



Mass and number size distributions of particulate matter components: Comparison of an industrial site and an urban background site



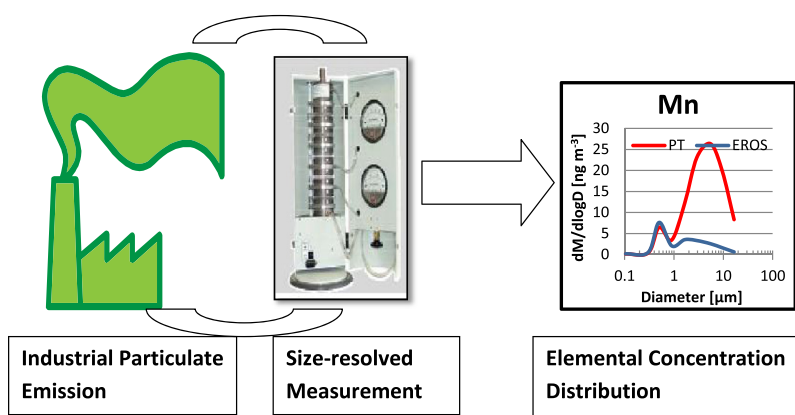
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HIGHLIGHTS

- Size distribution of major ions and trace metals is reported.
- Comparison is made between an industrial (steelworks) site and urban background.
- The steelworks impacts heavily upon coarse mode mass and concentration of Ca, Mg, K, Fe, and Mn.
- Steelworks site also shows elevated Zn and Cr.
- Concentrations of traffic-associated metals (especially Ba, Sb, Cu and Pb) are greatest at urban background.

GRAPHICAL ABSTRACT



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ABSTRACT

Size-resolved composition of particulate matter (PM) sampled in the industrial town of Port Talbot (PT), UK was determined in comparison to a typical urban background site in Birmingham (EROS). A Micro-Orifice Uniform Deposit Impactor (MOUDI) sampler was deployed for two separate sampling campaigns with the addition of a Grimm optical spectrometer at the PT site. MOUDI samples were analysed for water-soluble anions (Cl^- , NO_3^- and SO_4^{2-}) and cations (Na^+ , NH_4^+ , K^+ , Mg^{2+} and Ca^{2+}) and trace metals (Al, V, Cr, Mn, Fe, Cu, Zn, Sb, Ba and Pb). The PM mass distribution showed a predominance of fine particle ($\text{PM}_{2.5}$) mass at EROS whereas the PT samples were dominated by the coarse fraction ($\text{PM}_{2.5-10}$). SO_4^{2-} , Cl^- , NH_4^+ , Na^+ , NO_3^- , and Ca^{2+} were the predominant ionic species at both sites while Al and Fe were the metals with highest concentrations at both sites. Mean concentrations of Cl^- , Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cr, Mn, Fe and Zn were higher at PT than EROS due to industrial and marine influences. The contribution of regional pollution by sulphate, ammonium and nitrate was greater at EROS relative to PT. The traffic signatures of Cu, Sb, Ba and Pb were particularly prominent at EROS. Overall, PM at EROS was dominated by secondary aerosol and traffic-related particles while PT was heavily influenced by industrial activities and marine aerosol. Profound influences of wind direction are seen in the 72-hour data, especially in relation to the PT local sources. Measurements of particle number in 14 separate size bins plotted as a function of wind direction and speed are highly indicative of contributing sources, with local traffic dominant below 0.5 μm , steelworks emissions from 0.5 to 15 μm , and marine aerosol above 15 μm .

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1. Introduction

Particulate matter is commonly classified in three modes namely ultrafine (nucleation and Aitken mode, diameter less than 0.1 μm), fine (mainly accumulation mode, aerodynamic diameter between 0 and 2.5 μm) and coarse (aerodynamic diameter between 2.5 and 10 μm). Generally, fine and ultrafine PM are formed from high temperature processes such as vehicular exhaust, oil and coal combustion, biomass burning, industrial processes, and chemical reactions in the atmosphere (Harrison et al., 2003a; Samara et al., 2003). Coarse particles are generally evolved from attrition processes including mechanical abrasion of crustal material and re-suspension of road and soil dusts, sea spray, volcanic eruptions and brake and tyre wear from vehicles (Allen et al., 2001).

Atmospheric PM is made up of diverse chemical substances including water soluble ions, trace metals and organic compounds. Water-soluble ions constitute a significant portion of PM mass (Yin and Harrison, 2008), and therefore play an important role in aerosol chemistry. Sulphate and nitrate are formed mainly from oxidation of SO_2 and NO_x . Sodium, magnesium and chloride are the main components of sea spray; potassium arises from biomass burning or soil and Ca from construction, soil and steelworks emissions (Oravisjarvi et al., 2003; Pandolfi et al., 2011). A number of anthropogenic, geogenic and biogenic activities are responsible for emissions of trace metals into the atmospheric environment and hence play important roles in determining size distributions (Allen et al., 2001). Each has a characteristic size distribution reflective of its source.

The Micro-Orifice Uniform Deposit Impactor (MOUDI) has been widely used for particle size measurement in both indoor and outdoor pollution studies. These studies have reported PM size distributions for water soluble and trace metal components (Allen et al., 2001; Cabada et al., 2004; Harrison et al., 2003a; Chang et al., 2008; Dall'Osto et al., 2008; Liu et al., 2008; Zhao and Gao, 2008; Gietl et al., 2010; Ny and Lee, 2011). Na, Cl, Ca and Al typically show modes in the coarse fraction while Cd, Zn, Mn, Ni and Cu have modes in the fine fraction (Ny and Lee, 2011). Allen et al. (2001) reported MOUDI data for trace metals from three urban background sites in the UK. Dall'Osto et al. (2008) employed a MOUDI for particle size-resolved measurements at a steel industry site in the UK. Water-soluble ions in particulate matter, from nanoparticles to the coarse mode have been determined with a MOUDI and nano-MOUDI in Taiwan by Chang et al. (2008). In London, particle size-segregated aerosol has been measured at roadside and background sites by Gietl et al. (2010). PM size-segregation and associated metallic elements in an industrialized city in Korea have been reported (Ny and Lee, 2011). None of these studies have compared the size distribution of PM and its components collected at urban background and industrial (especially steelworks) locations for both water soluble ions and trace metals. In this study, particle size distributions of both ionic species and trace metals at typical background and industrial sites were studied, offering an opportunity for identifying source signatures of components contributing to PM in the atmosphere of the two study areas. The results add to a relatively small international database of mass size distributions for specific chemical components, and highlight the very different sources of particulate matter at the two sites. Additionally, particle number spectra from 0.3 μm to >15 μm are reported and analysed according to wind speed and direction.

2. Materials and methods

2.1. The study areas

2.1.1. Port Talbot (PT)

PT is a coastal industrial town with a population of approximately 35,000 and located on the M4 corridor in South Wales (51° 34' N and 3° 46' W). The Tata steel complex located in Port Talbot town is the main industry in the study area and a major source of PM emissions

(AQEG, 2011). The site covers approximately 28 km^2 , comprises of ~50 km of roads, 100 km of railway, and 25,000 vehicle movements per day. The production capacity is around 5 m tonnes per year with the main processes in the steelworks being iron-making (sintering, blast furnace and raw materials), steel-making (basic oxygen steel-making (BOS) and coking) and rolling mills (hot and cold mills) (Moreno et al., 2004; Dall'Osto et al., 2008). The location of the sampling site (Fire Station) is shown in Fig. 1.

2.1.2. Elms Road Observatory Site (EROS)

EROS (1.93°W; 52.46°N) is a typical suburban background site located in an open field within the University of Birmingham campus. The site is about 3.5 km southwest of the centre of Birmingham (population of over one million and part of a conurbation of 2.5 million population (Yin et al., 2010). The EROS study site is shown in Fig. 2. The nearest roads are lightly trafficked and the nearby railway line carries mainly electric trains.

2.2. Particulate matter sampling

Size-fractionated particle sampling was carried out with 8-stage MOUDI™ (Model 100) having cut points of 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32 and 0.18 μm , and a nominal flow of rate 30 L/min. As a flow rate of 21.5 L/min was achieved throughout the sampling periods at both sites, a correction factor was applied using the formula: $D_p \times \sqrt{(F1/F2)}$ where D_p is the MOUDI stage nominal cut-point, F1 is the design flow rate of the MOUDI (30 L/min) while F2 is the achieved flow rate during the campaign (21.5 L/min). Polytetrafluoroethylene (PTFE) filters (Whatman, diameter 47 mm and pore size 1.0 μm) were used for particle collection on all the impaction stages while quartz filters (Whatman, diameter 37 mm) were used as backups. At EROS, a total of four MOUDI 72 hour-samples were generated during the sampling period between March 30 and April 11. At the PT sampling site, ten MOUDI samples of 72 h each were collected during a one month sampling campaign that started on April 17 and ended on May 16, 2012. The tenth sample was collected for just 36 h. Prior to sampling and after sampling, all filters were weighed with a Sartorius microbalance (Model MC 5; 1 μg sensitivity) equipped with a Polonium-210 anti-static source having been subjected to at least 24 h pre-conditioning (20 ± 5 °C and $50 \pm 10\%$ R.H.) in our clean weighing room.

2.3. Meteorological conditions

Average wind speed and temperature at the Birmingham (Tyburn) and Port Talbot (Fire Station) Automatic Urban Rural Network (AURN) sites were calculated (<http://uk-air.defra.gov.uk/networks/aurn-site-info>). The AURN station at Birmingham, Tyburn was used to represent the EROS site. During the period of sampling at EROS (March 30–April 11), the average wind speed and temperature were 4.3 ± 1.8 m s^{-1} and 6.7 ± 1.4 °C respectively. At PT where the sampling campaign took place between April 17 and May 16, the values were 6.3 ± 2.3 m s^{-1} and 8.6 ± 1.4 °C.

2.4. Sample digestion and analysis

Exposed filters were cut into two equal halves. One half was analysed for water-soluble ions (Na^+ , Mg^{2+} , Ca^{2+} , K^+ , NH_4^+ , Cl^- , NO_3^- , SO_4^{2-}) while the second half was analysed for trace metals (Al, V, Cr, Mn, Fe, Cu, Zn, Sb, Ba and Pb). Blank filters were also analysed and subtracted from the exposed filter data.

Filter samples for ionic species analysis were extracted with 7.5 mL distilled de-ionised water (DDW, conductivity of 18.2 M Ω) with agitation on a mechanical shaker (Model IKA Labor Technik KS 250 basic) set at 240 rpm for a period of 40 min. Prior to addition of DDW and shaking, PTFE filters were first treated with 0.3 mL propan-2-ol to wet the surface. The extracts were analysed with a Dionex DX 500 and

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