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MONITORING OF SIZE-SEGREGATED PARTICULATE MATTER FRACTIONS WITH OPTICAL INSTRUMENTS IN URBAN AREAS

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Abstract

The assessment of harmful PM concentrations i.e. particles with an aerodynamic diameter below 2.5 µm, requires continuous monitoring conducted for 24 hours a day, for 365 days a year. Monitoring campaigns for screening the PM levels in a particular urban area facilitate the conceiving of a continuous monitoring plan by establishing where to deploy optimally the optical instruments for on-line measurement. The paper presents the practical efficiency of the outdoor monitoring of PM size fractions using a new optical equipment i.e. Dusttrak DRX 8533 with environmental enclosure and heating module. The experiments were carried out in Targoviste city, Romania, between 2014 and 2015 within the first two phases of the ROkidAIR project (http://www.rokidair.ro) to perform a screening of the PM concentrations existing in these urban areas and to calibrate the prototype of the PM2.5 microstation developed within the project .The utilization of the DustTrak instrument showed that in heavy traffic conditions without significant industrial emissions, the most frequent PM fraction is the submicrometric one (PM1).The results pointed out the usefulness of monitoring four size segregated mass fractions and their relationship with the potential PM emission sources. Outdoor PM2.5 measurements provide key information for evaluating population exposure, planning of air quality and establishing of reliable measures that allow the lowering of PM emission.

Key words:*PM2.5, PM1, size segregated mass fractions, photometric measurement, DustTrak DRX 8533.*

INTRODUCTION

Recent years showed a constant increase of the interest of authorities and research entities in finding new monitoring and modeling solutions using multi-criteria approaches to mitigate the impact of air pollution on the health of city residents by limiting exposure using early warnings during air pollution episodes with high concentrations of pollutants (Brauer et al., 2012). The governmental programs concerning the air quality monitoring and the dissemination activities of the monitoring results require cooperation, compatibility and mutual interest to access a wider monitoring network, enabling a comprehensive analysis of the state of air quality at various spatial scales (Dunea, 2014; Iordache et al., 2015). The information collected from monitoring programs followed by its dissemination using reports regarding the state of environment supports the decision-making in society regarding the management strategies and their adaptation to the existing conditions resulted from the socio-economic pressures and impacts (Iordache and Dunea, 2015).

Particulate matter in the ambient air of urban areas is mainly occurring because of the emissions from anthropogenic sources (industrial sources, traffic, combustion of fossil fuels and biomass, domestic heating, etc.), and emissions from natural sources (dust transported by wind, marine aerosols, emissions of volatile organic compounds, biomass decay, etc.). Furthermore, most of the anthropogenic sources that are responsible for the presence of PM in ambient air are located in urban areas with high population densities (Iordache and Dunea, 2015).

The airborne PM is a complex heterogeneous mixture. The size and chemical composition of this mixture may change in time and space depending on emission sources, atmospheric conditions, topography and weather. Regarding their potential to affect human health, PM presents the highest risk from the air pollutants because they penetrate the sensitive regions of the respiratory system and can lead to health problems and even premature deaths (WHO 2013; Olsen et al., 2014).

The following terminology is widely used to indicate the relative penetration of a particle in the respiratory system: inhalable particles - penetrate the bronchi; thoracic particles - enter directly into the bronchioles; and respirable particles - penetrate to the alveoli (gas exchange area) and therefore in the circulatory system. PM10 fraction is known as coarse particles (particle diameter - $\phi \leq 10$ μm), while PM2.5 represents the fine fraction ($\phi \leq 2.5$ μm) and PM0.1 is the ultrafine fraction ($\phi \leq 0.1$ μm). Respirable particles have a diameter lowerthan4 μm (PM4). Latest researches (AQEG, 2012; WHO, 2013; Liu et al., 2013; Iordache et al., 2015) have pointed out that fine particles are most responsible for adverse health effects in urban population.

EN 12341European standard is the reference method for PM10 allowing the use of three systems i.e., Wide Range Aerosols Classifier WRAC, high volume sampler HVS (flow of 68 m3 h-1), and low volume sampler LVS PM10 (2.3 m3 h-1) that is commonly used in United Kingdom (AQEG, 2012).

Each of these sampling devices has a PM10 inlet (impactor or cyclone) which is directly connected to a filter-substrate and a controlled flow regulator. After completion of the sampling period, PM10 particulate mass that was collected on the filter is determined gravimetrically. The filter must be weighed at a temperature of20 °C and a relative humidity of 50%.

In EU, the reference method for the measurement of PM2.5 is also a manual gravimetric method for estimation of daily concentrations and is described in EN 14907. On 21 May 2014, a revised standard for measuring PM10 and PM2.5, namely EN 12341: 2014 was provided describing the procedures regarding the use of sequential samplers with automated filter changer.

PM2.5 reference methods are not able to provide real-time data. EU regulations allow the use of equivalent methods where equivalence is defined in the guide for proving the equivalence methods (CEN/TS 16450: 2013). It establishes a procedure for quantifying the correspondence between the reference and equivalent methods through a series of parallel measurements resulted on field. The objective is that the equivalent instruments provide daily data with a measurement uncertainty less than that required by the Directive on ambient air quality i.e., ± 25% with a confidence level of 95% at concentrations close to the limit.

In present, the main measurement instruments for continuous monitoring of PM are TEOM, BAM (beta attenuation monitor), and optical analyzers (e.g., nephelometric analyzers fitted in automated air quality stations).

The ability of a new instrument to measure correct values of PM concentrations must be evaluated by comparing the 24-hour averaged values with the 24-hour results of a reference sampler (e.g., European Leckel SEQ 47/50). The reference method is a gravimetric one based on 24-hour sampling on filter. The results from this comparison will be used to establish a correction factor between the new instrument and the reference method. The repeatability of measurements will be evaluated by inter-comparing the measurement results. The ability to measure short-term values, e.g. 1, 5 or 60-minute averages must be evaluated by comparing the instrument results with the results of other calibrated online analyzers, e.g. TEOM, Eberline monitor etc.

In this context, the paper presents the practical efficiency of the outdoor monitoring of PM size fractions using a new optical equipment i.e. DustTrak DRX 8533 with environmental enclosure and heating module. The experiments were carried out in Targoviste city, Romania, between 2014 and 2015, within the first two phases of the ROkidAIR project (http://www.rokidair.ro) to perform a screening of the PM concentrations existing in these urban areas and to calibrate the prototype of the PM2.5 microstation developed within the project.

MATERIALS AND METHODS

Optical monitoring system for measuring PM fractions-TSI DustTrak^{TM} DRX 8533 Monitor

The DustTrak 8533 monitor is an optical instrument that simultaneously measures in real time the size segregated mass fraction

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concentrations i.e. PM1, PM2.5, PM4, PM10, and TPM over 0.001–150 mg/m3asconcentration range. The method combines a photometric measurement to assess the mass concentration range and a single particle detection measurement to allow the sizing of the sampled aerosol (TSI, 2016). Aerosol is directed into the sensing chamber in a continuous stream using a diaphragm pump. Part of the aerosol stream is split ahead of the sensing chamber and passed through a HEPA filter being injected back into the chamber around the inlet nozzle as sheath flow (TSI, 2016). The remaining sample flow passes through the inlet entering the sensing chamber. In this chamber, a sheet of laser light illuminates the sample. A laser diode forms the sheet of laser light. In the first step, the light emitted from the laser diode passes through a collimating lens and then through a cylindrical lens to create a thin sheet of light (TSI, 2016). A gold-coated spherical mirror captures a significant fraction of the light scattered by the particles and focuses it on to a photo detector (www.tsi.com).

Figure 1. TSI DustTrak DRX 8533 particulate matter (PM)monitor, which allows the simultaneous measuring of various PM fractions i.e. PM1/submicrometric, PM2.5/fine, Respirable/PM4, PM10/Thoracic, and Total PM (http://www.tsi.com)

The measurement performed by DustTrakDRX 8533 Aerosol Monitor with environmental enclosure to size segregated mass fraction has the size resolution of an OPC together with a much higher mass concentration range like a typical photometer (www.tsi.com).The particle mass is calculated and recorded in one of the four size segregated mass fractions i.e. PM1 – sub micrometric fraction, PM2.5 – fine fraction, PM4 – respirable fraction, PM10 – Thoracic fraction, and Total PM. The aerosol contaminants such as dust, smoke, fumes and mists can be monitored using this type of instrument.

The 8533 instrument uses a sampling compartment with one 37 mm filter that can be attached in line with the flow of the aerosol at the exit of the optical camera. This allows the gravimetric analysis without using an external pump and a special filter holder.

Technical specifications of the DustTrak DRX Monitor

- Measuring domain: 0.001 - 150 mg/m3
- fractions of PM: PM1, PM2.5, PM4, PM10 and total PM
- resolution: 0.001 mg/m3
- pump flow: 3.0 l/min
- accuracy of pump flow: ±5%
- operating temperature: 0 – 50°C.

Aspects considered during the field monitoring:

1. Monitoring was conducted as much as possible during the "rush" hours (7.00-13.00 a.m. and 3.00-7.00 p.m.).
2. The next monitoring campaign was conducted in a random sequence of points order.
3. If the time or weather parameters did not allow the measurements of all points in the same day, the screening analysis was conducted in two stages in two consecutive days: the western half points in the first day and the eastern half in the following day.
4. The monitoring campaigns were carried out with a measurement time per point for determining PM fractions of 60 minutes.
5. Two campaigns per month were performed for determining the PM levels.
6. The screening measurements were performed at least two days after a rainfall event.
7. After each measurement, the sampled PM disks that were collected were coded for identification (attaching a label with the point

number, location, time of sampling, the pump flow (start-stop) and the characteristics of the micro-climate (such as atmospheric pressure, air relative humidity, air temperature, wind speed and wind direction).

8. All the elements were noted in a specific field book adapted for the requirements of PM monitoring in urban environments.

Each monitoring campaign implied the PM measurements in ten sampling points that were disposed in a quasi-radial spatial arrangement in relation to the shape of the city (Figure 1). The instrument was placed out in the open on a tripod at a height of 1.50 m, away from obstructions that may disturb wind currents.

RESULTS AND DISCUSSIONS

The monitoring campaigns performed during 2013-2014 using another optical monitor i.e. Casella Microdust Pro, and in 2015 using both Casella and DustTrak instruments allowed the drawing of maps concerning the PM levels occurring in Targoviste city, Romania. The developing of the corresponding layers was performed in QGIS (www.qgis.org).

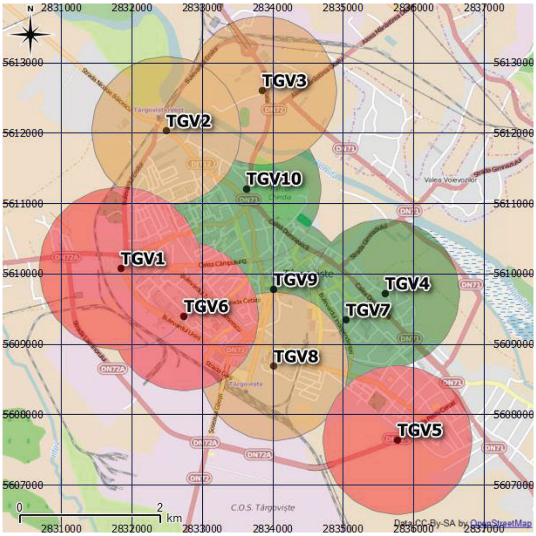

Figure 2.Potential PM2.5 levels in the city of Targoviste based on the measurements performed in 10 sampling points and modeling of emissions from stationary sources using AERMOD dispersion model (red circles – annual high concentrations 13-23 µg m-3; orange – moderate concentrations 7-9.5 µg m-3; green – low concentrations 4-6.5 µg m-3); circles have an area of representativity with a radius of 800 m (±25% of concentration); grid with UTM coordinates.

Figure 2 shows an example for the assessment of annual exposure in Targoviste urban areas by overlapping in situ PM data recorded in various campaigns performed between 2013 and 2015 together with the results of dispersion modeling of point sources existing in the area.

The main point sources in Targoviste city area are as follows: a metallurgical plant for special steels production and several metalworking facilities located in the south of the city; a company that produces rigs located in the middle of the town, most of the installations were dismantled and the buildings and chimneys were demolished; and a coal thermal plant, which stopped functioning in 2009 and some chemical point sources located in the northwest of the city. The household heating has been insured by decentralized systems (mainly small gas boilers and wood stoves) because the firm that operated the centralized cogeneration system went bankrupt. Most of the major industrial point sources that had significant PM emissions in the past are not functioning in the present or were dismantled or demolished because of the economic recession.

Consequently, the main sources of PM emissions remained the heavy traffic and the residential heating, together with some active industrial point sources. Because the residential heating is based on numerous individual systems, the dispersion modeling of these sources is a difficult task. A reliable option is to develop a monitoring network using continuous monitors that will complement the existing official infrastructure (one UNITEC PM10 optical analyzer located in the EPA air quality station from Targoviste) for PM monitoring.

Table 1.Example of a DustTrak DRX 8533 monitoring file obtained during one hour in the "rush" time interval showing the size segregated mass fraction concentrationsi.e. PM1 – submicrometric fraction, PM2.5 – fine fraction, PM4 – respirable fraction, PM10 – Thoracic fraction, and Total PM (TGV6).

Instrument Name	DustTrak DRX
Model Number	8533EP
Test Start Time	1:24:42 PM
Test Length [D:H:M]	0:01:00
Test Interval [M:S]	0:01
PM1 Average [mg/m3]	0.017
PM1 Minimum [mg/m3]	0.007
PM1 Maximum [mg/m3]	0.148
PM1 TWA [mg/m3]	0.002
PM2.5 Average [mg/m3]	0.017
PM2.5 Minimum [mg/m3]	0.007
PM2.5 Maximum [mg/m3]	0.148
PM2.5 TWA [mg/m3]	0.002
PM4 Average [mg/m3]	0.017
PM4 Minimum [mg/m3]	0.007
PM4 Maximum [mg/m3]	0.148
PM4 TWA [mg/m3]	0.002
PM10 Average [mg/m3]	0.017
PM10 Minimum [mg/m3]	0.007
PM10 Maximum [mg/m3]	0.148
PM10 TWA [mg/m3]	0.002
TOTAL Average [mg/m3]	0.017
TOTAL Minimum [mg/m3]	0.007
TOTAL Maximum [mg/m3]	0.148
TOTAL TWA [mg/m3]	0.002
Photometric User Cal	1
Size Correction User Cal	1
Flow User Cal	0
Number of Samples	3600

In this context, the monitoring campaigns performed in Targoviste provided the screening of concentrations that established the most polluted areas, where it is most likely to locate a PM2.5 continuous monitoring instrument. Based on the results, and the multi-criteria correlation with the objectives of the ROkidAIR project, three monitoring locations were established for Targoviste city area i.e. TGV3, TGV6 and TGV8 points on the map (Figure 1). The PM2.5 fraction was selected to be monitored in Targoviste because:

- includes the nanoparticle fraction (PM0.1) that is difficult to be measured in outdoor conditions and was found to have the most negative health effects,
- has a recent revised standard and well-defined thresholds in correlation with the adverse health effects using the classification in index bands as recommended by USEPA 2012,
- the existing optical instruments and sensors performs adequate continuous measurements of this fraction.

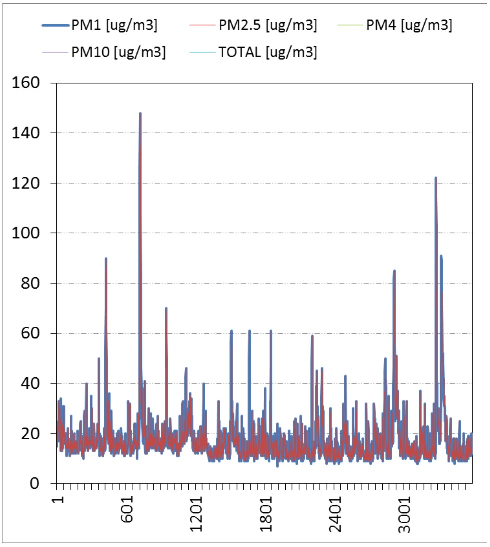

Figure 3.Time series of size segregated PM fractions recorded in TGV6 sampling point in Targoviste City (time scale in minutes)

The utilization of the DustTrak instrument showed that in heavy traffic conditions without significant industrial emissions, the most frequent PM fraction is PM1 (e.g. Figure 3).
Table 1 presents in detail the log file of a

monitoring event that was selected to show the influence of the diesel vehicle emissions in an urban area with heavy traffic during "rush hours". The results show that the submicrometric fraction was the only recorded fraction during the testing interval (1 hour). Furthermore, the system recorded significant variations of the PM concentrations, probably associated to the passing of a specific vehicle near the sampling location as well as to the wind currents (Figure 2). The recorded peaks have also importance in the early warnings of sensitive population, especially if a person is exposed to these high concentrations.

CONCLUSIONS

The air quality estimations are important to establish correlations with potential health effects and thus provide useful information about the unsafe environmental conditions in a certain urban area. This information is very valuable especially for sensitive population groups, such as asthmatics and children, who can act accordingly by avoiding certain areas or try to stay indoors during the critical hours of air pollution. The results pointed out the usefulness of monitoring four sizes segregated mass fractions and their relationship with the potential PM emission sources. Outdoor PM2.5 measurements provide key information for evaluating population exposure, planning of air quality and establishing of reliable measures that allow the lowering of PM emission.

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