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Analyzing cleaner alternatives of solid and gaseous fuels for iron ore sintering in compacts machines

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ABSTRACT

The steel industry has faced challenges with regard to the raw materials and fuels and hence economic and environmental restrictions. This paper is focused on searching alternatives based on biomass and gaseous fuels suitable for replacing the coke breeze fossil fuel. Nevertheless, testing these technologies are expensive. Therefore, comprehensive mathematical models based on transport phenomena are efficient tools to study and indicate new possibilities for designing operational conditions as well as resizing the machines for minimizing the hazardous emissions. We proposed new concept of operation combining gaseous fuels and biomass for partially replacing the coke breeze in a compact sintering machine. Thus three possible ways for 20% of the amount of coke breeze replacement are analyzed in a combined manner: a) replacement by steelmaking mixing gas, b) replacement by biogas and c) replacement by pellets of biomass. The results indicated that about 20% of the solid fossil fuels could be replaced by waste solid residue of biomass (processed as small pellets). For the analyzed cases, the productivity increase of 5% for the steelmaking mixing gas, 15% for the biomass pellets and 25% for the biogas fuel. For all cases considered it was predicted a decrease of the amount of hazardous compounds emissions.

1. Introduction

The steel industry is considered as a carbon and fossil energy intensive industry. About 80 kg of fossil coal per ton of product are consumed at the operation units for raw materials preparation. At the sintering machine only about 50 kg of fossil fuel per ton of sinter are used. Thus, new technologies are welcome with the focus of neutralizing the carbon emissions. The iron ore sinter process is an important operation unit in the integrated steel plant. This step plays an important role at the steel plant, furnishing suitable raw materials for the blast furnace, and usually is responsible for recycling the inner fine dust produced within the whole steel-making facilities. The size and capacity of the sinter machines vary widely and are mainly limited by the design and capability of the air suction systems. Larger machines, however, present small ability to handle low-grade raw materials although high-energy efficiencies are usually obtained. The small and compact machines are increasingly becoming attractive due to their ability to use different source of raw materials and low-grade iron ores (Castro et al., 2013a, b; Naglaa et al., 2015).

The traditional sinter plant is composed of raw materials preparation, blowing and suction system, sinter strand, cleaning gas, cooling and sinter product classification. Fig. 1 shows a schematic view of the sinter facilities proposed for a new concept of operation integrated with a steel plant combining a large and small blast furnaces. In Fig. 1 the micropelletizer and the auxiliary systems are drawn. The raw materials are received at the dosage system and depending on the product formulation, the materials are fed into a bed and sent to a mixer and micropelletizer, where additives are adjusted. The micropelletizer system is equipped with a screening system that allows the control of the size of the materials charged in the sinter bed. The sintering bed is composed of a hearth sinter layer and the micropellets are charged at the bed

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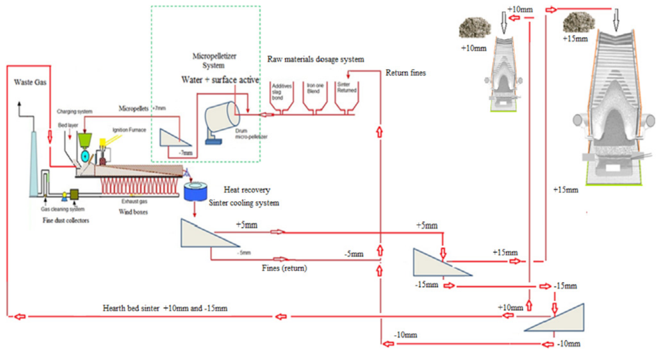

Fig. 1. Flowsheet proposal for new operation system of compact iron ore sintering facilities.

uniformly. The Fig. 1 is an actual tested proposal in a steel industry. Actually, this process furnish sinter for two blast furnaces. A large blast furnace and a mini one. This allows the use of variable size of sinter product. The sinter of size over than 5 mm is transported for the large blast furnace screening system and before charged is screened where the size over 15 mm is sent to the large blast furnace charging system while the size between 10 and 15 mm are used as hearth layer and the excess are furnished for the small (mini) blast furnace of about 280 m^3. The remained fine materials (less than 5 mm) are charged as returned material for the raw materials dosage system. A typical materials distribution in the original operation (without using micropelletizer and additional screening system) used to be about 20% as hearth bed layer and 15% as fine return to dosage system. The operation with this new proposal has operated with a new material flow distribution, using the outlet strand production as reference, as follows: 10% for hearth bed layer material (10–15 mm), 15% of materials less than 5 mm returned to the dosage system, 20% as product of size between 10 and 15 mm and the remained 55% as sinter product larger than 15 mm. This new distribution was possible due to a better control and larger size charged to the bed of the sinter machine allowed by the new pelletizer system. Thus the new facilities allowed important gains in both, sinter process and blast furnaces charging control. This is possible due to the flexibility offered by the combination of large and mini blast furnaces demand. It is worthy to mention that for all the operation discussed in this study the drum index attained the large and mini blast furnace requirements. Therefore, the sinter product resistance was not a concern.

The product gas and air are sucked and passed through a gas cleaning system with electrostatic precipitators and filters before being discharged to the environment. New challenges concerning the outlet gas recycling have been proposed and this paper considers these possibilities as analysis cases to partially reuse the outlet gas of specific wind boxes. Another possibility is the partial replacement of the solid fuels by steelmaking gas such as blast furnace and coke oven gases. This paper explores analysis cases where this technology is considered. Finally, solid fuels replacement by small pellets of biomass produced from fines of charcoal and wood processing are considered. For all cases, however, the need of process adjustments are required. The main process parameters to be controlled are the temperature profile developed and the bonding phases formed, which are aimed at reaching smooth operation with suitable sinter parameters quality such as reducibility and tumbler index. Also a concern are the main hazardous substances and particulates that are produced depending on the operational and raw materials used (Castro et al., 2013a, b; Xu et al., 2018).

In this study, the ignition furnace is modified and enlarged dividing ignition and gas burnout zones in order to allow gas fuel utilization and oxygen injection into five wind boxes length aiming to increase the sinter machine efficiency and decrease the specific emissions.

The burner furnace is adapted to have two zones: a) Ignition zone using natural gas and b) Gas burner zone using steelmaking or biogas with oxygen enrichment. This concept is suitable for designing different gas utilization systems. The feeder system is adapted to have height control and allows bed adjustments with uniform distributions.

Many efforts have been made to develop new technologies aiming at the decrease of the fossil fuels utilization due to the environmental restrictions and also the decrease of the process carbon intensity (Oyama et al., 2011, Guilherme and Castro, 2012). The process is complex and involves various physical and chemical phenomena such as heat, mass and momentum transfer coupled with chemical reactions (Yamaoka and Kawaguchi, 2005; Castro et al., 2012a, 2012b, 2013a, b, Ahan et al., 2013, Kasai et al., 2005). These phenomena take place simultaneously, increasing considerably the complexity of process analysis. Thus, an effective way of developing new concepts and their quantification is the development of comprehensive mathematical models able for handling simultaneously: (a) the mass transfer using reliable rate equations for the chemical reactions, (b) momentum transfer for complex bed structure and (c) interphase heat transfer considering simultaneously convective, radiation and chemical reactions heat transfer.

The proposal of this study is to adapt the actual sintering machine to improve the flexibility of the process and allow simultaneously operation with gas recycling, fuel gas utilization, operation with partial operation of mill scale and biomass together with fossil fuels as coke breeze or anthracite. The purpose of this study is to demonstrate the feasibility of using waste biomass from the charcoal technology processing and wood industry by using a micropellets agglomeration and partial replacement of the coke breeze, which has a strong impact on the environmental performance of the iron sintering. This has only a delicate restriction for the actual operation on the integrated steel industry. The demonstration of the feasibility of the proposed technology leads to important improvement on the steelmaking plant. This technology is considered a potential green house mitigation and/or cleaner production. The main focus of the present study therefore is to analyze and propose new design and operational conditions suitable for use in steelmaking by adapting the compact sinter machine in a combined manner, with the pellets of biomass produced using dried and torrefaction processes and recycling gas.

2. Methodology

2.1. Model formulation

The iron ore sinter process takes place at a moving strand where air is sucked through the bed transversely while the strand moves. The phenomena that occur within the bed are complex and involve several chemical reactions. A model able to simulate the inner bed have to consider the macroscopic phenomena of heat, momentum and mass transfer with the rate equations experimentally determined. Thus, in this work a mathematical model based on a set of partial differential equations representing the conservations of momentum, energy and chemical species for gas, solid (raw material mix and solidified liquid) and melting phases is presented and applied for simulating the inner bed features. Similar approaches have been used by several authors, with particularities for the detailed mechanisms adopted and the focus of the model development (Cumming and Thurlby, 1990; Mitterlehner et al., 2004; Castro et al., 2012a, b; Ahan et al., 2013; Guilherme and