THEOPHRASTOS: PMX EMISSION FACTORS – DISPERSION FROM FUGITIVE DUST SOURCES IN LIGNITE MINES OF WESTERN MACEDONIA, GREECE

TRIANTAFYLLOU A.[1,2], MOUSSIOPOULOS N.[3], GARAS S.[1], KRESTOU A.[2], DOUROS I.[3], DIAMANDOPOULOS CH.[1], SKORDAS J.[1], MATTHAIOS V.[2], LEIVADITOU H.[2], TSEGAS G.[3], FRAGKOU E.[3], PAVLOUDAKIS F.[4], ANDREADOU M.[4] and KOURIDOU O.[4]

[1] LAPEP – Laboratory of Atmospheric Pollution and Environmental Physics, TEI of Western Macedonia, 50100 Kozani, Greece, [2] TRC – Technological Research Center, 50100 Kozani, [3] LHTEE – Laboratory of Heat Transfer and Environmental Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, [4] PPC, Western Macedonia lignite Center
E-mail: atria@kozani.teikoz.gr

ABSTRACT

According to the Regulation 166/2006 of the European Parliament, mining enterprises are obliged to quantify the pollutants emissions from their fugitive sources in order for an integrated, publicly accessible pollutant-release and transfer register to be established at the European Community level. Western Macedonia comprises a Greek region where intensive industrial activities are present, mainly in the electricity production sector. Four open lignite mines feed the five lignite power plants operating in the area, thus contributing to the atmospheric pollution of the region. For the quantification of fugitive emissions, emission factors are required as input data in dispersion simulation tools which are used in integrated systems for environmental management and decision making. A review of bibliographical sources indicates only a limited availability of such factors, mainly corresponding to open pit mines in Canada, India and the U.S.A., that are not representative for all mining operations. The determination of PMx emission factors for fugitive emission sources of the lignite mines operating in Western Macedonia, as well as the study of PM dispersion from such sources is the subject of the project THEOPHRASTOS, which is presented in this paper. The scarcity of literature on validated experimental data on emission factors points to the necessity of field campaigns and combined modelling approaches for assessing fugitive PM emissions from mining operation.

Keywords: Fugitive dust sources, emission factors, open pit mines, Reverse Dispersion Modelling.

1. Introduction

A key element for the environmental protection in areas where open pit mines operate is the confrontation of the problems generated by the dust emitted from the various mining operations. The reliable quantification of the total pollutants emissions from the fugitive sources, that is an obligation of the mining enterprises according to the 166/2006 Regulation (Regulation 166/2006), with a special emphasis in the contribution of each mining activity (excavation – transportation – deposition for barren, lignite and ash) to the total dust emissions is the first step in applying corresponding countermeasures.

The selection of the proper emissions quantification methodology is case specific. For example, in the case of diffuse dust sources, as the open pit mines in Western Macedonia, the most applicable methodology is the one using emission factors. These factors relate the quantity of a pollutant released – emitted in the atmosphere with the associated activity and are expressed as mass of emitted pollutant per mass, volume, distance or duration of the connected activity. The basic bibliographic reference for the aforementioned emission factors and the corresponding empirical equations is the USEPA edition, known as AP-42 (US EPA- AP42). These factors have been developed for U.S. mines therefore their applicability in Europe (IIASA) and especially in Western Macedonia is limited. In Australia, the "Minerals Council of Australia" has contributed to the publication of a manual (NPi, 2001) based on the USEPA publication, aiming to help the national industry towards the development of a national pollutants inventory. At the European level, there can be found a limited number of emission factors that vary significantly. The basic catalogue of emissions records (EMEP/EEA, 2013) is missing data concerning emission factors from mining activities, with the exception of Chapter “Fugitive emissions from solid fuels: coal mining and handling” which however is based on USEPA – AP42 and a single study (Vrins, 1999). The use of such data in the case of Western Macedonia mines can therefore lead to results with huge deviations, since the quantification of dust emissions from open pits is strongly related to the exploitation method applied, the equipment used, the dust and other transported materials characteristics (e.g. silt content) as well as to the meteorological characteristic of the area. As a result, real data covering the area under study are necessary for a reliable calculation of dust emissions. The current work presents the methodology of such a calculation for a) the estimation of emissions of Particulate Matter with aerodynamic diameter up to 10μm (PM10) from open lignite mines in Western Macedonia as the sum of emissions from each fugitive dust source, b) the customization of the resulted emission factors and c) the study of mines’ emissions dispersion. The whole study was conducted in the framework of the program “THEOFRASTOS”, with field campaigns executed in the Western Macedonian lignite open mines for a three years period.

2. Methodology

The methodology applied in the present study is a combination of field measurements, laboratory analysis and simulations using mathematical dispersion models. All the performed actions within the program are schematically summarized in the flow diagram presented in Figure 1. Field measurements were conducted for all the main fugitive dust sources (excavation – transportation – deposition for barren, lignite and ash) in the four open lignite mines in Western Macedonia, named South Sector (SS), Kardia (K), Mavropigi (M) and Amyntaio (A). For every experiment, the measured PM10 concentrations were processed and together with meteorological parameters and data from the Lignite Centre of Western Macedonia (LCWM) were used as input in Reverse Dispersion Models (RDM). Thus an emission rate (e_r) and an emission factor (e_f) were calculated for every activity- fugitive dust source under study. The estimated emission factors were further combined with activity data from LCWM in order to calculate the mass of PM10 emitted from each activity (E_i , i=1…n) and the total mass of fugitive dust emitted from the whole mine (Ex, x=SS, K, M, A). In total 74 experiments - field measurements were conducted, out of which 63 were adequate for further analysis.

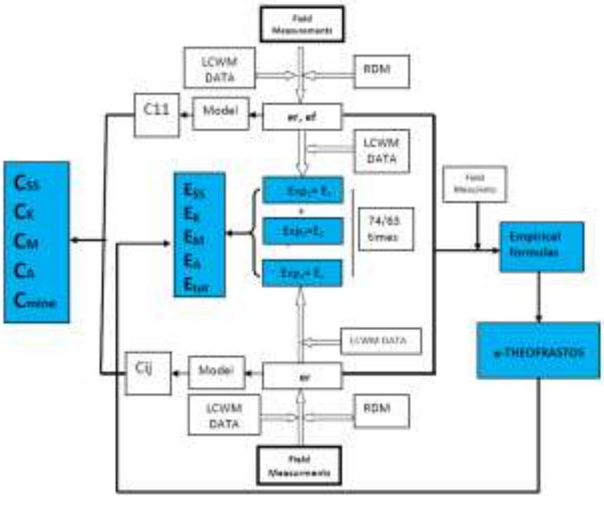


Figure 1: “THEOFRASTOS” flow diagram.

The aforementioned activity data, together with proper field measurements were used for the development of empirical formulas relating the emission factor of one activity (depended variable) with independent variables such as silt content (%) and humidity (%) of the materials handled, wind speed (m/sec) etc.. These equations comprised the core of a software tool developed by the Laboratory of Atmospheric Pollution and Environmental Physics, TEI of Western Macedonia, named "e- THEOFRASTOS", which calculates the fugitive dust emissions from mining activities. The calculated emission rates were also used in the dispersion model to determine PM10 concentrations to recipients due to a specific fugitive dust source in a mine (Cij) as well as to calculate the contribution of each mine (Cx, x=SS, K, M, A) to the measured PM10 concentrations in specified recipients.

The following equation 1 (US EPA, 2009), calculates the mass of fugitive dust generated from activity i during one day,

$$\mathrm{E}_i = A_i \times E_{f,i} \prod \left(1 - n_j\right) \quad (1)$$

where, E_i is the PM10 mass emitted from activity i, A is the capacity of activity (mass of material handled), E_{fi} is the emission factor of the activity expressed in mass of fugitive dust per mass of materials handled and n_j is the effectiveness of emission control measures applicable to activity i. The emission factor of each activity, E_{fi}, is expressed by equation 2 (Cowherd, 2001). The total mass of PM10 emitted from one mine is equal to the sum of PM10 mass emitted from every single activity of the same mine.

Two are the methods suggested by literature (EPA- 454/R-93-037, 1993) for the measurement of emission rate in the case of fugitive dust: the "upwind – downwind" method, according to which the equipment for PM10 measurement is installed upwind and downwind the fugitive dust source and the "exposure profile method" according to which the concentration of the PM10 plume is measured at multiple heights downwind the fugitive dust source and one point upwind. The selection of the proper method is depended on the type of the source, site characteristics etc. The method applied to the current study was the "upwind – downwind" method, in conjunction with the Reverse Dispersion Modeling method (BS EN 15445:2008). Prior to the commencement of each field test, the prevailing wind direction in the area under study was determined. PM10 concentration measurements followed in selected points upwind and downwind the activity – fugitive dust source considered (e.g. excavation, loading, transportation in unpaved roads inside the mine, unloading) together with meteorological parameters monitoring. The collected data were analyzed and processed in order to calculate the respective emission rate (g/s) by the RDM method. In field tests of this kind, the installation points of the equipment and the number of parallel measurements are critical parameters determined by the source type (point, linear, surface), local conditions etc.

3. Equipment - analysis

3.1. Field measurements

Five PM10 concentration analyzers with parallel meteorological parameters measurement were installed for each experiment. Critical parameters for the calculation of emission rates were, along with the meteorological conditions during the experiments, the materials characteristics (e.g. silt content, humidity), control measures that are applied by the mining operators for the reduction of the emitted dust (e.g. wetting) and the activity capacity (e.g. quantity and type of material handled, unloading height, vehicle speed). Thus, during all experiments material sampling was performed, with the samples matching the material handled by the activity under study. These samples were analyzed in the laboratory in terms of their humidity and silt content, according to standard method (ASTM-C-136), (Krestou wt. al, 2011). During the experiments, other factors were also recorded depending on the activity, such as number of vehicles per hour, type of vehicles, wetting etc. The procedure was followed in all four open lignite mines of LCWM during the hot (May to October) and the cold (November to April) periods.

3.2. Reverse Modelling

Reverse Modeling method provides an estimate of the mean emission rate of each source by a statistical analysis of the following parameters:

- Measured PM10 concentration measurements in selected points, and
- Calculated dispersion rates, α

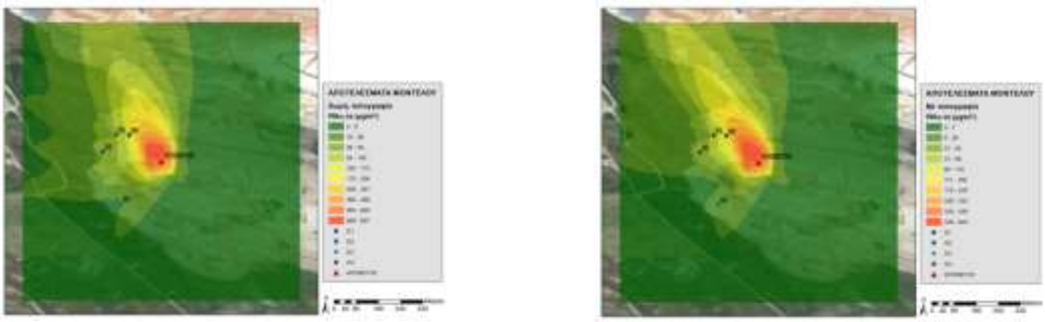
in order to solve the following equation 3:

$$c_{rd}\left(t\right)=\sum_{i}c_{ird}\left(t\right)=\sum_{i}a_{irdt}e_{id} \quad (3)$$

where, c_{ird} is the concentration of particles with aerodynamic diameter d that are emitted from the source i in the sampling location r, $α_{irdt}$ is the dispersion rate of particles with aerodynamic diameter d between the source i and the sampling area, and e_{id} is the emission rate of particles with aerodynamic diameter d emitted from the source i, to be calculated.

The dispersion of the fugitive matter depends on the location and geometry of the source, the topography of the area and the aerodynamic diameter of the fugitive particles. Using the proper dispersion model and applying a predetermined emission rate e = 1 g/s, dispersion rate α can be calculated in various locations around the considered source. The contribution of other sources can be isolated by parallel sampling in multiple points and estimation of the correlation coefficient Rα among the corresponding dispersion rates α.

AERMOD V 8.0.5 and AUSTAL 2000 were applied in the current study. AERMOD is a Gaussian model recommended amongst others by USEPA for the State Implementation Plan in current sources, for New Source Review and for the development of Prevention of Significant Deterioration programs. Wind speed, wind direction, temperature, Monin-Obukhov length, friction velocity, the appreciable heat flux, the blend layer and the roughness length are the meteorological parameters required as input in the model. AUSTAL 2000 is a Lagrangian particle model developed for the German Federal Environment Agency in accordance with German benchmark VDI 3945 (URL1). The model has been applied in a wide range of applications at the local scale, while in the recent years it is widely applied as a tool for assessing air quality, according to the German Regulation on Air Quality (Janicke and Janicke, 2003, TA Luft, 2002). With AUSTAL, different states of the time – varying dispersion can be estimated, in flat as well as in complex terrain. The typical time scale of the model is one year while the spatial scales are of a few hundred meters up to about 100 km. AUSTAL 2000 dispersion model requires as input time series of hourly speed and wind direction values as well as time series of atmospheric stability. Moreover, the calculations take into account the influence of local topography to configure the local flow field and thus the field concentrations of pollutants emitted. In the following Figure 2, the average surface area PM10 concentrations is presented, as resulted with calculations with and without the influence of topography, for the activity “Unloading” of South Sector mine during the cold period. As shown in this figure, with the incorporation of the real topography the PM10 dispersion is restricted towards the South- West area of the mine while it is enhanced towards the prevailing wind direction (South – East). Thus it was decided the topography of the terrain around the fugitive dust sources to be considered in the dispersion calculations, since it is a critical parameter for these calculations.



(a) **(b)**

Figure 2: Average surface area of PM10 concentrations, estimated for a) flat and b) complex (real) topography.

3.3. Empirical formulae and software development

All data were statistically analyzed and empirical formulae were developed for the calculation of the emission rates from each mining activity. These formulae comprise a useful tool for LCWM in order to predict PM10 emissions from current and future activities and are the core of user friendly software calculating the mass of fugitive dust from mining activities. Thus, the LCWM will conform with the 166/2000 Regulation.

4. Conclusions

The quantification of dust emissions for open pits is imposed by the EC under the European registry of pollutant release and transfer. This obligation, together with the necessity for an air quality monitoring plan to be developed in areas with intensive industrial activity, as the area of Western Macedonia is, has led to the implementation of project “THEOFRASTOS” aiming to a) quantify the PM10 emissions from activities taking place in open lignite mines in Western Macedonia, b) to quantify the PM10 emissions from every open lignite mine in Western Macedonia, c) to calculate the dispersion fields of particulate matter emitted from mining activities and d) to develop proper empirical formulas and a user friendly software for the calculation of the aforementioned emissions from the current and future activities of LCWM. The goal of the project was achieved by conducting field measurements through the cold and hot periods of the year in each mine and applying proper simulations and computational models.

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