NEW IRON ORE SINTERING TECHNOLOGY BASED ON BIOMASS AND OXYGEN INJECTION*

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Abstract

In this paper a new technology for a compact iron ore sintering machine is analyzed. The compact sintering process is based on the massive injection of gaseous fuels and the solid fuel is only agglomerated fine charcoal obtained by biomass. The solid fuel used in this study is obtained by agglomeration of fine charcoal produced from elephant glass which has very short period for production and CO2 capture(less than 6 months in tropical climate). To overcome the lower heat supply into the combustion front of the sintering process the simultaneous injection of oxygen and gaseous fuel is proposed. The proposed methodology is to combine the solid fuel (agglomerated fines charcoal) and steelworks gases in a compact machine to enhance heat and mass transfer with high productivity (about 5 times the conventional large machine). A multiphase mathematical model based on transport equations of momentum, energy and chemical species coupled with chemical reaction rates and phase transformations is used to analyze the inner process parameters. A base case representing a possible actual industrial operation of the sintering machine is used in order to compare different scenarios of practicable operations which represents advanced operations techniques. The model was used to predict six cases of combined operation with biomass and fuel gas utilization with oxygen support.

Keywords: Compact sintering process; Mathematical modeling; Bio-fuels; Gas injection.

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1 INTRODUCTION

The sintering process has attain several improvements in the recent years mainly due to changes on the materials resources available. At the present days, the reduction of CO_2 emissions has become an urgent issue in the steel industry as countermeasure for greenhouse emissions. It is estimated that nearly 60% of the steel industry emissions are attributed to the pig iron production operation units, which includes sintering and blast furnace processes, and only the sintering process represents around 20% of this amount [1-5]. Therefore, sintering and blast furnace processes offer good opportunities to decrease the CO_2 emissions since small decrease of the coke breeze rate and bonding agent used in iron ore sintering process could decisively contribute to the environment [6-10]. Thus, alternative sources of energy with lower environmental impact or the replacement of the coke breeze by inner gaseous fuel are attractive to technologies to enhance the iron ore sintering process. One alternative for developing cleaner sintering process is to replace coke breeze by fines charcoal produced by biomass such as elephant glass. However, the temperature distribution and the residence time of the materials at the higher temperature zone is lower, which may deteriorates the sinter quality. To overcome this phenomena, the gaseous injection combined with oxygen is proposed [7-9]. The concept of gaseous injection into the sintering bed has been successfully applied and enhancement of the sinter properties related with reducibility and strength have been observed, in addition to drastically decrease of the return sinter(<5mm) [11,12]. One of the important features of the sintering strand is regard as the heat supply on the top region of the sintering layer, which implies in a non uniform sinter product. aiming to avoid this phenomenon, additional injection of oxygen to early burnout the gas has been proposed [9,12]. In this context, the present work aims to apply a comprehensive multiphase multi component mathematical model to analyze the sintering process based on the biomass with the energy support of gaseous fuel and oxygen into the first 15 wind boxes of a total of 23, which correspond to the sintering zone. The cooling zone is decreased by higher suction of rum temperature air. Thus, the model is used to quantify the impact of this newly proposed technology on the sintering process of iron ore. This work represents a step forward in the development of the process by proposing a new technology which combine the high rates of heat supply in a compact strand machine with very high productivity compared with the traditional technology. This study follows similar purpose which has been tested into pot test experiments and industrial trials and therefore a comprehensive model can reveal the inner conditions compatible with optimum sinter quality since optimized and uniform thermal history can be design along the sinter bed.

2 MATERIALS AND METHODS

In this paper a model to predict the sintering process of an industrial compact machine is proposed based on a multiphase, multi-component transport equations of momentum, mass and energy for gas, solid and liquid phases. The model is stationary, tridimensional and considers the phases interacting simultaneously with the chemical species of each phase calculated based on the chemical species conservation equations linked by the rate equations for the chemical reactions and phases transformations. The model concept and phase interactions are shown in Figure 1. The model is based on conservation equations for mass, momentum

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energy and mass fraction of chemical species of gas, solid phases: sinter feed, fine sinter (returned fine sinter<5mm), coke breeze (or charcoal), scales (fines of steel plant), fluxes and limestone [2-9].

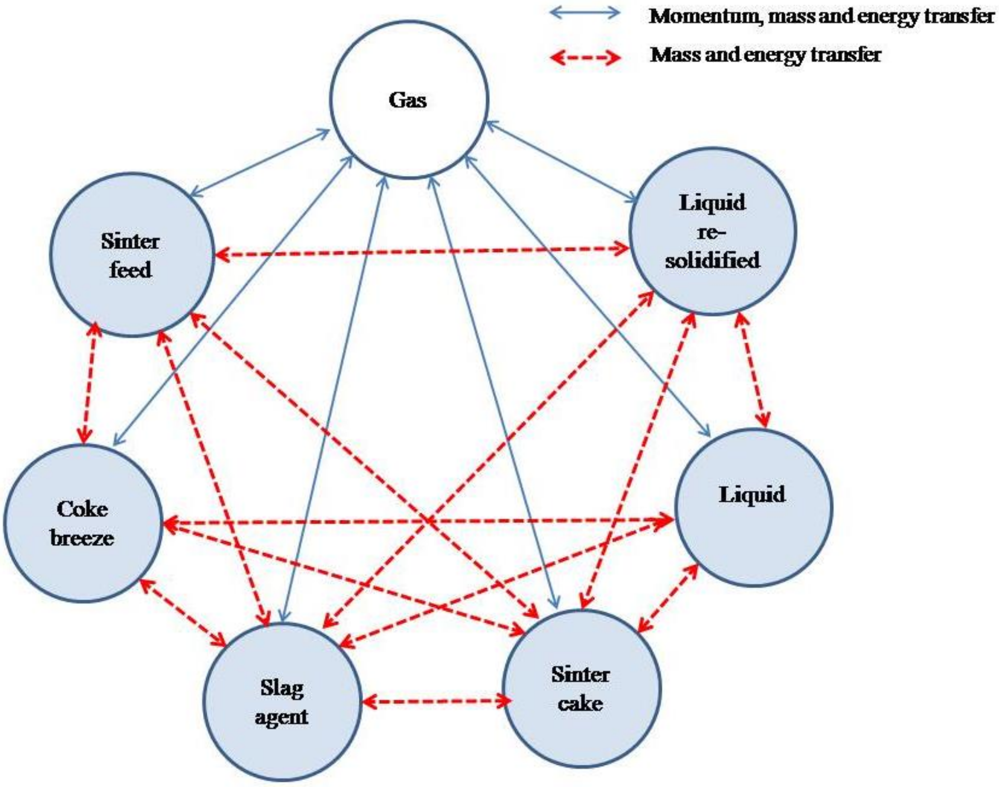

Figure 1. Phases interactions considered in this model

In the present model it is assumed that the liquid phase formed will move together with the remaining solid phase due to the viscosity and considering that the liquid are formed attached on the surface of the unmelted particles, thus, equations for momentum transfer and enthalpy of the solids will account for this mixture of viscous liquid and solid materials. The thermo physical properties used on the mathematical model are assumed to obeys the mixture rule accounting for the individual phase properties pondered by the phase volume fractions [10,11].

The equations for momentum, energy and chemical species are as follows [2-10]:

Momentum:

$$\frac{\partial\left(\rho_i\varepsilon_i u_{i,j}\right)}{\partial t}+\frac{\partial\left(\rho_i\varepsilon_i u_{i,k}u_{i,j}\right)}{\partial x_k}=\frac{\partial}{\partial x_k}\left(\mu_i\frac{\partial u_{i,j}}{\partial x_k}\right)-\frac{\partial P_i}{\partial x_j}-F_j^{i-l} \tag{1}$$

Continuity:

$$\frac{\partial\left(\rho_i\varepsilon_i\right)}{\partial t}+\frac{\partial\left(\rho_i\varepsilon_i u_{i,k}\right)}{\partial x_k}=\sum_{m=1}^{Nreacts}M_n r_m \tag{2}$$

Enthalpy balance:

$$\frac{\partial\left(\rho_i\varepsilon_i H_i\right)}{\partial t}+\frac{\partial\left(\rho_i\varepsilon_i u_{i,k}H_i\right)}{\partial x_k}=\frac{\partial}{\partial x_k}\left(\frac{k_i}{C_{p_i}}\frac{\partial H_i}{\partial x_k}\right)+E^{i-l}+\sum_{m=1}^{Nreacts}\Delta H_m r_m \tag{3}$$

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The chemical species are individually considered within the phase, for gas, or components of the solid or liquid phases as presented in Eq. 4. Detailed chemical reactions and rate equations describing the in bed conditions of iron ore are found elsewhere [2-10].

$$\frac{\partial(\rho_i \varepsilon_i \phi_n)}{\partial t} + \frac{\partial(\rho_i \varepsilon_i u_{i,k} \phi_n)}{\partial x_k} = \frac{\partial}{\partial x_k}\left(D_n^{eff} \frac{\partial \phi_n}{\partial x_k} \right) + \sum_{m=1}^{Nreacts} M_n r_m \tag{4}$$

For the Equations. (1)-(4) the indexes *i* and *l* represent the phases, *j* and *k* are the indexes for coordinates component direction *n* is chemical species and *m* the indicator of the reactions, M is the molecular weight of the species, *P* is phase pressure, *F* is component of momentum interactions among the phases and *r* is the rate of chemical reactions. ρ,ε,Cp, k and ∆H are phase density, volume fractions, heat capacity, heat conductivity and heat due to chemical reactions, respectively. The quantity $E^{i\text{-}l}$ is the heat transfer among the phases and accounts for convective and radiation heat transfer. The gas -solids momentum interactions are represented by $F^{i\text{-}l}$. The differential equations, Equations (1)-(4), which represents the phenomena within the sinter bed, are solved using the boundary conditions accounting for the process of gas suction and solid feeding, as well as, the heat losses to the environment by convections and radiation.

Table 1. Chemical analysis of the fuels used for the cases analysis

<table>
<tr><td></td><td colspan="2">C(fixed)(%)</td><td colspan="2">Volatiles(%)</td><td>H_2O(%)</td><td colspan="2">SiO_2(%)</td><td>Al_2O_3(%)</td><td>CaO(%)</td></tr>
<tr><td>Solid fuel (charcoal)</td><td colspan="2">68.25</td><td colspan="2">23.00</td><td>5.00</td><td colspan="2">0.10</td><td>1.00</td><td>2.65</td></tr>
<tr><td colspan="10">Gaseous fuels</td></tr>
<tr><td>Blending(%)</td><td>CH_4</td><td>C_2H_6</td><td>C_3H_8</td><td>C_4H_{10}</td><td>CO</td><td>CO_2</td><td>H_2</td><td>H_2O</td><td>O_2+N_2</td></tr>
<tr><td>Case 02</td><td>5.25</td><td>0.15</td><td>-</td><td>0.012</td><td>0.10</td><td>-</td><td>-</td><td>-</td><td>94.49</td></tr>
<tr><td>Case 04</td><td>0.25</td><td>0.25</td><td>0.80</td><td>0.50</td><td>1.00</td><td>0.41</td><td>2.09</td><td>0.21</td><td>94.49</td></tr>
<tr><td>Case 06</td><td>0.21</td><td>0.80</td><td>0.25</td><td>0.25</td><td>2.00</td><td>1.02</td><td>0.78</td><td>0.20</td><td>94.49</td></tr>
</table>

Note: Blending obtained by mixtures of natural gas, coke oven gas, blast furnace gas and oxygen

The numerical solution is obtained by using the finite volume method based on the power law scheme to compute the algebraic coefficients and the SIMPLE (Semi Implicit Method for Pressure Linked Equations) for solving the velocity components and pressure simultaneously [13,14].

The raw materials used in this study are composed of sintering mix from the micro pelletizer circuit and the return sinter to form the bedding layer. The fuels are formed with the solid fuel(charcoal, coke breeze or anthracite) and in this study, a mixture of fuel gas is used. Table 1 presents the fuels used in the cases analyzed in this study.

3 RESULTS AND DISCUSSIONS

In this study three cases of possible operational conditions are compared with a base case which represents an actual operation of the industrial machine. The calculated results presented in this study where selected with the aim of identifying cases of high gas utilization and drastic decrease of solid fuel rate. Table 2 presents a summary of the global parameters calculated and compared with the base case. As can be observed the fuel rate of the fines charcoal is replaced by the gas fuels and

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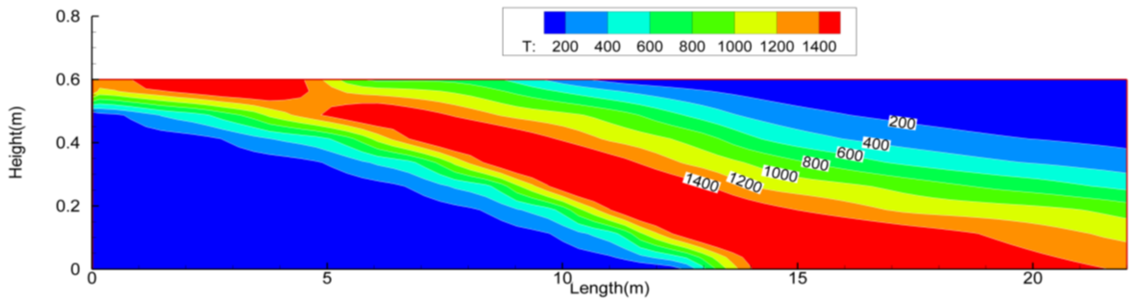
the overall specific carbon emissions is decreased around 45% which represents great improvement on the cleanness of the sinter process,

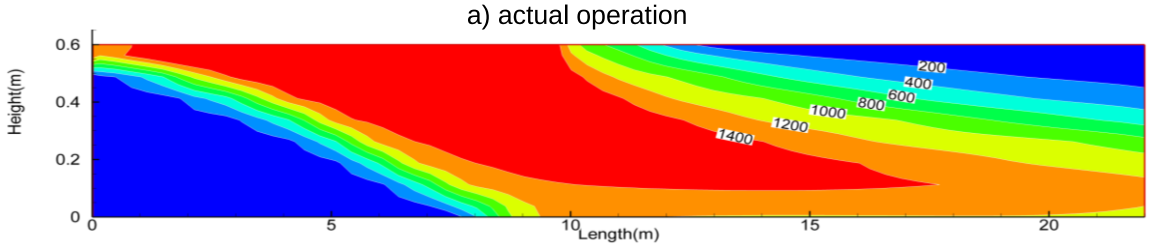
Table 2. Predictions of process parameters for the cases considered in this study

Parameters	Cases			
	Base	#01	#02	#03
Productivity (t/h)	255.13	279.30	288.16	295.64
Solid fuel (charcoal) (kg/t)	81.49	45.10	34.13	23.58
Gas fuel(kg/t)	0.00	18.47	23.95	44.41
Pressure drop(-kPa)	10.65	19.99	24.75	49.46
Calcium ferrites(%)	29.79	28.05	30.37	23.50
Liquids (%)	99.77	99.82	95.40	98,15
Sinter average size (mm)	45.12	44.23	43.96	47.68
Return sinter (<5mm) (%)	32.00	26.10	21.50	28.80
Carbon emission(kg/t)	95.95	74.19	57.83	48.94

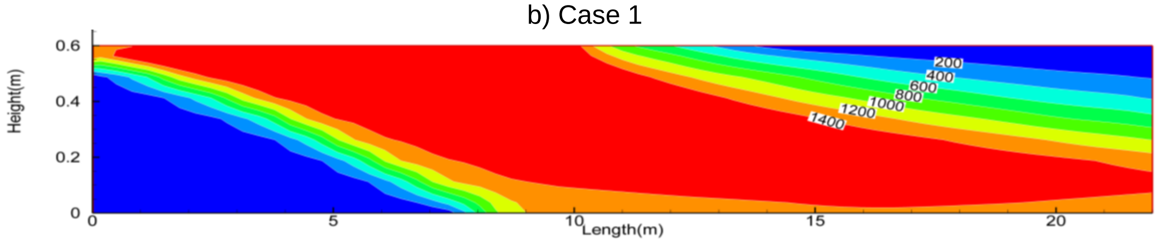
Note: sinter strand dimensions: 3.4 x 22 m: bed height 0.60-0.70 m: working area = 74.80 m^2



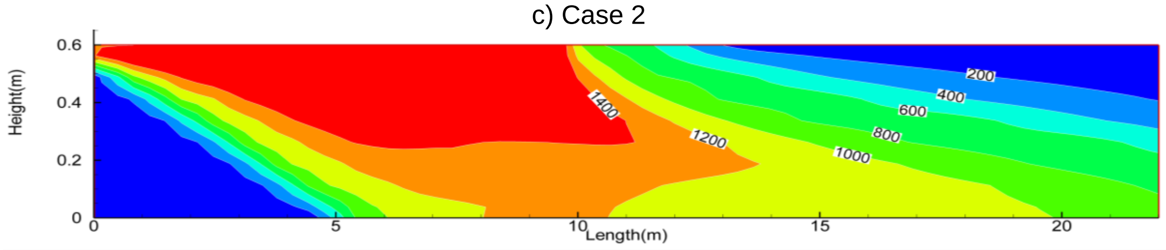
a) actual operation



b) Case 1



c) Case 2



d) Case 3

Figure 2. Inner temperature distributions for the analyzed cases compared with the actual operation

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4 CONCLUSIONS

In this study a new operational technology for the iron ore sinter process is presented. This technology is analyzed using a comprehensive mathematical model which takes into account inner phenomena of the sinter bed. Predicted results indicated that the solid fuel rate could be decreased around 75% while specific carbon emissions could be decreased to around 45%. Inner temperature distributions of the sinter bed predicted by the model indicated similar pattern with the actual process operation.

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