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Mercury emission from coal seam fire at Wuda, Inner Mongolia, China

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HIGHLIGHTS

- Coal seam fire releases mercury and contributes to global mercury inventory.
- Elevated mercury level in fire area air may cause occupational hazards.
- Adjacent urban area ambient air is polluted due to long-term effect of coal fire.
- Only smoldering is measurable, which may impede mercury inventory calculation.

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ABSTRACT

The underground coal seam fire in the Wuda, Inner Mongolia of china is one of the most serious coal fires in the world with a history over 50 years and endangers the neighboring downwind urban area. To investigate the potential mercury emission and migration from the coal seam fire, in situ real-time measurement of total gaseous mercury (TGM) concentration using Lumex RA-915 + mercury analyzer were implemented on the fire zone and the urban area. The results show an average TGM concentration of 464 ng m^{-3} in the fumes released from surface vents and cracks on the fire zone, which leads to an elevated TGM concentration of 257 ng m^{-3} (211–375 ng m^{-3}) in the near-surface air at the fire zone and 89 ng m^{-3} (23–211 ng m^{-3}) at the peripheral area. The average TGM concentration in the adjoining downwind urban area of Wuda is 33 ng m^{-3}. This result suggests that the coal seam fire may not only contribute to the global mercury inventory but also be a novel source for mercury pollution in the urban areas. The scenario of urban areas being adjacent to coal seam fires is not limited to Wuda but relatively common in northern China and elsewhere. Whether there are other cities under influence of coal seam fires merits further investigation.

1. Introduction

Coal seam fires can result when coal seams have long-term exposure to air (Bell et al., 2001; Heffern and Coates, 2004; Pone et al., 2007; Stracher and Taylor, 2004; U.S. Department of Energy, 1993; Walker, 1999). It begins with continuous absorption of oxygen by the exposed coal. When the heat generated from the oxidation reaction (Limacher, 1963) accumulates within the coal seam, it will give rise to first smoke and then ignition as the temperature increases (Rein, 2011). This phenomenon has occurred through geological times. The coal seam fire in the Powder River Basin (Heffern and Coates, 2004) in the US started 4 million years ago and there are still coal seam fires in this region. The original long-term air exposure location may be a natural coal outcrop or newly exposed coal due to mining. After the coal ignites, the overlying and surrounding rock layer will be scorched and decrepitated forming cracks or even subsidence resulting in new access for air exposure. In geological terms, the coal seam fire is intrinsically a natural event, as is evidenced by paleo-coal fires reported in the US, Australia (Ellyett and Fleming, 1974), Tajikistan (Sharygin et al., 2009), and China (Zhang et al., 2004). However, the anthropogenic history of large-scale coal mining after the industrial revolution has tremendously expedited and exacerbated the occurrence and expansion of coal seam fires by prompting air exposure opportunities to coal seams (Stracher and Taylor, 2004). Coal seam fires are reported across the world and are most acute in industrialized and coal-rich countries (Kuenzer and Stracher, 2012; Stracher, 2004).

The coal seam fire caused by anthropogenic mining activities has shown its capability to reshape human society in a negative

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manner by depriving local habitability of mining areas through environmental impact and terrain shift (Finkelman, 2004; Wu and Liu, 2011). In Centralia, Pennsylvania, the coal fire started in 1962, and a population of 1100 residents were relocated during a government campaign from 1985 to 1991, in which 42 million dollars was spent (Nolter and Vice, 2004). Currently, China has the most coal seam fires, both in magnitude and multitude. One reason is that China's annual coal production ranks first in the world for years. In 2011, China's coal production reached 3.471 billion tons—45.2% of global coal production (7.678 billion tons) (World Coal Association, 2012). Coal fires have been stimulated by both large-scale coal mining and multitudinous private coal pits. Coal fires mainly take place in the vast area of northern China, stretching 4800 km longitudinally from Heilongjiang Province in the east to Xinjiang Uygur Autonomous Region in the west. The overall population density is relatively low, since the arid, semi-arid dryland and desert conditions compose most of its terrain. However, due to the rich coal and other natural resource deposits in this area, many middle or small-scale cities emerged and prospered from the coal mining industry—the early settlements of coal mine workers and their families have become so called coal-based cities today. In many cases, these densely populated coal-based cities are in the vicinity of large coal mines, many of which have or currently are suffering from coal fires. Therefore, a study of potential environmental impact of coal seam fires on local habitats and especially the living environment of the populated area is of urgent importance.

Mercury, a highly toxic element, can cause intellectual impairment of the exposed population and neonatal dementia and mental retardation or other serious health hazards. Atmospheric mercury species, in particular, may contribute to regional or global mercury pollution through long-range transportation (Dastoor and Larocque, 2004; Seigneur et al., 2001), for their residence time ranging from few days to two years in the atmosphere (Schroeder and Munthe, 1998). Mercury mobilization and its environmental and human health impact has been receiving extensive global attention, including studies on mercury emission inventory of coal-fired power plants (Feng, 2005; Meij, 1991; Pirrone et al., 2001; Wang et al., 2000) and domestic use of coal (Feng et al., 2002, 2003; Finkelman, 1999; Finkelman et al., 1999, 2002). Studies on mercury emission (O'Keefe et al., 2010), alongside with emissions of CO_2, CO, VOCs, PAHs, SO_2, etc. (Carras et al., 2009; Zhao et al., 2008) from coal seam fire were reported in recent years, in studies mainly focused on modeling the mercury and carbon emission inventory of coal seam fires (O'Keefe et al., 2010; Pirrone et al., 2010; Streets et al., 2005). Due to the complex coal fire conditions and technical difficulties, these studies have not yet to provide in-situ real-time measurement of mercury emission from underground coal seam fires, except for one recent study by Engle et al. (2012). However, the potential environmental and health impacts from the migration of mercury emissions from underground coal seam fires, especially on the adjacent populated areas, has not been discussed. Considering the general fact that many cities in northern China are adjacent to coal seam fire areas, this study targets a typical coal-based city in the vicinity of a major coalfield with a coal fire history more than 50 years and documents the mercury emissions from the coal seam fire and mercury distribution pattern in the near-surface atmosphere in the populated area of this city.

2. Methodology

2.1. Study site

The Wuda District of Wuhai City (39°29′N, 106°42′E) is located in central Inner Mongolia at the northern end of Helan Mountain, southern edge of Ulan Buh Desert, adjacent to the Ningxia Hui Autonomous Region, and with the Yellow River crossing through from south to north at its eastern edge. The area of the Wuda District is about 220 km^2, with a population of about 130,000 (2004). Wuda is in the temperate zone, with a strong continental and arid climate. The annual precipitation is 168.5 mm and evaporation is 3496.0 mm. A prevailing northwesterly wind is observed in this area, with an annual average wind speed of 4.8 m s^{-1} and average gale (Beaufort scale >7) days of 32 (Wuda Municipal Government, 2012). The Wuda Coalfield is located in the northwest of the Wuda District, with an area of 35 km^2. It is rich in Carboniferous-Permian coal, with over 16 minable seams and a reserve of 660 million tons, and mainly produces bituminous coal (high sulfur content) (Zhang et al., 2008).

Industrialized coal mining in Wuda coalfield was initiated in 1958, and since then Wuhai City has grown into a typical coal-based city. The first coal seam fire in this area was reported in 1961, and had expanded to 6 surface fire zones by 1978. By the end of 2004 fire zone number reached 26, with a total area of about 4 km^2 (Zhang et al., 2008). From 2006 to 2008, a surface block excavation method was employed in this area, aiming to extinguish coal fires. However, this method—basically digging the burning coal out, putting it out on the surface, filling the ground up and paving it level with hardener—failed to recognize the intrinsic nature of coal seam fire and the continuity of the underground coal seam, which lead to an accelerated coal fire spreading and nearly full surface devegetation in the mining area, and has received extensive international attention (Kuenzer et al., 2012; Zhang et al., 2011). Since 2009 the central government has put great effort in the control of coal seam fire in Wuda, but a recent study (Kuenzer et al., 2012) still shows a growing trend of coal fires.

This study focuses on three areas: X area (39°30′43″ N, 106°37′11″ E, elevation: 1233.5 m) (Fig. 1), Y area (39°31′01″N, 106°37′11″ E, elevation: 1230.8 m) (Fig. 2) in Fire-Area 8 in Wuhushan coal mine of Wuda coalfield, and W area (39°30′21″N, 106°43′11″E, elevation: 1112 m)—urban area of the Wuda District (Fig. 3). The relative positions of X, Y and W areas are shown in Fig. 4. The landscape of north part of X area is shown in Fig. 1b. Based on the occurrence of coal fire, the X area can be categorized into two parts: central and peripheral areas. The ground surface of central area is five-meter-thick limestone layer, and the underlying coal seam is the 4-m-thick No. 10 coal seam which has been ignited, which leads to heavy smog in the near-surface air (Fig. 1a). Surface vents (Fig. 1ghij) and cracks (Fig. 1lm) with or without fumes are scattered upon central area, along with several small-scaled open flame sites (Fig. 1ef). An eight-meter-deep pit lies between southeast of the central area and the peripheral area, which was meant for the fire extinguish project (surface block excavation method) yet half-way abandoned—a giant coal pillar that goes through overlying rock layer to the surface still stands by the pit. And there are fires at both the bottom of the pit (Fig. 1cd) and on the surface of the central X area. In the peripheral area, there are many different types of flattened surfaces, with no vent or crack or open flame site. Underneath the peripheral area's surface there is the same unmined No. 10 coal seam, with 5–8 m of limestone layer atop. The ground surface of the peripheral area has been recently leveled, leaving the undisturbed indigenous soil only visible in the southernmost end. At the northeast corner of the peripheral area there is a cement floor built for washed coal storage for a newly built coal washing plant on the side (by the time of our study this plant had yet came into operation and no coal had been piled up). At the east side of the peripheral area the ground surface is also leveled for the raw coal storage for the coal washing plant. Also, there is another coal washing plant under construction in the southeast side. On the north and west edge of the whole area there is a five-meter-high coffer wall piled up with large crushed stones and other waste