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Sinter strength evaluation using process parameters under different conditions in iron ore sintering process ☆

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ABSTRACT

There exists internal connection between the process parameters and real sinter quality in the sintering process. However, few investigations on bridging the process parameters and real sinter quality for engineering applications were reported. For example, only process parameters (flow resistance, heat condition of sintering bed and off-gas composition) can be obtained by numerical method in the previous studies. Actual sinter strength and reducibility can't be captured due to lacking of reliable models and the limited computing resource. This paper focused on solving the problem, which was substantial for parameters optimizing in both numerical simulation and on-line control of sinter quality. The melt quantity index (*MQI*), combining the peak temperature and duration time of melting temperature (*DTMT*), was used in this study. We also explained its physical significance as the effective "energy" for melting phase formation. Then the corresponding relation between *MQI* and sinter yield was widely confirmed by our own experimental data and the reproduced data from published references. Consequently, the *MQI* was recommended as a wise indicator of real sinter strength. The effects of three operating parameters (fixed carbon content, sintering pressure and fuel reactivity) on sinter strength were investigated by examining the *MQI*, sintering speed and air flowrate. Besides, the influencing mechanism of two important performance parameters (combustion and heat utilization efficiencies) on *MQI* was clarified. The monitoring of the above parameters would provide a powerful support for the transparency of sintering process "black-box" and optimization of operating parameters. Finally, a conceptual design for the on-line control of sinter strength was even proposed based on the present results.

1. Introduction

The integrated iron and steel industry is the most energy-intensive sector, accounting for 10–15% of the total energy consumption in the world [1]. In 2009, the CO_2 emission from Chinese iron and steel sector is nearly equal to 50% of the world's steel industry's CO_2 emission [2]. It is aimed at converting iron ore fines to suitable feed for efficient iron-making in the blast furnace using agglomeration technology. The process is complex and involves various physical and chemical phenomena such as momentum, heat and mass transfer coupled with combustion, melting, solidification, evaporation and condensation. Within the descending narrow flame front, the melting and coalescence of iron ore fines occur. After cooling and solidification, sinter cakes with better gas permeability are obtained. Lu [3] described the detailed process of sintering. Producing sinters of suitable quality at the lowest fuel rate and the highest productivity is the ultimate goal of most operations. Therefore, various fundamental researches and new technologies have been investigated by numerical and experimental methods in the last decade.

Yang et al. [4] verified their numerical model and examined the effects of coke content, air supply and fuel type on peak temperature, melting zone thickness and flame front speed. Zhou et al. [5] improved the previous model by considering detailed reactions, melting and solidification sub-models. Then sensitivity analyses results [6] showed that the bed bulk density, solid and gas thermal capacities, coke level and size and post-ignition air flowrate had large influences on flame front speed and heat pattern. And in their subsequent work [7], the computational model was further improved by integrating the granulation impact and two endothermic reactions into the heat treatment model. Zhou et al. [8] numerically investigated the feasibility of utilizing spent ion exchange resin (SIER) in iron ore sintering process. The authors established

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Nomenclature

c	specific heat capacity in constant pressure, J kg^{-1} K^{-1}
T	temperature, °C
v	gas velocity, m s^{-1}
y	coordinate direction, mm
W	work, J
f_0	friction force, N
F	pulling force, N
P	position of object
s	displacement, m
DTMT	duration time of melting temperature, s
FFS	flame front speed, m s^{-1}
MQI	melt quantity index, °C s
HTFS	heat transfer front speed, m s^{-1}

Greek symbols

τ	time, s
ε	porosity
ρ	density, kg m^{-3}
η	heat utilization efficiency

Subscripts

p	peak
m	melting
g	gas
s	solid

a 3-D model to examine the thermal conditions at different mass fractions of spent ion exchange resin (SIER). Nath and Mitra [9] carried out the mathematical modeling and optimization of two-layered sintering process for sinter quality and fuel efficiency using genetic algorithm. Pahlevaninezhad et al. [10] numerically investigated the sintering process by comprehensively considering the chemical reactions in gas and solid phase. A wide range of parameters, including coke and limestone size, inlet air velocity and coke content were carefully examined. Mitterlehner et al. [11] developed a simulation model of the sintering process with special focus on the propagation velocity of the heat front through the bed. The effects of program-internal and user provided parameters were evaluated using this model. Ahn et al. [12] proposed a modeling approach for a sintering bed using flowsheet process simulator as the starting point for studying the effect of flue gas recirculation on the sintering process. In the companion paper [13], the details of the modeling cases and the corresponding results were reported. The above simulation investigations adopted porous medium model, ignoring the single particle behavior and different particles interaction. The detailed processes of melting and coalescence were also neglected due to the limited computing resource and inaccurate mathematical model. As a consequence, the sinter strength can't be captured in the simulation. At the current stage, simulation method can only model the heat transfer, mass transfer and combustion phenomena as an auxiliary means of experimental test. If a reliable and convenient method bridging the process parameters (such as thermal and combustion performances) and real sinter quality indices is developed, simulation work would play a much more important and extensive role on optimizing the operating parameters and predicting the performance at extreme conditions. However, a small amount of work on solving the problem has been reported.

There is another typical problem bothering the operators for a long time. When the sintering process progressed, the solid fuel burning and water evaporation increase the porosity and improve the oxygen supply and bed permeability. Moreover, the increasing preheating time improves the combustion and heat utilization efficiencies. In the conventional case, the above changes will lead to an imbalance of heat distribution which is inevitable, as shown in Fig. 1(a). For example, insufficient heat in upper bed results in low sinter strength and excessive heat in lower bed leads to the energy waste. In the ideal case, heat distribution should be optimized to produce uniform sinters, as shown in Fig. 1(b). Segregation of solid fuels and charging condition were investigated with the aim at improving the heat distribution in sintering bed [14]. Zhou et al. [15] proposed a novel technique, three-layered bed structure, to study the effect of coke level, properties and combustion behavior on NO_x emission. In order to maximize the combustion efficiency and optimize the heat distribution, the effect of additional oxygen supply with an adjustment of injection position was discussed [16]. The gaseous fuel injection technology was developed [17], which provided a secondary combustion area above the original combustion area to produce high quality sinter without increasing the fuel consumption. Castro [18] carried out the numerical investigation on gaseous fuel injection technology. On this basis, Iwami et al. [19] employed the oxygen enrichment method with an aim at controlling the position of secondary combustion area. Adding fuel externally to the raw ores was adopted and found to be beneficial to fuel combustion in both lab-scale sintering pot [20] and commercial sintering plant [21]. Loo and Wong [22] developed a laboratory sintering technique. Then based on the new technique, the effects of bed height, limestone, the level of return fines, mix moisture and suction on sintering behavior were examined [23]. Zhou et al. [24] studied the influence of flame front on sintering production and quality. Abreu et al. [25] adopted charcoal as supplementary fuel in the iron ore sintering process. The results indicated that the blend with 50% charcoal in the fuel mix was possible from both environmental and operational perspectives. However, the inaccuracy and hysteresis of manual adjustment of fuel segregation, fuel particles size, fuel distribution and even external operation are not able to satisfy the future automatic management of sinter production. Actually, on-line control is a perfect alternative method to solve this problem. It is noted that,

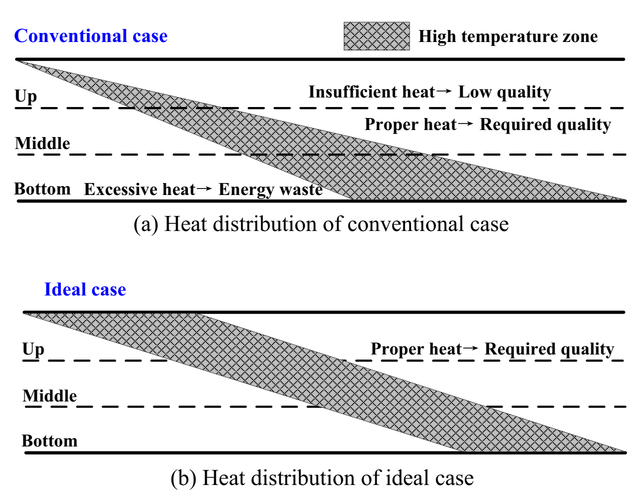

Fig. 1. Comparison of heat distribution of conventional case and ideal case.