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Review

A review of studies on atmospheric mercury in China

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ABSTRACT

Due to the fast developing economy, mercury (Hg) emissions to the atmosphere from Chinese mainland have increased rapidly in recent years. Consequently, this issue has received a considerable attention internationally. This paper reviews the current understanding of and knowledge on atmospheric Hg emissions, distribution and transport in China. The magnitude of Hg emissions to the atmosphere from Chinese anthropogenic sources has been estimated to be in the range of 500–700 tons per year, whereby comprising a significant proportion of the globe total anthropogenic emissions. Emissions of Hg from natural surfaces including bare soil, water, and vegetation covered soil tend in a comparison to be higher in China than in Europe and North America, indicating the importance of this source category. Atmospheric Hg exhibits a significant concentration variability among urban, semi-remote, and remote areas. Total Gaseous Mercury (TGM) concentrations in urban areas of China were often 1.5 – 5 folds higher compared to the corresponding settings in North America and Europe. In turn, particulate mercury (PHg) concentrations in urban areas of China were up to two orders of magnitude higher compared to North America and Europe. Atmospheric observations made at strictly remote sites in China also include the presence of occasional high concentrations of TGM, and the more short-lived fractions PHg and Reactive Gaseous Mercury (RGM). Accordingly, Hg deposition fluxes tended to be higher in China, with remote areas and urban areas being 1–2 times and 1–2 magnitude higher than those in North America and Europe, respectively.

Contents

1. Introduction

Mercury (Hg), especially its methylated forms (e.g., methyl mercury (MeHg) species, dimethyl mercury (DMeHg)), is a highly toxic pollutant that can pose adverse effects on human health and

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wildlife. Unlike other heavy metals pollutants that tend to exist in the atmosphere as the particulate phase, Hg exists mainly in the gaseous phase (Wängberg et al., 2001; Poissant et al., 2005; Gabriel et al., 2005; Aspmo et al., 2006; Valente et al., 2007; Chand et al., 2008). In current speciation/fractionation schemes, atmospheric Hg can be divided into gaseous elemental Hg (GEM), reactive gaseous Hg (RGM), and particulate Hg (PHg) (Schroeder and Munthe, 1998). RGM and to some extent PHg have a high surface reactivity and water solubility and are readily scavenged from atmosphere via wet and dry deposition. However, GEM, the predominant form of atmospheric Hg (>90% of the total Hg in atmosphere), is fairly stable in the lower atmosphere with a residence time of several months to a year, with the exception of certain situations including polar regions, upper troposphere, and marine boundary layer (Schroeder and Munthe, 1998; Lu et al., 2001; Lindberg et al., 2007; Faïn et al., 2009; Obrist et al., 2010). This enables Hg^0 to undergo long-range transport and eventually become well-mixed on a hemispherical scale.

China is the largest developing country worldwide. Due to the fast developing economy, China has emerged as the world's biggest energy consumer. For example, coal combustion in China claims more than 25% of the total worldwide coal production. Combustion of fossil fuels represents the largest single anthropogenic source of Hg to the atmosphere (Pacyna et al., 2006). Moreover, other industrial activities including non-ferrous metal smelting and cement production prevalent in China also release large amounts of Hg to the atmosphere. Hence, China is considered to be the largest anthropogenic Hg source region over the world. Recently, significant efforts have been made to study the emissions of atmospheric Hg and its distribution in China. In order to provide a better understanding of current knowledge with respect to atmospheric Hg in China and promote future studies, this paper provides an overview of current atmospheric Hg studies in China.

2. Source of atmospheric Hg in China

2.1. Anthropogenic sources

China is the largest emitter of atmospheric Hg worldwide. The anthropogenic Hg emission from China was estimated to be at about 535 tons in 1999 (Street et al., 2005). Due to the increased energy consumption during the past decade, anthropogenic Hg õemission has rapidly increased with predicted amount of 695 tons for the year 2003, which is about 26% higher than that in 1995 and corresponds to an average annual increase of 3.0% (Wu et al., 2006). Anthropogenic Hg sources are irregularly spatially distributed over China. As can be seen in Fig. 1, the emissions from provinces of Guangdong, and Guizhou are the highest. The high anthropogenic Hg emissions of Liaoning and Guangdong were linked to non-ferrous smelters, while high Hg content of raw coal and relatively large amount of uncontrolled coal combustion affect the emissions from Guizhou (Street et al., 2005).

Coal combustion is the most important anthropogenic source of Hg in China. According to the studies by Wu et al. (2006) and Pirrone et al. (2010), coal combustion in China released approximately 256–268 tons of Hg to the atmosphere in 2003, accounting for about 40% of the total anthropogenic emissions in China. Hg emission factors for coal combustion show a large span in China from 1.5 to 350 mg ton^{-1} (Tang et al., 2007; Zhang et al., 2008; Wang et al., 2010), which was comparable with the global mean estimates (40–300 mg ton^{-1}, Street et al., 2009; Pacyna et al., 2010). Coal type and coal Hg content are important factors affecting Hg emission and its speciation from coal combustion. Anthracite coal tends to have a higher concentration of Hg than bituminous coal and is therefore suggested to release more Hg during combustion (Wang et al., 2010). Moreover, the Hg emission factor from coal combustion is

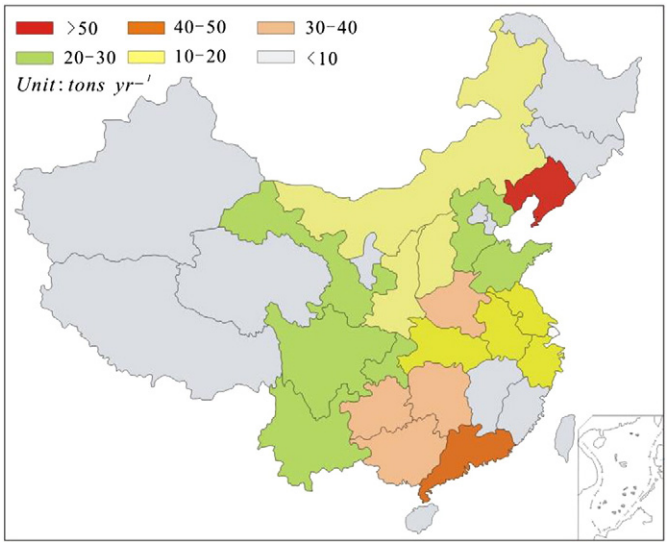

Fig. 1. Anthropogenic emissions of Hg in China, by province (Street et al., 2005).

evidently influenced by the implementation of air pollution control devices. Wang et al. (2010) investigated Hg emission factors from six typical coal-fired power plants of China and found the average Hg removal efficiency was at 73% in the plants including a combination of electrostatic precipitators (ESP) and wet flue gas desulfurization (FGD). In addition, Tang et al. (2007) reported that Hg emission factors for small industrial coal coal-fired boilers decreased by about 40% when wet FGD systems were in operation.

Non-ferrous metal smelting also constitutes an important anthropogenic Hg source category in China. This sector was estimated to release about 230 tons of Hg to the atmosphere in 1995, which was revised up to 320 tons for 2003 (Wu et al., 2006). In the global perspective, the non-ferrous metal smelting in China makes up a much larger portion of the domestic anthropogenic Hg emissions than most other countries. However, it should be noted that the estimates of Hg emission from non-ferrous smelting in China are associated with significant uncertainties due to various smelting methods and pollution-control techniques applied. Among the non-ferrous metals, the contribution from zinc smelting emerges as the largest single source (Street et al., 2005; Wu et al., 2006). Li et al. (2010a) estimated Hg emission factors for industrial-scale zinc smelting plants in China to be in the range 5.7 – 122 g ton^{-1} (mean = 33.1 g ton^{-1}) using the mass balance method. Of the several plants investigated, the Hg emission factors related to artisanal and imperial smelting process operations were found to be the highest. On the basis of the calculated emission factors, Li et al. (2010a) estimated that zinc smelting released 80–104 tons of Hg annually to the atmosphere during the period 2002 to 2006, which is much lower than the estimates obtained from previous studies (Street et al., 2005; Wu et al., 2006). Again, the employment of air pollution control devices will significantly affect Hg emissions from zinc smelting. Wang et al. (2010) measured Hg concentrations of flue gas in a hydrometallurgical zinc smelter and found that most of emitted Hg was removed by air pollution control devices. The emission factor for this hydrometallurgical zinc smelter was as low as 0.5 g Hg ton^{-1} zinc.

Cement production, Hg mining, biofuel combustion, and household waste burning constitute in China comparatively minor sources of atmospheric Hg, which combined accounted for the release of more than 80 tons of Hg to the atmosphere in 2003 (Wu et al., 2006).

2.2. Emissions of Hg from natural surfaces

Table 1 summarizes measurement studies of Hg air–natural surface exchange performed in typical landscapes of China. Some