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Review

Mercury-impacted scrap metal: Source and nature of the mercury

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ABSTRACT

The reuse and recycling of industrial solid wastes such as scrap metal is supported and encouraged both internationally and domestically, especially when such wastes can be used as substitutes for raw material. However, scrap metal processing facilities, such as mini-mills, have been identified as a source of mercury (Hg) emissions in the United States. This research aims to better define some of the key issues related to the source and nature of mercury in the scrap metal waste stream. Overall, it is difficult to pinpoint the key mercury sources feeding into scrap metal recycling facilities, quantify their associated mercury concentrations, or determine which chemical forms are most significant. Potential sources of mercury in scrap metal include mercury switches from discarded vehicles, electronic-based scrap from household appliances and related industrial systems, and Hg-impacted scrap metal from the oil and gas industry. The form of mercury associated with scrap metal varies and depends on the source type. The specific amount of mercury that can be adsorbed and retained by steel appears to be a function of both metallurgical and environmental factors. In general, the longer the steel is in contact with a fluid or condensate that contains measurable concentrations of elemental mercury, the greater the potential for mercury accumulation in that steel. Most mercury compounds are thermally unstable at elevated temperatures (i.e., above 350 °C). As such, the mercury associated with impacted scrap is expected to be volatilized out of the metal when it is heated during processing (e.g., shredding or torch cutting) or melted in a furnace. This release of fugitive gas (Hg vapor) and particulates, as well as Hg-impacted baghouse dust and control filters, could potentially pose an occupational exposure risk to workers at a scrap metal processing facility. Thus, identifying and characterizing the key sources of Hg-impacted scrap, and understanding the nature and extent of associated releases, represent a practical research need that is essential for improving the environmental management of Hg-impacted scrap and assessing measures to protect workers from potential health and safety hazards that might be posed by mercury and Hg-impacted scrap.

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1. Introduction

Mercury (Hg) is widely known as a persistent toxic substance in the environment that has been distributed throughout the globe via atmospheric transport (ATSDR, 1999; UNEP, 2008). This extremely volatile metallic element is present in air, water, soil, and sediment, as well as in manufactured materials and their wastes. The human contribution to mercury in the environment has been steadily increasing. It is estimated that approximately half of the current atmospheric mercury levels can be attributed to anthropogenic sources (UNEP, 2008), with levels increasing approximately 300–500% in the past 250 years (Sunderland and Mason, 2007). Although combustion facilities, such as coal-fired power plants and waste incinerators, have been identified as the main source of mercury emissions in the United States, other sources include secondary steel production, such as scrap metal processing facilities (AMAP/UNEP, 2008).

Currently, the reuse and recycling of industrial solid wastes, such as scrap metal, is supported and encouraged both internationally and domestically, especially when such wastes can be used as substitutes for raw material (UNEP, 2014; EPA, 2013; EC, 2011). Mini-mills that melt and refine steel, typically in an electric arc

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furnace (EAF), are the largest recyclers of scrap metal in the United States (EPA, 2009). The EAF can produce steel from 100% scrap metal feedstock in an energy-efficient and flexible manner.

In the United States, under the Resource Conservation and Recovery Act (RCRA) 40 CFR 261.4(a)(13) (EPA, 1980), recycled scrap metal is not considered solid waste; it is excluded from regulation as a hazardous waste and does not require waste characterization as long as it meets the definition of scrap metal as defined by the statute. With the exception of a few states (e.g., California and Massachusetts) that impose stricter regulations on the use of scrap metal, most states follow the RCRA regulations. As a result, the scrap metal stream is not commonly tracked or screened for contaminants (other than radioactivity) or required to comply with U.S. Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) requirements related to hazardous waste. The research presented in this paper aims to better define some of the key issues related to the source and nature of mercury in the scrap metal waste stream in order to improve the environmental management of that material.

2. Sources of mercury in scrap metal

Various studies have indicated that scrap metal processing and recycling facilities could emit measurable amounts of mercury (OSHA, 2008; EPA, 2008; Sastry et al., 2004; Morgan et al., 2003). However, limitations in the current literature make it difficult to pinpoint key sources of mercury in the scrap metal used as feedstock by these facilities. Researchers who have attempted to correlate mercury emissions with a specific raw material have indicated that neither the entry of mercury into an EAF nor the chemical forms that are most significant in determining potential hazards are well understood (Rosenborough et al., 2006b; Orrling, 2010). Some possible sources of mercury in scrap metal include mercury switches, other electronic-based scrap, including household appliances and related industrial systems, and Hg-impacted scrap metal generated by the chlor-alkali and oil and gas industries. These potential sources are discussed below.

2.1. Vehicles

Switches are standard components of automobiles, trucks, and other vehicles, serving the essential function of opening and closing electrical circuits. They can be activated by a change in temperature (e.g., temperature switch), pressure (e.g., pressure switch), or position/motion (e.g., tilt switch, float switch) (MPCA, 2001). Because of the inherent properties of liquid mercury, including high electrical conductivity, it has been widely used in hermetically sealed switching devices. Mercury switches are preferred over other switching devices for several reasons, including their reliability (consistent operation throughout their electrical life), high load capability, and moderate cost (Sastry et al., 2004).

Nearly all (99%) of the mercury in vehicles is contained in switches (Woodruff, 2004). Most vehicles manufactured from 1960 into the 1990s contain mercury switches. In the early 1990s, European automobile manufacturers stopped using mercury switches in all models. However, U.S. companies did not discontinue this use across all models for another several years, e.g., not until the late 1990s for Chrysler and the early 2000s for Ford and General Motors (Griffith et al., 2001). It has been estimated that as many as 250 million mercury switches were present in vehicles on the road in North America in 2001 (Griffith et al., 2001). Mercury switches in cars were used in various applications, such as convenience lights in trunks and on hoods, four-wheel drive antilock braking systems (ABS), antitheft systems, and headlamps (i.e., high-intensity discharge lamps). A vehicular mercury switch contains around 0.7–1.5 g of mercury (IEPA, 2005; Sastry et al., 2004; Woodruff, 2004; MPCA, 2001; Griffith et al., 2001).

Vehicles that reach the end of their operating life and are discarded are commonly sent to recycling yards, where they are shredded and packed into bundles that are eventually melted at recycling facilities such as steel mini-mills. Thus, most of the mercury from unremoved switches eventually ends up in scrap processing facilities. This mercury can then be released into the environment, presumably as metallic mercury or elemental mercury [Hg(0)], during processing and recycling. Two studies using data from the late 1990s provide some context for the scale of the mercury issue associated with discarded vehicles. The first study from the Steel Recycling Institute estimated that the steel industry recovered and recycled enough steel from old cars to produce more than 13 million new automobiles in 1999, for a recycling rate of 91% (Sastry et al., 2004). The 2012 automotive recycling rate was estimated to be approximately 93% (SRI, 2012). The second study used 1997 data from the U.S. Environmental Protection Agency (EPA) to estimate that about 11 tons of metallic mercury waste was generated from car switches in the United States (IEPA, 2005). It is noted, that the mercury contribution to scrap metal resulting from vehicle switches should decrease with time as the number of older vehicles containing mercury switches (i.e., pre-2003) declines.

2.2. Household and industrial devices

Mercury switches are available in different shapes, sizes, and electrical ratings designed to assure their reliable performance in applications that range from thermostats to gas pressure regulators to sensitive instruments and system controls used in heavy industry (EPA, 2011; Tibbetts, 2011; NEWMOA, 2010; Sastry et al., 2004). Mercury switches are used as measurement and control devices in a variety of household and industrial appliances, including furnaces, refrigerators, freezers, and sump pumps. In addition, mercury switches are used under the lids of washing machines, where they are responsible for turning on a light or stopping a spin cycle, and they can also be found in safety switches of smaller appliances such as clothes irons and space heaters.

Data on thermostats found in residences, businesses, and industrial settings, estimate approximately 3 g of elemental mercury per switch, noting that some larger units can contain multiple switches with up to 12 g of mercury total (Tibbetts, 2011; NEWMOA, 2010). According to 2007 figures, mercury use for thermostats sold in the United States has decreased approximately 73% since 2001 (i.e., from approximately 14.6 tons [13,000 kg] in 2001 to around 3.9 tons [3500 kg] in 2007). This downward trend is likely a result of more states enacting legislation that restricts the sale and/or distribution of mercury-containing thermostats, leading to an increase in the use of non-mercury programmable thermostats (NEWMOA, 2010). In addition, numerous collection and recycling programs exist for mercury thermostats at both the mandatory state (e.g., California, Connecticut, Illinois, Iowa, Maine, Massachusetts, Minnesota, Montana, New Hampshire, New York, Oregon, Pennsylvania, Rhode Island, and Vermont) and voluntary industry-sponsored (e.g., Thermostat Recycling Corporation) level (TRC, 2014; NEWMOA, 2010).

As with discarded vehicles, metallic mercury can be released from these devices and appliances after they are scrapped and sent to a recycling yard. No recent, reliable estimates exist for the amount of mercury actually scrapped each year from all household and commercial products combined. As context for the scale of this issue, the Steel Recycling Institute estimated a 90% recycling rate for U.S. steel appliances in 2011 (SRI, 2014), but provided no information on the potential mercury content of these appliances. However, a 1997 EPA report suggested thermostats alone would account

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