Journal of Cleaner Production 101 (2015) 387–394

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Operational and environmental assessment on the use of charcoal in iron ore sinter production

Guilherme Correa Abreu [a, b], João Andrade de Carvalho Jr. [a, *], Bernardo Enne Correa da Silva [b], Rinaldo Henrique Pedrini [c]

[a] São Paulo State University, Faculty of Engineering, Guaratinguetá, SP, Brazil
[b] ArcelorMittal Tubarão, Environment Management, Serra, ES, Brazil
[c] ArcelorMittal Tubarão, Sinter Production Management, Serra, ES, Brazil

ARTICLE INFO

Article history:
Received 14 October 2014
Received in revised form
6 April 2015
Accepted 6 April 2015
Available online 15 April 2015

Keywords:
Sintering
Iron ore
Charcoal
Environmental impact

ABSTRACT

A study was carried out into the use of charcoal as a supplementary fuel in the iron-ore sintering process. The primary fuel was coke breeze and anthracite with 0, 10, 25, 50 and 100% replacement of the energy input with charcoal to produce sinter. This was achieved by considering the carbon content of each fuel and its corresponding participation on fuel blending, in order to have the same carbon input in each test run. An extensive analysis of the environmental impact was carried out regarding the atmospheric pollutants characterization (dust, sulphur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide, methane, total hydrocarbons, and dioxins and furans). Experimental results indicate that fuel blending where 50% of the heat input was provided by charcoal may be comparable with those using 100% coke, under normal sintering conditions, and may result in a 50% reduction on greenhouse gas emission. It was also observed that while dust, methane and hydrocarbons emissions increased, the total dioxins and furans, expressed as polychlorinated dibenzodioxins/furans, decreased approximately 50% when compared with operation with 100% coke.

1. Introduction

According to the IEA (2011), greenhouse gases (GHG) emissions from anthropic actions amounted to approximately 29.4 Gt in 2008 (20% of which from the industrial sector, that is, approximately 5.9 Gt). It is also estimated that the steel industry contributes nearly 5–7 % of the total global emissions, which means around 25–30 % of the industry share – whose main polluters also include the cement and petrochemical production sectors.

Brazil is included in this world scenario despite its peculiar characteristics, as a large portion of its greenhouse gas emission comes from the soil use and forest fires (MCT, 2009). The industrial sector, steel making included, is also partially responsible and has peculiarities inherent to Brazil as the production matrix includes solid renewable bio fuel and the largest part of the power production is done by hydroelectric plants.

The GHG emissions from an integrated steel production process, typically comprising the production of coke (by-products coke plants), sinter (continuous sinter plant), hot metal (conventional blast furnaces) and crude steel (basic oxygen furnaces – BOF), produce approximately 2.045 t of GHG per ton of steel (Fruehan et al., 2000). Coal combustion contributes with approximately 90% of the total energy related to GHG emissions by the steel industry (Jing et al., 2014). The combustion of gases generated in the blast furnaces and steel making correspond to 81% of total GHG emissions and are inherent to the current state-of-the-art production of steel, i.e., these emissions are unavoidable unless there are significant technological changes in the routes of production, which is estimated to be under industrial tests in 15–20 years (Birat, 2012; Cornelissen et al., 2012).

Recent research on CO_2 mitigation in the iron and steel industry includes the works by Yu et al. (2015), Wen et al. (2014) and Hasanbeigi et al. (2013) (for China), Morrow III et al. (2014) (for India), Moya and Pardo (2013) and Pardo and Moya (2013) (for EU27), Sodsai and Rachdawong (2012) (for Thailand), and Kuramochi (2015) (for Japan). Their scenarios go up to 2030. Their general evaluation was that energy conservation technologies can aid significantly in promoting CO_2 reduction.

Approximately 12% of GHG emissions from a steel making plant come from sintering process; thus, it is reasonable to investigate

* Corresponding author. Tel.: +55 12 31232838.
E-mail address: joao@feg.unesp.br (J.A. Carvalho).

http://dx.doi.org/10.1016/j.jclepro.2015.04.015
0959-6526/

alternatives for GHG emission reduction with broader evaluation concerning other pollutants behaviour on different tests conditions. In this context, it is important to investigate the partial replacement of the fuel mix used for charcoal produced from sustainable biomass, i.e., using wood from planted forests so that the process carbon cycle is neutral. Sodsai and Rachdawong (2012) acknowledge the importance of biomass combustion, which they consider to be the most attractive option for a country with abundant biomass supply.

The use of charcoal to produce sinter under specific conditions and environmental assessments involving the emission of sulphur dioxide, nitrous oxide and dioxins/furans has been investigated in previous works (Dell'Amico et al., 2004; Lovel et al., 2007; Ooi et al., 2011). The use of other types of biomass in iron ore sintering has also been studied experimentally (Zandi et al., 2010). The conclusion was that the replacement is possible from a technical and environmental point of view.

In general it can be stated that there is still a lack of previous research in the area, and this paper discloses results of an investigation on pilot-scale tests of replacing coke and anthracite with charcoal to reduce GHG emissions in sinter production. An extensive environmental assessment of its atmospheric emissions (dust, sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), total hydrocarbons (CHt), and dioxins and furans) is also reported. Up to 50% charcoal substitution showed to be viable, which means that, under normal sintering conditions, this may result in a 50% reduction on greenhouse gas emission. Also, the total dioxins and furans decreased approximately 50% when compared with operation with 100% coke.

2. The sinter production process

The sintering process is a well-established process in use at integrated steel making plants. It consists of an agglomeration through an oxidizing/reducing fusion of iron ore fines (sinter feed) and fluxing agents (lime, limestone, etc.) as well as re-circulated materials (dust, sludge, etc.) at temperatures between 1200 °C to 1400 °C. A carbon based solid fuel is added to this mix to supply the necessary energy to make process reactions happen. A scheme of the sinter production process is shown in Fig. 1.

The process is complex and involves several physical and chemical phenomena. The raw materials used can vary to a wide extent, from iron ore to dust recycling (Castro et al., 2005). The process takes place in a moving strand with such configuration to transport the mix to the upper part until the end of the process, and returning in sequence to the lower part. The mix and water are continuously charged to form a thick bed of approximately 400 mm–600 mm, positioned over a pre-layer of sintered material of 30 mm–50 mm high. This pre-layer helps to keep the mix from going above the grooves between the grates and also to protect them from the heat generated in the process.

The combustion of solid fuel begins at the top of the layers, and, as it moves, a relative narrow band of ignition zone moves down through the bed. Several chemical reactions and phase transformations take place within the bed, part of the materials melts when the local temperature reaches the melting temperature and as it moves, the solidification process occurs. The partial melting and diffusion within the materials causes the particle to agglomerate forming a continuous porous sinter cake.

The sinter, the final product in the sintering process of agglomerating iron ore, is mainly used as part of the metallic charge to be reduced in the blast furnaces. The sinter for blast furnaces is a porous product whose granulometry varies from 5 mm to 50 mm and must have the desired properties for its use associated to an adequate production cost for the business.

As process fuel, coke fines (<5 mm) are largely used; the partial use of anthracite in the coke mix also brings good results. The economic factor, resulting from the oscillation in the prices of coke and anthracite are the strongest determinants of the use of one instead of the other, or even the fraction of each one to be used. Based on the results found at the pilot scale tests, the use of charcoal is possible and it is the scope of this paper.

3. Materials and methods

3.1. Sinter pilot unit

The pilot-scale tests were carried out in a sinter pilot unit that includes an ignition furnace, a sinter pot and ancillary equipment as shown in Fig. 2.

The sinter pot has a height of 400 mm high and a diameter of 300 mm. Two thermocouples are installed, one at the sintering layer height of 150 mm (T1) and the other at 250 mm (T2). There is a third thermocouple at the exhaust gases outlet (T3). The tests were carried out using a mixture for the bed of approximately 60 kg (wet basis) and 2 kg used in the lining layer made of < 5 mm sinter. The aimed moisture in the mix was 6.5%. Mix average granulometry varied between 2.28 mm and 3.32 mm, while the average fraction >1 mm was 63%.

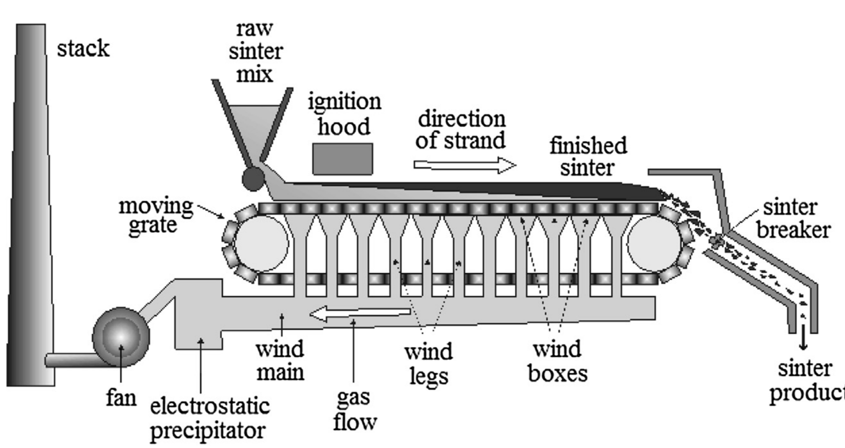

Fig. 1. Scheme of the sinter production process.