



Review

Reviews on atmospheric selenium: Emissions, speciation and fate

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Abstract

The atmosphere is an important transient reservoir of selenium (Se). According to recent evaluations of the global Se budget, approximately 13,000–19,000 tons of Se is cycled through the troposphere annually. Most studies suggest that atmospheric deposition is an important source of Se contamination and it is therefore critical to evaluate the source emissions and fate of Se in the atmosphere. This paper presents a broad overview of current state of knowledge and understanding of major aspects of atmospheric Se and its natural and anthropogenic sources. The significant physical and chemical species encountered in the atmosphere are examined and special attention is paid to atmospheric speciation and its atmospheric pathways and processes. In addition, thermodynamic and kinetic data for atmospheric Se speciation are provided, which aid our understanding and the modelling of Se behaviour in the atmospheric environment. We also document how Se isotopes might be useful for tracing atmospheric sources and pathways. Important gaps in our current knowledge of Se in the atmospheric environment are identified, and suggestions for future research are offered.

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Keywords: Atmospheric selenium; Source; Flux; Atmospheric pathway; Physical and chemical speciation

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1. Introduction

Selenium (Se) is an essential trace element for human and animal health and vegetation. However, its overabundance and depletion may cause serious biological and ecological problems, such as Se toxicosis and chronic Keshan disease (due to Se depletion) (Fordyce et al., 2000; Wang and Gao, 2001). One of the most important features of Se is the very narrow margin between nutritionally optimal and potentially toxic dietary exposures for vertebrate animals (Wilber, 1980). The duality depends on its concentration and chemical forms (Cutter and Cutter, 2004).

Se exists in the atmospheric, marine and terrestrial environments, where it may be transported and transformed via different chemical and physical pathways. The distribution of Se is greatly inhomogeneous, resulting in the relative Se enrichment and depletion in the different environments. In particular, elevated levels of Se in the aquatic environment and in terrestrial plants such as lichens and mosses remote from anthropogenic emission sources have been documented, indicating that atmospheric deposition may be an important source of contamination (Beavington et al., 2004; Bennett, 1995; Cutter and Church, 1986; Cutter and Cutter, 2004; Haygarth et al., 1991; Kagawa et al., 2003).

According to the latest evaluation of the global Se budget, approximately 13,000–19,000 tons of Se is cycled through the troposphere annually (Mosher and Duce, 1987). Se is emitted into the atmosphere from a variety of natural and anthropogenic sources, the former accounting for 50–65% of total emissions at the global scale (Mosher and Duce, 1987). However, since the onset of industrialization, anthropogenic emissions have greatly increased compared to natural sources. As a result, the scientific community is paying increasing attention to atmospheric Se and its sources, transport, diffusion, transformation and deposition, in an effort to constrain its importance in the environment.

In 1984, Ross made the first systematic summary in his research report ‘Atmospheric Selenium’. An

atmospheric Se model was presented which incorporated speciation and chemical transformations, along with a depositional budget for regions between 30°N and 90°N (Ross, 1984, 1985, 1990). However, the model raised a number of ambiguous questions concerning the Se atmospheric cycle due to the lack of available data at that time. For example, the model treats the atmosphere as a single-homogeneous reservoir where a mass balance exists between the sources and sinks. However, new data from field investigations and experiments have since become available that may be used to further constrain the atmospheric processes involving Se. Thus, it now seems an appropriate time to summarize and update our current understanding of the atmospheric Se cycle and its environmental impact. Special attention is paid to atmospheric speciation and its speculated atmospheric pathway and processes. In addition, thermodynamic and kinetic data concerning atmospheric Se speciation are reviewed, which might be used to improve our understanding of Se behaviour in the atmospheric environment.

2. Atmospheric Se sources and global fluxes

As for other metals, the atmospheric Se sources can be divided into two categories: natural and anthropogenic emissions. Mosher and Duce (1987), Nriagu (1989) and Nriagu and Pacyna (1988) suggest that the natural sources include crustal weathering (wind blown soil dust), volcanoes, sea salt, and the continental and marine biospheres, while the anthropogenic sources mainly comprise combustion (coal, oil, wood, biomass, incineration, etc.), nonferrous metal melting, manufacturing and utilization of agriculture products.

The atmosphere plays an important role in the dispersion, transport and transformation of Se in the environment. Therefore, the evaluation of the relative contributions of natural and anthropogenic emissions of Se has become a long-term research interest. To achieve this task, available data, particularly which gained from field measurement are essential. Ross (1985) estimated that between 8600 and 10,700 tons of Se is released annually into

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