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Source apportionment of $PM_{2.5}$ carbonaceous aerosol in Baghdad, Iraq

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ABSTRACT

Baghdad is the second largest city in the Middle East and suffers from severe air quality degradation due to the high levels of the atmospheric particulate matter (PM). Limited information exists regarding the sources of PM in Baghdad, and the lack of information on sources inhibits the development of control strategies to reduce air pollution. To better understand the nature of fine particulate matter ($PM_{2.5}$) in Baghdad and the Middle East, a one year sampling campaign to collect $PM_{2.5}$ was conducted from September 2012 through September 2013, missing August 2013 samples due to the security situation. 24-hour integrated samples collected on a 1-in-6 day schedule were analyzed for the major components, and monthly average samples were analyzed by gas chromatography mass spectrometry (GCMS) methods to measure particle-phase organic molecular markers. The results of organic molecular markers were used in a chemical mass balance (CMB) model to quantify the sources of $PM_{2.5}$ organic carbon (OC) and $PM_{2.5}$ mass. Primary sources accounted for 44% of the measured $PM_{2.5}$, and secondary sources were estimated to make up 28% of the measured $PM_{2.5}$. Picene, a tracer of coal combustion detected in Baghdad where there is no evidence for coal combustion, can be attributed to burning crude oil and other low quality fuels in Baghdad. Source apportionment results showed that the dominant sources of the carbonaceous aerosols in Baghdad are gasoline ($37 \pm 6\%$) and diesel engines ($17 \pm 3\%$) which can be attributed to the extensive use of gasoline and diesel powered generators in Baghdad. Wood burning and residual oil combustion contributed to 5 ± 0.4 and $1 \pm 0.2\%$ respectively of OC. The unresolved sources contributed to $42 \pm 19\%$ of the OC which represented the secondary organic aerosol (SOA) and the unidentified sources.

1. Introduction

Particulate matter (PM) has been implicated in both urban health problems such as asthma and cardiovascular diseases (Habre et al., 2014; Nelin et al., 2012; Van Ryswyk et al., 2014), and environmental problems such as visibility degradation and climate change (Kuo et al., 2013). During the last two decades, more attention has been given to the particles with an aerodynamic diameter of <2.5 μm ($PM_{2.5}$) since these particles have an ability to penetrate deeply into the lungs (Habre et al., 2014; Huang et al., 2009). However, the effects of $PM_{2.5}$ has been attributed to their chemical composition (Biswas et al., 2009;

Abbreviations: AIHL, Air and Industrial Hygiene Laboratory; CMB, chemical mass balance; CI, confidence intervals; EC, elemental carbon; GC/MS, gas chromatography/mass spectrometry; IC, ion chromatography; NAAQS, National Ambient Air Quality Standards; OC, organic carbon; PM, particulate matter; SD, standard deviation; SE, standard error; SF-ICP-MS, Sector field-Inductively Coupled Plasma-Mass Spectrometry; SOA, secondary organic aerosol; USEPA, United States Environmental Protection Agency; WHO, World Health Organization; WIOC, water insoluble organic carbon; WSLH, Wisconsin State Laboratory of Hygiene; WSOC, water soluble organic carbon.

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Dellinger et al., 2001; Shafer et al., 2010; Xia et al., 2004). Carbonaceous aerosol is a major component of $PM_{2.5}$, contributing to about 20–80% of the total mass of $PM_{2.5}$ in urban and industrialized areas (Daher et al., 2011; Nunes and Pio, 1993; E.A. Stone et al., 2010); this component is divided into organic carbon (OC) and elemental carbon (EC) (or black carbon, BC). OC contains mutagenic/carcinogenic compounds such as polyaromatic hydrocarbons (PAHs), and polychlorinated bicycles (PCBs) and toxic elements, whereas EC intervenes in the gas–particle heterogeneous reactions involving SO_2, NOx, and O_3; all are found to be detrimental to human health (Lee et al., 2012; Novakov, 1984). Therefore, there is a great need to understand the sources of carbonaceous aerosol in highly polluted urban areas. Numerous studies have been performed, focusing on carbonaceous aerosols and their sources in the world (Cao et al., 2003; Daher et al., 2011; Moldanová et al., 2009; Zhang et al., 2008), upon which people relied to develop air quality standards to protect the environment and public health from this particulate matter.

In the Middle East, there has been very limited research regarding air quality; National Aeronautics and Space Administration (NASA) has monitored the air quality in this region and showed that many of the bigger cities (including Baghdad, Iraq and Tehran, Iran — the two largest cities in the Middle East) in this region suffer from very high levels of air pollution (Richard, 2013). In addition, global scale of atmospheric modeling research has shown that the Middle East is a significant region for photochemical air pollution (Lelieveld et al., 2009; Li et al., 2001). Therefore, there is a great concern about the regional and global environmental consequences of air pollution in this area (Akimoto, 2003).

In this study, we focus on the second largest city in the Middle East (Baghdad, the capital of Iraq) which has a population of about 7 million (DWUA, 2014). Iraq is considered to be one of the most affected countries in the Middle East in regard to dust storms, where dust storms hit and last for days resulting in dusty days (Shahsavani et al., 2012). And because the humidity in Baghdad is very low (usually under 10%), due to Baghdad's distance from the Persian Gulf, dust storms from the deserts are normal occurrences during summer. It has been found that the severe air pollution in this city has compounded with the absence of regulation and control, resulting in a public health tragedy for the people in Baghdad (Ala'din, 2004). Several sources could be implicated in air quality degradation including the leaded gasoline and high sulfur fuel, the extensive operation of diesel and gasoline electric-generators due to the lack of power, and the uncontrolled emissions from industries (Jones et al., 2012; Programme, 2005; UNEPA, 2014a, 2014b). Therefore, a one-year sampling campaign in Baghdad city was conducted to collect the particulate matter ($PM_{2.5}$) and study the composition and sources to help people develop a strategy to reduce these particles to protect the environment and public health. A low volume air sampler was deployed on the roof of one of the Iraqi Ministry of Environment buildings in central Baghdad, and samples were collected for a period of 24 h from September 2012 through September 2013. Johann et al. have shown that Baghdad has the highest levels of $PM_{2.5}$ among the studied countries of the Middle East (Johann et al., 2008). Although some strategies have been implemented to mitigate emissions from some stationary sources such as transition to natural gas operated power plants, there still a large contribution from other sources such as gasoline and diesel operated power generators that are used very widely for cooling in summer due to the lack of power in Baghdad. This might not just impact the levels of $PM_{2.5}$ but also be implicated in increasing the temperature due to the high emission of carbonaceous aerosol from such sources (IEA, 2012); thus, Baghdad is identified as one of the hottest cities in the world (NCDC, 2014). As there is a great need to control the particulate matter concentrations in Baghdad to improve the environment and protect human health, a clear understanding of the composition and sources of $PM_{2.5}$ carbonaceous aerosols is required. Source apportionment that links sources to air quality is critical in the development of effective and efficient air quality control measures. Samples of $PM_{2.5}$ from Baghdad were analyzed for chemical compositions, and a receptor model (chemical mass balance (CMB)) based on aerosol chemical compositions obtained at the sampling site was used to explore the sources of the respirable carbonaceous aerosols (Gordon, 1988). This model has extensively been successfully applied to reveal sources of the carbonaceous aerosol in many areas of the world (Daher et al., 2011; Heo et al., 2013; Schauer et al., 1996; E. Stone et al., 2010; Zhang et al., 2008). Therefore, CMB was used in this study to determine the seasonal variability in source classes that might derive the $PM_{2.5}$ chemical species to provide information to help the regulatory communities design more effective control strategies to protect public health from these toxic particles. This is the first time that particle-phase organic molecular markers-based CMB model is applied to quantitatively apportion the sources that contribute to $PM_{2.5}$ carbonaceous aerosol concentration in Baghdad.

2. Materials and methods

2.1. Sampling location and method

Samples were collected in Baghdad, the capital of Iraq (33.3191°N and 44.3920°E), which is one of the hottest cities in the world, and nighttime temperatures in summer are seldom below 24 °C (75 °F) (NCDC, 2014). Fig. S1a,b in the Supplementary materials shows the ambient temperatures in Baghdad during the studied year. The total annual precipitation averages 156 mm; most of the annual rainfall in this area occurs between November and April, with brief violent rainstorms in the winter. The remaining months, particularly the hottest ones including June, July, and August, are dry (NCDC, 2014).

Fifty-three sets of filter samples were collected from September 15, 2012 to September 16, 2013 using $PM_{2.5}$ air sampler which was located on the roof of one of the Iraqi Ministry of Environment offices/Department of the Environment in Central Iraq-Baghdad (Central Baghdad, Al-Andalus Square, Baghdad-Iraq); this location is a neighborhood where several hospitals and parking lots are established. A low volume air sampler which was fitted with a $PM_{2.5}$ Teflon-coated aluminum cyclone (Air and Industrial Hygiene Laboratory (AIHL) design (Cao et al., 2013)) for particle classification was used in this study. The sampler was operated for 24 h on each sampling event at a nominal air flow rate of 24.0 L min^{-1} (two 8 L min^{-1} sample legs that were operated with quartz filters (47 mm, Pall Life Science), and one 8 L min^{-1} sample leg that was operated with a Teflon filter (47 mm, Teflo Membrane, Pall Life Sciences)). The air flow rate through the Teflon filters was found to be