monitoring Station installed at a rested construction site

B. Numerical – FDM Model

The Fugitive Dust Model (FDM) was used in this study. FDM is an air quality model designed specifically to compute emission concentrations and deposition impacts of fugitive dust sources [16]. The model is based on the Gaussian plume formulation but specifically adapted to incorporate an improved gradient-transfer deposition algorithm.

Fig. 2 The second monitoring station installed at a background location at the north from the first station

Emissions of each source are apportioned into a series of particle size classes, where a gravitational settling velocity and a deposition velocity are computed by the model for each class. The pollutant transport is governed by the general atmospheric advection-diffusion equation. After a number of simplifying assumptions , the equation for the concentration becomes [16]:

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z u} e^{-\frac{y^2}{2\sigma_y^2}} e^{\left[\frac{-v_g(z-h)}{2K} - \frac{v_g^2\sigma_z^2}{8K^2}\right]} \left[e^{\frac{-(z-h)^2}{2\sigma_z^2}} + e^{\frac{-(z+h)^2}{2\sigma_z^2}} - \sqrt{2\pi}\frac{v_1\sigma_z}{K} e^{\left[\frac{v_1(z+h)}{K} + \frac{v_1^2\sigma_z^2}{2K^2}\right]} erfc\left[\frac{v_1\sigma_z}{\sqrt{2K}} + \frac{z+h}{\sqrt{2\sigma_z}}\right] \right] \quad (1)$$

Per minute values of wind speed, wind direction, humidity, pressure and temperature were provided by the AQ stations. In this work two sets of calculations were made; once with 15-minutes averaged values and another with hourly averaged values of meteorological data.

For the emission rates of fugitive dust which are often functions of the wind speed, the FDM model accounts for this proportionality by:

$$E = Q_o u^w \quad (2)$$

where, “E” is the emission rate, “Q_o” is the proportionality constant, “u” is the wind speed and “w” is the wind speed dependence factor.

To develop the source-receptor function, the emission rate was considered constant for all sources. As an initial estimate, a value of 1 $g/m^2.s$ was assumed for the emission rate for the first run of the model. This first run of the FDM model was used to estimate the model predicted concentrations. In order to develop the emission factors, the measured and the predicted concentrations were used to correct the emission rate for each time period, based on the linear relationship between the emission rate and the concentration:

$$ER' = ER\frac{C_M}{C_P} \quad (3)$$

where, “Cp” is the predicted concentration by the model, “CM” is the measured concentration and “ER`” is the corrected emission rate.

The calculated Emission Rates (ER`), for each particle size class, were classified based on their wind direction into twelve wind sectors of 30 degrees each. This classification aimed to filter the data to study only the wind sectors covering the area sources and analyze the correlation between the emission rates and the meteorological parameters.

The below logarithmic distribution represents the wind speed profile in the surface boundary layer [8]:

$$u(z) = \frac{u^*}{0.4}\ln\frac{z}{z_o} \quad (4)$$

where, “u*” is the friction velocity, “z” is the height above test surface, “z_o” is the roughness height and the 0.4 is the von Karman’s constant.

The friction velocity (u*) is a measure of the wind shear stress on the erodible surface [8]. Equation (4) was used to calculate the friction velocity (u*) for the selected data. The Emission rates were plotted against the friction velocity to obtain the behavior of the fugitive dust erosion.

III. RESULTS AND DISCUSSION

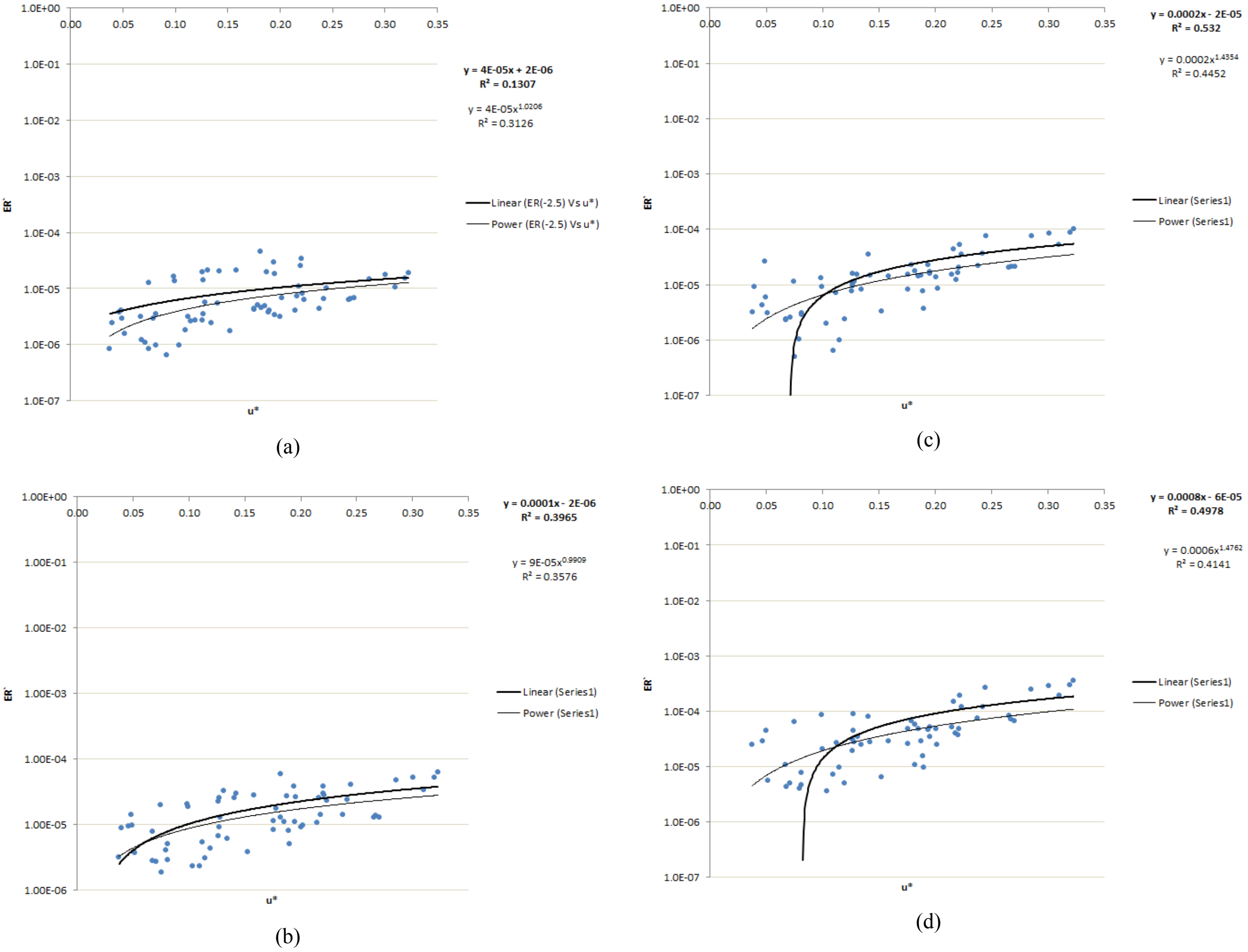
Five particle size classes have been identified and are listed in (Table I), with the corresponding diameter range. In this study, the FDM model was run five times for each data set. Each run specifies a particle size class. For the FDM input of particle density, which varies depending on the type of the soil material, soil samples have been collected from different areas of the site and tested in the lab in order to compute the particle density. The average particle density of the tested soil used in this work is 2.34 g/cm^3.

TABLE I
DIAMETER RANGE FOR EACH PARTICLE SIZE CLASS

Particle Size Class	Characteristics Diameter (µm)
1	0 - ≤ 2.5
2	>2.5 - ≤ 6
3	>6 - ≤10
4	>10 - ≤ 20
5	> 20 - ≤ 30

Based on the 15-minute average data, a comparison between the meteorological measurements and concentrations at the receptor point and background location was made to examine the correlation between all variables. A high correlation (between 0.7-0.9) was observed between the concentrations of different size classes in both locations. This means that all particle classes are strongly related and the largest fraction is affected by the same sources. In parallel there is a significant difference between the construction site and background measurements. Therefore, it was considered a safe assumption that the construction site produces the majority of the measured particles. Similarly, it was assumed that the background location is not affected by a single source.

Finally, this means that, both locations are affected by sources that have very similar size profile; construction activities and natural dust are our estimation.



(a) (b) (c) (d)

Fig. 3 Emission Rate (ER) vs friction velocity (u*) plots for a) 0-2.5 µm size class, b) 2.5-6 µm size class, c) 6-10 µm size class and d) 10-20 µm size class

Time series of the measured concentrations and wind speeds were plotted. The difference between the concentrations at the receptor and the background showed deviations from the usual behavior at some times. This is probably due to the background station being location too far away from the receptor, which may be affected by factors that did not affect the construction site.

The emission rates were compared with the meteorological measurements from construction site and background location. Results based on the 15-minutes averages showed a relatively good correlation between the emission rates and wind speeds, especially for the smaller particles (<10 µg/m^3). This correlation seems to be even higher when using the hourly averages. This was expected since the wind speed is the one that induces the particles.

Some results based on the hourly averages showed higher correlation between the emission rates for the small particles (0-6 µg/m$^{3)}$ and the background wind speed, and between the larger particles (6-30 µg/m^3) and the receptor wind speed. This means that probably the smaller particles are coming from the background and the larger particles are coming from the construction site.

In general, for the 15 minute averages, the wind direction did not follow the expected pattern to give clear information about its effect on the emission rates.

In order to develop emission factors of fugitive PM emission, the hourly emission rates for each particle size class were plotted versus the friction velocity. The behavior of the fugitive PM and the relationships of the emission rates are presented in Fig. 3.

IV. CONCLUSIONS

The releases of airborne PM from major building activities such as building construction is largely unknown for the Middle East area. In the present study, fugitive PM releases from a construction site in Middle East area were examined.

PM concentrations from the experimental campaign along with the FDM model results were used to correlate meteorological variables, concentrations and emission rates to understand the behavior of the fugitive dust emissions. In this study the fugitive PM emission factors reported in USEPA AP-42 "Compilation of Air Pollutant Emission Factors" 5 were determined and new emission rate relationships were developed to apply for Middle Eastern conditions.

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