Journal of Cleaner Production xxx (2015) 1–8

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Recycling of basic oxygen furnace steelmaking dust by in-process separation of zinc from the dust

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ARTICLE INFO

Article history:
Received 11 November 2014
Received in revised form
13 May 2015
Accepted 2 July 2015
Available online xxx

Keywords:
Recycling
Steelmaking dust
Basic oxygen furnace
Zinc
Separation
Blast furnace

ABSTRACT

High zinc content in solid wastes from basic oxygen furnace steelmaking offgas cleaning systems is one of the main barriers for source recycling of the solid wastes back into ironmaking and steelmaking process. Over-limit zinc loadings to blast furnaces might damage blast furnace refractory materials, and hence shorten blast furnace campaign life. In addition, high zinc input into blast furnaces might also cause operation difficulties of the blast furnaces, and thus decrease blast furnace productivities. Therefore, how to separate zinc from the solid wastes in an economic way becomes a crucial step for recycling of the solid wastes in sintering–blast furnace ironmaking process. There are three general strategies of separating zinc from the solid wastes, which are referred to as before-process separation, post-process separation and in-process separation. In-process separation is to separate zinc from the solid wastes in the process while the solid wastes are being collected. In this research paper, industrial trials are reported on measuring zinc distributions in dry offgas cleaning systems of two ArcelorMittal basic oxygen furnace steelmaking plants. The results show that primary dusts contain negligible zinc and have good qualities comparable with virgin iron ores. Therefore, in-process separation strategy has a potential to be applied in existing basic oxygen furnace steelmaking offgas cleaning systems to make cleaner offgas byproducts without revamping the offgas cleaning systems. However, in order to recycle more of the solid wastes with low level of zinc, it will be needed to install high-efficiency primary dust collectors and more advanced offgas pre-conditioning mechanisms prior to the primary dust collectors.

1. Introduction

Basic oxygen furnace (BOF) steelmaking plays a key role in steel production. According to United States Geological Survey (USGS) and World Steel Association, in 2013, basic oxygen furnaces produced 40% of the total steel in the United States (USGS, 2014) and 70% of the total steel worldwide (World Steel Association, 2014). However, along with the steel production, basic oxygen furnaces also generate tremendous amounts of BOF offgas (OG) solid wastes, which are carried out of BOF vessels by BOF offgas and collected by BOF offgas cleaning equipment. A dry BOF offgas cleaning system produces a dry BOF OG solid waste, referred to as BOF dust, while a wet BOF offgas cleaning system produces a wet BOF OG solid waste, referred to as BOF sludge.

Depending on operating conditions, such as raw materials, operation modes and steel grades, basic oxygen furnaces generate OG solid wastes at rather varying rates, from 3.7 to 31 kg per metric ton of liquid steel (kg/tLS) according to a survey of 41 participated BOF steelmaking plants by International Iron and Steel Institute (1994), and between 0.75 and 24 kg/tLS based on European Commission best available technique reference report (Remus et al., 2013). On average, the generation rate of BOF OG solid wastes is around 18 kg/tLS (International Iron and Steel Institute, 1994; American Iron and Steel Institute, 2001). In 2013, steel production was 87 million tons in the United States and 1582 million tons globally (World Steel Association, 2013). Accordingly, it can be estimated that in 2013 generation of BOF OG solid wastes was about 626,000 tons in the United States alone and 20 million tons globally.

BOF OG solid wastes are rich in iron, CaO and MgO, and could be recycled back into ironmaking and steelmaking process to replace costly virgin iron ores and limestone or dolomite. However, due to utilization of zinc-containing steel scrap in BOF steelmaking process, BOF dust and sludge often contain zinc. Zinc concentration in BOF OG dust and sludge is generally too high to recycle the dust and

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http://dx.doi.org/10.1016/j.jclepro.2015.07.009
0959-6526/

Please cite this article in press as: Ma, N., Recycling of basic oxygen furnace steelmaking dust by in-process separation of zinc from the dust, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.07.009

sludge in blast furnace ironmaking process, but too low to utilize the dust and sludge as raw materials for zinc recovery. For modern blast furnaces, zinc loading limits are generally set at 100–150 g per ton hot metal (Geerdes et al., 2004). Over-limit zinc loadings to blast furnaces might damage refractory materials of the blast furnaces, and hence shorten blast furnace campaign life. In addition, high zinc input into the blast furnaces might also cause operation difficulties of the blast furnaces, and thus reduce blast furnace productivities. Therefore, how to separate zinc from BOF OG dust and sludge in an economic way has become a critical step for retaining recyclability of the dust and sludge in ironmaking and steelmaking process.

As discussed in a previous paper, there are three general strategies in separating zinc from BOF OG solid wastes and they are referred to as before-process separation, post-process separation and in-process separation, respectively (Ma et al., 2012). Before-process separation is to eliminate zinc input into the BOF steelmaking process so that the BOF OG solid wastes would not be contaminated with zinc and the BOF OG solid wastes could be 100% recycled in sintering–blast furnace ironmaking process without facing zinc issues. This strategy largely depends on availability of inexpensive zinc-free steel scrap (Koros, 2003), which is harder and harder to obtain. When zinc-free steel scrap is not available on market, zinc-coated steel scrap will need to be dezinced by thermal removal (Fujio, 1992; Ozturk and Fruehan, 1996) or caustic leaching (Niedringhaus et al., 1992; Koros, 2003) or acidic leaching (Hödl et al., 2011). However, up to now, economic feasibilities have not been proven for any dezincing technologies (Ozturk and Fruehan, 1996). Therefore, before-process separation of zinc is hardly economically justified in general, especially when BOF steelmaking is running with a high consumption rate of purchased zinc-containing steel scrap (Ma, 2015).

Post-process separation is to separate zinc from the BOF OG solid wastes after the solid wastes already reach the ground state, i.e. zero speed, ambient temperature and stable constituents (Ma, 2014). Many post-process separation technologies have been discussed, developed and tested, such as carbonaceous thermal reduction separation with rotary kilns (Ruetten, 2006), rotary hearth furnaces (McClelland, 2002), electric arc furnaces (Fleischanderl and Daum, 2006), shaft furnaces (Bartels-vonVarnbüler et al., 2002) and multiple hearth furnaces (Roth et al., 2001). Separation of zinc from BOF OG solid wastes by acidic leaching has also been studied (Kelebek et al., 2004; Trung et al., 2011). This end-of-pipe separation strategy is often first considered when dealing with the issue of recycling BOF OG solid wastes. However, this strategy generally requires large capital investment, high operating cost and additional measures for environmental protection. As a result, utilization of the post-process separation strategy is generally not economic.

In-process separation is to separate zinc from the BOF OG solid wastes in the process while the BOF OG solid wastes are being collected. As a general strategy, in-process separation was previously discussed for recycling any solid wastes by separating unwanted components from the solid wastes in the process while the solid wastes were being generated (Ma, 2014). Advantages of in-process separation include utilization of process excess energy without requiring large amount of additional energy, enabling separation of unwanted components from the solid wastes by inserting or replacing separation equipment and adding operation without requiring construction of a standalone separation plant, and no need for additional environmental protection. In-process separation has also been discussed for beneficially solving issues of recycling blast furnace offgas solid wastes (Ma et al., 2009), electric arc furnace dust (Ma, 2011), basic oxygen furnace offgas solid wastes (Ma et al., 2012) and hot rolling mill scale (Ma, 2012).

In order to facilitate in-process separation of zinc from BOF OG solid wastes, two or more dust separators need to be installed in series in a BOF offgas cleaning system. BOF OG solid wastes collected by primary dust collectors contain less zinc than those collected by final dust collectors. Consequently, BOF OG solid wastes are separated in the offgas cleaning process into lower-zinc portions and higher-zinc portions. The lower-zinc portions of BOF OG solid wastes could be recycled in sintering–blast furnace ironmaking process if the zinc contents in the lower-zinc portions of the solid wastes are sufficiently low, and the higher-zinc portions could be recycled in zinc recovery facilities if the zinc contents in the higher-zinc portions of the solid wastes are sufficiently high. Compared to before-process separation and post-process separation, in-process separation has the advantages of less or no additional energy consumption, less capital investment and operating cost and no additional requirement for environmental protection (Ma et al., 2012; Ma, 2014). Exergy analysis of recycling electric arc furnace dust with in-process separation strategy demonstrated substantially higher exergy efficiency than other separation strategies (Suetens et al., 2014).

In-process separation is an evolutionary strategy. Industry has long acknowledged that coarse BOF OG solid wastes, accounting for about 10–30% of total BOF OG solid wastes generated, contain less zinc than fine BOF OG solid wastes and could be recycled in sintering–blast furnace ironmaking process (International Iron and Steel Institute, 1994). It is natural to inquire whether the lower-zinc fraction of BOF OG solid wastes can be increased to a larger extent and whether the zinc level in the lower-zinc fraction of BOF OG solid wastes can be further decreased to a negligible level. In a previous paper, it was suggested that installation of high-efficiency primary dust collectors might increase the ratio of lower-zinc BOF OG solid wastes to higher-zinc BOF OG solid wastes, and more advanced pre-conditioning of BOF offgas prior to the primary dust collectors might inhibit zinc contamination to the lower-zinc portions of BOF OG solid wastes (Ma et al., 2012).

In order to effectively separate BOF OG solid wastes into a lower-zinc part with a large quantity and a higher-zinc part with a small quantity using the strategy of in-process separation, it is indispensable to understand zinc distributions in existing BOF offgas cleaning systems, which has not been found in literature to the best knowledge of the author's. In this paper, test results on zinc distributions in two ArcelorMittal BOF offgas cleaning systems are reported and discussed. These two BOF steelmaking plants, abbreviated as X and Y plants, respectively, both are equipped with dry gas cleaning systems, and hence dry BOF OG dust is generated at these two steelmaking plants. Before the test work was conducted, BOF OG solid wastes generated in these two steelmaking plants had both been comingled and disposed of at landfills, causing tremendous amount of money losses and negative effects on environmental protection.

2. Materials and methods

2.1. Layout of BOF offgas cleaning systems

The two BOF offgas cleaning systems under study are schematically shown in Figs. 1 and 2. At X steelmaking plant, after dust-laden BOF offgas leaves a BOF vessel, the offgas is first cooled with atomized water in a duct. The offgas then enters a cooling tower where it is further cooled. Besides cooling, the cooling tower also serves as a dust collector. The cooled offgas travels along an offgas duct and is directed into three parallel three-field electrostatic precipitators (ESPs) where the offgas is finally dedusted. Therefore, at X BOF steelmaking plant, the cooling tower serves as a primary dust collector and the ESPs serve as final dust collectors.