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Evaluation of particulate matter emissions from manganese alloy production using life-cycle assessment

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ABSTRACT

Life-cycle assessments (LCAs) provide a wealth of industry data to assist in evaluating the environmental impacts of industrial processes and product supply chains. In this investigation, data from a recent LCA covering global manganese alloy production was used to evaluate sources of particulate matter (PM) emissions associated with the manganese alloy supply chain. The analysis is aimed at providing an empirical, industry-averaged breakdown of the contribution that processes and emissions controls have on total emissions, manganese releases and occupational exposure.

The assessment shows that 66% of PM emissions associated with manganese production occur beyond manganese facilities. Direct or on-site emissions represent 34% of total PM and occur predominantly as disperse sources during mineral extraction and hauling, and as primary furnace emissions. The largest contribution of manganese-bearing PM at ground-level is associated with fugitive emissions from metal and slag tapping, casting, crushing and screening.

The evaluation provides a high-level ranking of emissions by process area, to assist in identifying priority areas for industry-wide initiatives to reduce emissions and occupational exposure of manganese. The range of PM emission levels in industry indicate that further enhancements in PM emissions can be achieved by sharing of best practices in emissions controls, limiting furnace conditions which lead to by-passing of emissions controls and application of secondary emission controls to capture fugitive emissions during tapping and casting. The LCA approach to evaluating PM emissions underscores the important role that process optimization and resource efficiency have on reducing PM emissions throughout the manganese supply chain.

1. Introduction

The mining and metals sector can have a significant impact on the environment, energy and natural resources, and is the precursor to countless process supply chains and human activities. As a result, leading industry associations have prioritized sector-specific approaches to understanding and communicating the environmental performance of their metals within and outside of their industries. Manganese is a critical component for the steel and stainless steel industry. Similarly to many metals, the process for mining and smelting manganese alloys is fairly consistent from site to site. However, the size of operation, geographic location, management and technology can bring significant variation in the environmental performance of a given site.

Dust is generated during mining and smelting of manganese alloys. Particulates from mining activities are typically larger than those from smelting or welding activities. Over the years researchers have reported some neurological effects in workers exposure to manganese dust in occupational settings. Roels et al. (1992) reported motor effects on reaction time, tremor and hand–eye coordination in workers exposed to respirable manganese dioxide dust. Mergler et al. (1994) confirmed adverse motor effects, among workers employed in ferromanganese and silicomanganese plants. Lucchini et al. (1999) also reported motor function changes identified in a group of ferroalloy workers but found no evidence of progressive deterioration in workers whose exposure to manganese had been reduced.

In contrast, the studies of Gibbs et al. (1999) among manganese metal production workers exposure (respirable fraction 0.04 mg/m^3 (GM), total dust 0.11 mg/m^3 (GM)) and of Myers et al. (2002), on miners (total dust 0.21 mg/m^3 – equivalent to estimated respirable levels of 0.04–0.08 mg/m^3) reported no effects, meaning that there

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is a threshold of exposure below which health effects are not triggered. It is these thresholds that authoritative bodies have aimed to derived over the years in respirable and inhalable dust fractions (EL, 2011; List of MAK and BAT Values, 2010; ACGIH, 2013).

While adverse health conditions in workers are being addressed by emissions reductions strategies, use of personal protection equipment and training by industry, community exposure still remains a problem. Some studies have reported a correlation between increase in environmental exposure to airborne metals and particulate matter and criminal activity (Haynes et al. (2011)). Others have reported environmental exposure affecting children's attention, cognition, behavior, and academic performance (Bouchard et al. (2011), Menezes-Filho et al. (2011), Torres-Agustin et al. (2013), Bowler et al. (2015)).

It is therefore important to characterise environmental performance in mining and smelting activities with specific attention to different processes within the production cycle.

The International Manganese Institute (IMnI), with the assistance of Hatch, completed the first globally representative life cycle assessment (LCA) of manganese alloy production as part of the IMnI Sustainability Programme. LCA is a tool for quantifying the direct and indirect environmental impact associated with a product (or service) through a systematic process modeling approach. LCA can also be used to evaluate the financial benefits of supply chain efficiency, resource consumption and technology optimization initiatives.

The aim of the LCA of Global Manganese Alloy Production was to develop a scientific and objective basis for evaluating, communicating and driving environmental performance throughout the industry and to downstream stakeholders. As such, the results of the LCA can provide industry data for a broad range of applications. This paper will discuss how the LCA of Global Manganese Alloy Production has been applied to understand the sources of manganese particulate matter emissions contributing to occupational exposure along the manganese supply chain. By applying an LCA approach, it is possible to draw connections between production practices, control technologies, emissions levels and units of production at manganese mines and smelters.

2. Material and methods

Data for this investigation is sourced from the LCA of Global Manganese Alloy Production completed by IMnI and Hatch (Dec 2014). The study used established methods for LCA standardized under ISO 14040 (2006a) and ISO 14044 (2006b) and was peer reviewed by an independent panel of LCA practitioners.

Life Cycle Assessment assesses the environmental impacts associated with all the process stages, from cradle to grave, of a product or service. An LCA consists of four stages:

- Goal and scope: sets the context of the study by specifying the functional unit, the system boundaries, any assumptions and limitations, allocation methods, and impact categories chosen to be evaluated.
- Life cycle inventory: gathers all flows from and to nature for a product system, including inputs of water, energy, and raw materials, and releases to air, land, and water.
- Life cycle impact assessment: evaluates the significance of potential environmental impacts.
- Interpretation: systematically identify, quantify, check, and evaluate information from the results of the life cycle inventory and/or the life cycle impact assessment.

The LCA included 16 mines and smelters, covering approximately 1/5th of global ore production and 1/10th of global alloy production, including high carbon ferromanganese, silicomanganese, and refined ferromanganese. As such, this LCA is the most comprehensive study of environmental impacts associated with the production of manganese alloys available in the public literature to date. The uniqueness of this study stems from the collection of primary data at each facility. A subset of member companies of the IMnI were invited to participate in the study based on characteristics contributing to their representativeness of the industry. These characteristics included:

- Regional distribution: facilities from all principal countries involved in manganese production;
- Production: facilities producing the three main manganese alloy types;
- Size: facilities covering a balanced representation of facility sizes.

The participating facilities are shown in Table 1.

The study focused its results in a number of ways towards improving and communicating sustainability within the industry and with external industry stakeholders. Beyond the LCA, the study included analysis to add value for the manganese industry and participating producers. Individual site and process benchmarking for participating producers allowed Hatch to provide direction to each site to address plant efficiency and throughput challenges. The study also leveraged Hatch's engineering and metals processing experience to translate the LCA into valuable insights for mine and smelter operators. Additional information about the LCA and a full listing of the methodology and results are provided in the ISO-

Table 1
Participating facilities.

Region	Company	Facility Name or Location	Type
Australia	OM Holdings	Bootu Creek	Mine
	BHP Billiton	GEMCO	Mine
	Consolidated Minerals	Woodie Woodie	Mine
China	CITIC Dameng Mining Industries Ltd.	Tiandeng	Mine and Smelter
	Guangxi Xin Manganese Group Co.	Xinzhen	Smelter
France	Eramet	Dunkerque	Smelter
	Glencore	Dunkerque	Smelter
India	MOIL, Ltd.	Balaghat	Mine
	Tata Ferroalloys	Joda	Smelter
	Sarda Energy & Minerals	Siltara	Smelter
South Africa	AssMang Ltd.	Cato Ridge	Smelter
	BHP Billiton	Metalloys	Smelter
	BHP Billiton	Mamatwan	Mine
	BHP Billiton	Wessels	Mine
USA	Eramet	Marietta	Smelter