Urban Air Pollution by Nanoparticles in Ostrava Region

Authors: Kaličáková Zdeňka², Míčka Vladimír¹, Lach Karel¹, Danihelka Pavel²

(1) Institute of Public Health Ostrava, Partyzánské náměstí 7, 702 00 Ostrava, Czech Republic
(2) VŠB–Technical University of Ostrava, Faculty of Safety Engineering, Lumírova 13, 700 30 Ostrava Výškovice, Czech Republic

E-mail: zdenka.kalicakova@centrum.cz

Abstract. Air pollution harms human health and the environment. Ostrava’s agglomeration and its immediate vicinity suffer regular exceeding of air pollution limits due to its geomorphologic location and present heavy industry. Maximum exceedances of air quality standards and especially PM10 which 24 hour limit value is in EU 50µg.m⁻³, must not be exceeded more than 35 days per year. This limit is being still often exceeded. In the year 2011 such as situation occurred 126 times. It is very important then for identify sources of air pollution to find out maximum information about air borne dust, like size distribution, chemical composition of individual size fractions, morphology of particulate matter together with other parameters like meteorological conditions, year season etc. Our measurement started two years ago. We focus on the critical situation when there are values of PM10 over a long period above the limit. In winter season it is so called inversion. By default, during the campaign it is measured size distribution of air born dust in range 5.6 nm - 560nm by FMPS and using the sampler Nanold are collected samples in range 1nm - 35µm in 12 size fractions for chemical analysis and morphological observations. This contribution deals with results of size distributions only.

1. Introduction

The town of Ostrava is the third largest town in the Czech Republic. The region is the most air-polluted in the country. As for geomorphology, Ostrava is located in the Ostrava basin [1]. Ostrava’s geomorphology and poor dispersion conditions both contribute to the air pollution and cause the pollution to concentrate here, especially in winter.

Although in the 1990’s the air quality in the Czech Republic improved considerably, industrial growth and transport expansion in the 2000’s made the situation worse again.

Industrial sources, emissions from road vehicles and local heating are the main causes of degraded air quality. Due to the prevailing north-west direction of airflow also come into consideration sources in the nearby industrial agglomeration and possibly also from large residential area in the Polish Lower Silesia region. There are freely available sources of information to confirm this hypothesis [2]. To evaluate the formation of fine and ultrafine
aerosol was used reverse trajectory model HYSPLIT [3]. Estimate of the impact of potential sources of pollution by PM10 was carried out for 22 days in which it was in years 2006-2011 one of the selected stations the daily (24-hour) average concentrations of PM10 at least 200µg.m-3. Air quality was monitored on nine locations. All episodes studied occurred in winter season. Only in four cases it was possible to reject the hypothesis of fine aerosol transport from the Polish territory where the main sources are rather local heating than metallurgical industry[2] [3].

Fig. 1: Map of the Czech Republic – air pollution concentration by PM$_{10}$ [4]

Limit values for particulate matter and other pollutants such as arsenic and benzo(a)pyrene are exceeded on a regular basis in Ostrava. These dangerous substances are, beside of particles, a major threat for people living in industrial areas. The exceeding of limit values for carcinogenic benzene also occurs in the Ostrava region. In warm seasons, problems arrive in the Czech Republic with tropospheric ozone, presence of which is related to the formation of photochemical smog [5] [6].

The range of monitored pollutants grew over the years. Initially, only sulfur dioxide and suspended particulates were measured in most monitoring stations; a few years later nitrogen oxides monitoring was introduced. The monitoring was later extended by measurement of mass fraction of selected metals in particulate matter samples and carbon dioxide monitoring. The boom in automatic analyzers made possible independent monitoring of nitric oxide and nitrogen dioxide and, recently, monitoring of ozone, selected organic substances and dust aerosol PM$_{10}$ fraction. The PM$_{10}$ daily limit value of 50 µg.m$^{-3}$ is exceeded repeatedly and often by several times in some regions, especially the Ostrava’s one. The limit should not be exceeded more than 35 times a year; however, in some parts of the
Czech Republic it is exceeded more than 100 times a year (source of information: Czech Hydro-meteorological Institute). With time, PM\textsubscript{2.5} began to be measured and nowadays PM\textsubscript{1} is measured at some stations, too. The smaller the particle, the more easily it enters the human body, in addition, were also expect some of the negative health effects of nanoparticles in the air. Therefore, in the future nanoparticles should be monitored. Another reason to monitor nanoparticles is their properties: they work as carriers of organic pollutants and they may carry information about their origin and, thus, their source. This is the reason why this pilot study was performed [7] [8] [9].

In Ostrava, an increasing number of people suffer from upper and lower respiratory tract inflammations, asthma, nasopharyngitis, allergic rhinitis and atopic eczema. Long-term exposure to particles aerosol can lead to chronic bronchitis or shorten life expectancy. The inhabitants of Ostrava suffer much more often from cardiovascular diseases and the overall illness rates are higher than in other parts of the country. The most affected groups are children, senior citizens and people with respiratory and cardiovascular diseases [10] [11].

Objective of the measurement was to determine whether nanoparticles and microparticles under 560 nm contribute significantly to the contamination of air in Ostrava and whether their composition and distribution allow drawing any conclusions about their origin.

2. Methods

The area of investigation is located in the Moravian-Silesian Region in Ostrava-Mariánské Hory and Ostrava-Radvanice town districts. The first sampling location in Ostrava-Radvanice was located close to an industrial zone which was 1.5 to 3 kilometers from Mittal Steel iron and steel works, one from the main industrial polluters. The character of Ostrava-Radvanice is individual houses settlement with additional air pollution sources from local heating. The second sampling location in Ostrava-Mariánské Hory was chosen as it was situated in a densely populated area – a preschool and vegetation were close and the nearby traffic was high.
The measurements took place in four different days in years 2011-2012. Two consecutive measurements in one day were performed at each sampling location.

The distribution was measured with Fast Mobility Particle Sizer Spectrometer Model 3091 (FMPS™, ITS Inc., USA), a 5.6 – 560 nm range particle spectrometer. FMPS offering a total 32 channels of resolution. Due to its unique design, the FMPS spectrometer is capable of making particle size distribution measurement with one-second resolution, enabling you to visualize particle size distributions and events in real time.

Nano-ID Select™ (Naneum Ltd, UK) was used for sampling the entire aerosol ranging from 0.001 nm to 30 μm in 12 stages, 5 of which are in the 0.001-250 nm range. The wide range capabilities of this sampler are particularly useful when the area of interest extends into the nano and micro regions. The retrieved samples were analyzed in a laboratory using a scanning electron microscope (SEM) and an inductively coupled plasma mass spectrometer (ICP-MS) model THERMO X-Series2 [13] [14]. Results concerning chemical analysis and electron microscope observations will be subject of a separate contribution in a professional journal or conference [13] [14] [15].

3. Results and Discussion

The first measurement campaign started on 1st February 2011. That day the Czech Hydrometeorological Institute announced regulatory signal as the nitrogen dioxide or sulfur
dioxide or PM$_{10}$ special limit values had been exceeded. It means, according to Czech legislature, that the PM$_{10}$ concentration exceeded the 24-hour average concentration of 150 µg.m$^{-3}$ or the sulfur dioxide concentration exceeded 500 µg.m$^{-3}$ in three successive hours or the nitrogen dioxide concentration exceeded 400 µg.m$^{-3}$ in three successive hours [16]. The average daily temperature on that day was minus 6.3 °C. The wind direction was southwest and the average wind speed was 3 m/s. The first two measurements in Ostrava-Mariánské Hory on 1$^{st}$ February 2011 started in the afternoon. Distant local heating sources may have been, together with nearby industries, the sources of air pollution in this winter season. Transport may also have affected the measurement results as the measurement was carried out during rush hour. Two busy intersections were 400 m and 500 m far from the sampling location. Another two measurements started on 1$^{st}$ February 2011 in Ostrava-Radvanice. The wind was blowing southwest. One of sources that may have contributed to the air pollution was Mittal Steel iron and steel works. In immediate vicinity of the sampling site there were local air pollution sources from solid fuel local heating.

The second measurement started on 30$^{th}$ March 2011. The air dispersion conditions were good. The average daily temperature was 9.5 °C. The wind direction was east southeast and the average wind speed was 1.7 m/s. Two measurements took place in Ostrava-Mariánské hory on 30$^{th}$ March 2011 before noon. The measurement results may have been affected, among other things, by local heating sources. Sources located in Poland may also have contributed to the air pollution. Another two measurements started on 30$^{th}$ March 2011 in Ostrava-Radvanice. The measurement was carried out during rush hour. The measurement results may have been affected by local heating air pollution sources. The wind was blowing from Poland to the sampling site, which could influence the measured values.

The third measurement started on 7$^{th}$ September 2011. The dispersion conditions were good. The average daily temperature was 14.7 °C. The wind direction was southwest and the average wind speed was 2.7 m/s. In Ostrava-Mariánské Hory two measurements took place. The wind was blowing southwest from the air pollution sources. Local heating air pollution sources may have contributed to the pollution of the air. Two measurements took place on 7$^{th}$ September 2011 in Ostrava-Radvanice. The wind was blowing southwest from the air pollution sources.

The fourth measurement started on 22$^{nd}$ March 2012. The dispersion conditions were good. The average daily temperature was 8.2 °C. The wind direction was northwest to west and the average wind speed was 2 m/s. Two measurements took place in Ostrava-Radvanice on 22$^{nd}$ March 2012 at noon. At this measurement, particles of 6 nm to 12 nm were absent. The wind was blowing northwest from the air pollution sources. Another two measurements took place in Ostrava-Mariánské Hory on 22$^{nd}$ March 2012 before noon. The buildings of the preschool were being under reconstruction. The wind was blowing northwest. A coking plant, a steel mill and a chemical plant were among the sources that may have contributed to the air pollution. The local air pollution sources from local heating may also have contributed to the air pollution due to the cold weather.

The total number concentrations of particles and particle size distributions show remarkable differences in both locations. The differences may have been caused by different daily temperatures. On cold days, increased local heating may contribute to the air pollution.
more significantly. In individual houses areas, residents themselves pollute the air through local heating. The problem is that they frequently use low quality solid fuels and even household waste burning is not excluded. The overall air pollution in Ostrava-Radvanice is comparable to that in industrial Chinese cities of Guiyu, Taizhou, Tianjin [7]. Transport is another air pollution source. During rush hours the concentration of particles were increased. The wind direction had a measurable effect on the distribution of particles. When the wind blew from large industrial air pollution sources to the sampling locations, the concentration of particles was elevated. Air dispersion conditions may also have an effect on the air contamination.

In various cases, one, two or three from maxima of size distribution at ~10 nm, ~40 nm, ~100 nm were observed (see Fig. 3), which implies that various, but limited sources combines to form overall aerosol composition. Small number of measurements does not allow making deeper conclusions concerning sources. In some cases, the air pollution by nanoparticles is not homogenous in time and local maxima at different size distribution lasting for about minutes were frequently observed, which can be seen in Figure 4. We can explain this phenomenon by changing the direction and velocity of air flow making it difficult to assign a particular distribution of aerosols to a specific source. The fact is that the suspended aerosol can be transported at very large distances and thus resources can be tens of kilometers away from the measuring point. On Fig. 5 is demonstrated the opposite situation when the distribution and concentration rather constant which implies the hypothesis that pollution is already well mixed and stabilized in air and so, the source is rather significant and far away from place of measurement, because small local sources would not cause, due to the turbulence of air, stable concentration and distribution of fine aerosol. Generally it is very important complex statistics evaluation of all data measured with chemical composition and morphology of individual fractions collected by Nano-ID. It was not the intention of this brief study to detect all links leading to the identification of all sources of such as high PM10 pollution. Generally, higher concentrations were detected in the vicinity of industrial areas. In three out of four days of measurement, the pollution in Ostrava-Radvanice was higher than in Ostrava-Mariánské Hory.
Fig. 3a),b),c),d): Demonstration of results of size distribution of fine and ultrafine aerosol on two localities in Ostrava after 5s integration time measured by FMPS.

Fig. 4: Particle size distribution in time showing results of long term (1 hour) measurement of fine aerosol in Ostrava’s district Marianske Hory. The red color indicates the size area with the highest concentration of particles. There were very unstable conditions as for fine aerosol size distribution. The probable reasons for it were the changes in the air flow directions.
Another interesting fact is that the same maximum in the distribution of particles size was observed at both locations on the same day. On 7th September 2011, both in Ostrava-Mariánské Hory and Ostrava-Radvanice particles of 34 nm prevailed. Similarly, on 22nd March 2012, in one measurement in Ostrava-Radvanice and in one measurement in Ostrava-Mariánské Hory there were present particles that occurred in the largest distribution of particles of 81 nm.

The total mass concentration of nanoparticles and ultra-fine particles (5.6 - 560 nm) is relatively high, varying from few percent (w/w) of PM\textsubscript{10} at good dispersion conditions to more than 50 percent in the case of smog situation. While the number concentration is much higher for small particles, the distribution of measured particles represented at Fig. 3 gives the good picture describing overall particle number concentration distribution.

4. Conclusions

Fine and ultrafine aerosol participate significantly to the air pollution in the Ostrava region and during bad meteorological condition, the fraction 5.6 – 560 nm composes even more than 50% of total particulate matter mass in ambient air. Generally, higher concentration fine and ultrafine aerosol was detected in the vicinity of industrial areas. In three out of four days of measurement, the pollution in Ostrava-Radvanice near the big metallurgical plant ArcelorMittal Ostrava a.s. was higher than in Ostrava-Mariánské Hory in the centrum of the city Ostrava.

Various types of sources probably contribute to pollution by nanoparticles and all suspended particulate matter. An important source of variability in the distribution of ultrafine aerosol is the weather where the major factor for determining sources of nanoparticles is air flow direction. Typically were observed maxima at three sizes regions ~10 nm, ~40 nm, ~100 nm. This corresponds well to uni- bi- and trimodal distribution. These findings imply opinion that there is a complex system of different industrial sources, local heating emission and partly also road transport in this region which emit significant quantities of nanoparticles.
Further, systematic study of Ostrava region air pollution by fine and ultrafine particles is needed and therefore another project plans are preparing now, which will study this problem in more detailed way, involving chemical analyzes, not only air pollution but also emissions directly at the expected sources, etc. It is assumed also closer co-operation with Polish state authorities and relevant environmental organizations.

Acknowledgment

Authors thank to projects SAFETY AGENT CZ.1.07/2.4.00/31.0049 and INEF CZ.1.05/2.1.00/01.0036. for support.

Bibliography

[1] DEMEK, Jan a Jaromír. Z nížin do hor: geomorfologické jednotky České republiky. Vyd. 1. Praha: Academia, 2012, 343 p. ISBN 978-802-0020-260

[2] Śląski monitoring powietrza [online]. 2013 [cit. 2013-01-06]. Available from: http://stacje.katowice.pios.gov.pl/monitoring/

[3] BÍLEK, Jiří. Hodnocení znečištění ovzduší v Ostravě za roky 2006 – 2011 – Zpětné trajektorie. Dychamproostravu [online]. 2012 [cit. 2012-10-21]. Available from: Hodnocení znečištění ovzduší v Ostravě za roky 2006 – 2011 – Zpětné trajektorie

[4] Map of the Czech Republic - PM10 pollution. CHIM [online]. 2010 [cit. 2012-10-21]. Available from: http://portal.chmi.cz/files/portal/docs/uoco/isoko/grafroc/groc/gr10cz/png/oII42x8PM10rp.png

[5] Informace o vyhodnocení výsledků imisního monitoringu. Ministry of Environment of the Czech Republic [online]. 2009 [cit. 2012-10-21]. Available from: http://www.mzp.cz/C1257458002F0DC7/cz/kvalita_ovzdusi/SFILE/000-Monitoring_2007-20090112.pdf

[6] KAŠPAR, Jakub. Největším českým ekologickým problémem zůstává kvalita ovzduší. Ministry of Environment of the Czech Republic [online]. 2007 [cit. 2012-10-21]. Available from: www.mzp.cz/cz/news_xt071217ovzdusi

[7] KAZMAROVÁ, Helena. Vývoj znečištění ovzduší v ČR. Centrum pro otázky životního prostředí [online]. 2011 [cit. 2012-10-21]. Available from: http://www.czp.cuni.cz/projekty/sdcz/moduly/2A/2A2/kazmarova.pdf

[8] Imisní limity. Czech Hydrometeorological Institute [online]. 2012 [cit. 2012-10-21]. Available from: http://www.chmi.cz/files/portal/docs/uoco/isoko/info/limity_CZ.html

[9] LACH, Karel. Nanočástice v ovzduší Ostravska. Monitoring nanočástic v životním prostředí [online]. 2012 [cit. 2012-10-21]. Available from: http://iszp.kr-moravskoslezsky.cz/assets/nanocastice-v-ovzdusi-ostravska.pdf

[10] Ovlivňuje znečištěné ovzduší nás zdravotní stav?. Institute of Experimental Medicine AS CR, v. v. i. [online]. 2012 [cit. 2012-10-21]. Available from: http://www.iem.cas.cz/press/press/120612-oviivnuje-znecestene-ovzdusi-nas-stav.html

[11] ZNEČIŠTĚNÍ OVZDUŠÍ NA ÚZEMÍ ČESKÉ REPUBLIKY V ROCE 2010. Czech
Hydrometeorological Institute [online]. 2010 [cit. 2012-10-21]. Available from: http://portal.chmi.cz/files/portal/docs/uoco/isko/grafroc/groc/gr10cz/kap2421.html

[12] DANIHELKA, Pavel. Nanoparticles in Ostrava urban Atmosphere. [online]. 2011 [cit.2012-03-08]. Available from: http://www.zuova.cz/informace/poster_nanoparticles_in_the_ostrava_urban_atmosphere.pdf.

[13] Model 3091 Fast Mobility Particle Sizer TM Spectromete [online]. 2004 [cit. 2012-03-27]. Available from: http://www.kenelec.com.au/sitebuilder/products/files/116/3091.pdf.

[14] Wide Rande Aerosol Sampling System: Nano ID Select 005. Canterbury, 2009

[15] Model 3091 Fast Mobility Particle Sizer TM Spectrometer. TSI Incorporated [online]. 2004[cit.2013-01-23].Dostupněz: http://www.tsi.com/uploadedFiles/Product_Information/Literature/Spec_Sheets/3091F_MPS.pdf

[16] Analýza dopadů návrhu zákona o předcházení a nápravě ekologické újmy. Ministry of Environment of the Czech Republic [online]. 2006 [cit. 2012-10-21]. Available from: www.cemc.cz/clen_www/legislativa/prip_rizeni/.../ostatni/11_05.doc