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Mass and elemental distributions of atmospheric particles nearby blast furnace and electric arc furnace operated industrial areas in Australia

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HIGHLIGHTS

- Urban and steelmaking industrial air particles were collected from Australia.
- Size resolved air particles were analysed by using PIXE technique.
- The modality types of air particles were found to be variable.
- Iron was measured as the main metal at industrial sites in each particle size range.
- The industrial iron fraction in the submicron size particles was found up to 95%.

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ABSTRACT

The improved understanding of mass and elemental distributions of industrial air particles is important due to their heterogeneous atmospheric behaviour and impact on human health and the environment. In this study, particles of different size ranges were collected from three sites in Australia located in the vicinity of iron and steelmaking industries and one urban background site with very little industrial influence. In order to determine the importance of the type of industrial activity on the urban atmospheric quality, the industrial sites selected in this study were in the close proximity to two blast furnace operated and one electric arc furnace based steelmaking sites. The chemical compositions of the collected air particles were analysed using the proton induced X-ray emission (PIXE) technique. This study revealed significantly higher metal concentrations in the atmospheric particles collected in the industrial sites, comparing to the background urban site, demonstrating local influence of the industrial activities to the air quality. The modality types of the particles were found to be variable between the mass and elements, and among elements in the urban and industrial areas indicating that the elemental modal distribution is as important as particle mass for particle pollution modelling. The highest elemental number distribution at all studied sites occurred with particle size of 0.1 μm. Iron was found as the main dominant metal at the industrial atmosphere in each particle size range. The industrial Fe fraction in the submicron and ultrafine size particles was estimated at up to 95% which may be released from high temperature industrial activities with the iron and steelmaking industries being one of the major contributors. Hence, these industrial elemental loadings can highly influence the atmospheric pollution at local urban and regional levels and are required to consider in the atmospheric modelling settings.

1. Introduction

The industrial sectors contribute approximately 59% of PM_{10} and 45% of $PM_{2.5}$ emissions to the atmosphere in New South Wales (NSW), Australia (NSW EPA, 2012), which can potentially impact the health and environment of the nearby communities. To reduce the impacts from particle emissions and meet the standards and goals set by the National Environment Protection Measure (NEPM), the NSW government has operated an extensive air particle monitoring programme for PM_{10} and $PM_{2.5}$ in urban and industrial areas using both continuous tapered element oscillating microbalance (TEOM) technique and gravimetric high volume sampling. However, monitoring of particle mass is not sufficient as the impact of particles on human health and the environment is highly dependent on particle size distribution and associated chemistry (Spurny, 1996; Koliadima et al., 1998; Lighty et al., 2000; Seinfeld and Pandis, 2012; Portin et al., 2013; Mohiuddin et al., 2014).

Understanding the mass and elemental distributions of atmospheric particles is an important parameter, as the toxicity of particles depends on their size and chemical composition, specifically on the concentration

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of metals in the particles. Coarse particles can be deposited in the upper respiratory tract, fine particles can penetrate into the lungs, whereas ultrafine particles ≤0.1 μm can further reach into the alveolar region of the lungs (Krombach et al., 1997; Park and Wexler, 2008; Valiulis et al., 2008). Particles ≤3 μm can enter the lower airways during breathing and can deposit in the tracheobronchial and pulmonary regions of the lungs and the highest deposition of particles having a size range of 1 to 3 μm can occur in the pulmonary region (ICRP, 1995; NCRP, 1997). Metals associated with the particles can mediate toxicity depending on their chemical properties present in the particles (Oberdörster, 1993; Dick et al., 2003; Spurny, 2010). For example, Fe is an essential element for the human body but not in the form of inhalable particles as Fe-bearing particles can stimulate reactive oxygen species on the lung surface, which may further lead to scarring of the lung tissue (Knaapen et al., 2004). Iron and steel industries can generate large amounts of coarse to ultrafine range particles associated with high concentration of Cr, Fe, Mn, Ni, and Zn (Machemer, 2004; Querol et al., 2004, 2007; Garimella and Deo, 2008). These particles can impact the surrounding areas and the residents can be exposed to elevated levels of atmospheric particles of different mass and metal concentrations. Workers in industries are protected by occupational health and safety regulations; however residents living in close proximity to the industrial boundaries have no separate zoning or regulation protection arrangements, other than the NEPM goals.

The focus of this study was to investigate the mass and elemental distributions of particles collected nearby steelmaking industrial areas that operate under blast furnace and electric arc furnace operating regimes, and compare to one background urban site. Detailed elemental modality was examined in this work, including the elemental mass median aerodynamic diameter (MMAD) and geometric standard deviation (GSD) to standardise particle characterisation. Four sampling sites in Australian urban and industrial areas were selected and ten different size distributions of particles ranging from ≤0.18 μm to 18 μm were collected and analysed for particle mass and elemental composition of Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Br, Sr and Pb. This study provides the fundamental information of particle mass and elemental distributions in the vicinity of iron and steelmaking industries. The outcomes of this study may assist the development of improved particle monitoring programmes in the vicinity of industrial areas and also establish an elemental modality dataset which can be incorporated in the exposure and risk assessments of atmospheric particles.

2. Materials and methods

Three sites in the vicinity of Australian iron and steel industries and one site in the urban area, shown in Fig. 1, were selected for sampling of the size resolved air particle samples: (1) Cringila (CR) sampling site was located in the vicinity of the Port Kembla integrated iron and steelworks (blast furnace and basic oxygen furnace), with moderate traffic and strong industrial influence; (2) Rooty Hill (RT) sampling site was located in close proximity to the Rooty Hill mini-mill steelworks (electric arc furnace), with moderate traffic and strong industrial influence; (3) Whyalla (WH) sampling site was located

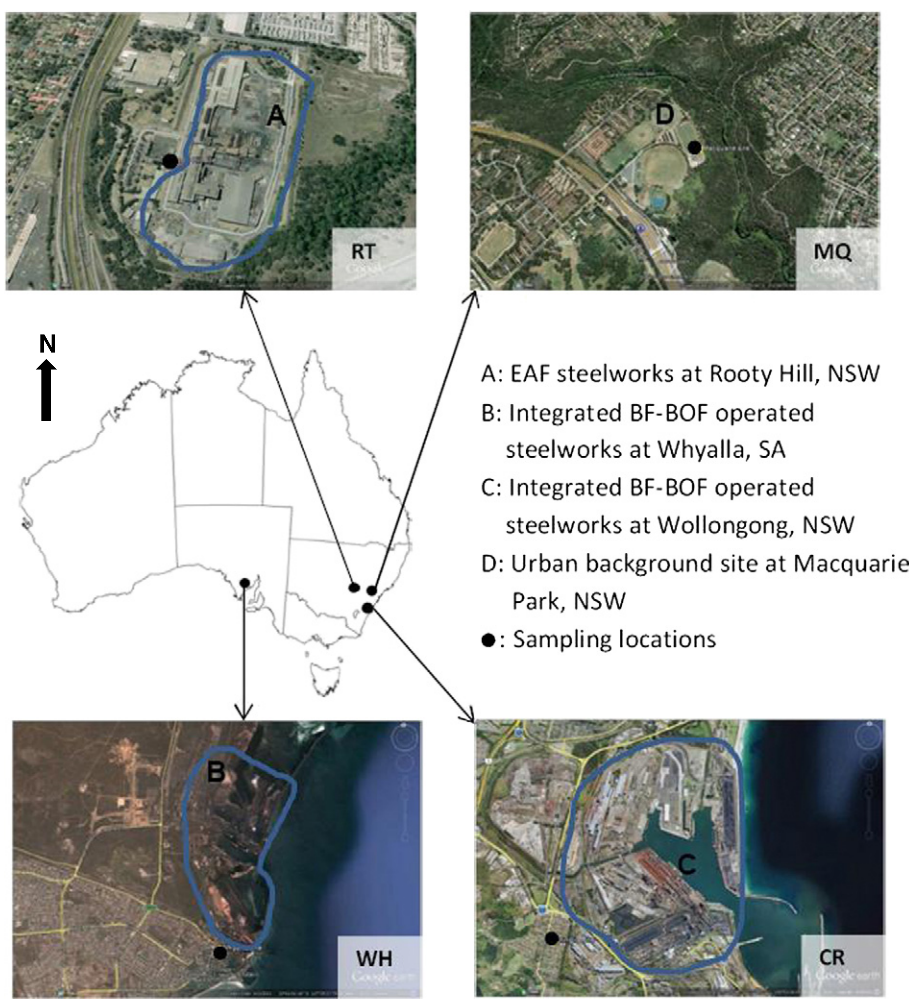

Fig. 1. Map of sampling locations in Australia.