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Experimental Study on Characteristics of Flame Front in the Iron Ore Sintering Process

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The combustion of solid fuel supplies heat in an iron ore sintering bed. The quality and productivity of the process are strongly dependent on the descending flame front. In this paper, sintering pot experiments are carried out to characterise the detail information of flame front in the sintering bed. The temperature-time profiles at different axial positions of the bed are measured continuously using thermocouples. Quantitative parameters are analysed on the basis of the temperature-time profiles, including peak temperature, duration time of high temperature (DTHT) and flame front speed (FFS). As the sintering process progresses, the trends of local peak temperatures, DTHTs and FFSes in height direction are observed, and the differences are reasonably explained. Moreover, higher coke content results in higher peak temperature, longer DTHT and lower FFS. However, higher suction pressure leads to lower peak temperature, shorter DTHT and higher FFS.

1. Introduction

Iron ore sintering is a process by which iron ore fines are agglomerated with other fine materials at high temperature, to create a single porous product that can be used to convert into iron in a blast furnace, without much change in the chemical properties of the ingredients. It is an extremely complex process due to the large number of physical and chemistry reactions, such as combustion, redox reactions, evaporation, condensation, melting and so on. The combustion of solid fuel supplies heat in an iron ore sintering bed. The sintering productivity and quality are highly relied on the flame front propagating downwards in the sintering bed. To increase the efficiency of the sintering process, masses of works have been carried out with the view to lower fuel consumption while maintaining sinter quality and productivity for several decades in the steelmaking industry and metallurgical research centers, as well as in universities all over the world. For example, the effect of fuel substitution by less expensive anthracite coal (Won et al., 2006) on iron ore sintering was evaluated. The lower peak temperature and slower sintering speed were observed. Ooi et al. (2011) revealed that biomass substitution skill could increase productivity, while maintaining the quality at low substitution amount; however the sintering performance weakened at very high substitution amount. Optimum coke segregation and charging condition for sintering operation were investigated with the aim of controlling the temperature of the sintering bed (Machida et al., 2009). However, a handful of experimental and numerical work was conducted to investigate the fundamental factors determining the sintering behaviours. The major resistance during sintering is from the flame front, while raising flame front temperature and thickness greatly increases airflow resistance(Loo et al., 2003) and leads to increased sintering time and reduced productivity (Loo et al., 2012).

Very limited temperature-time information (the determining factor of sintering "black box") in the height direction was recorded in these experiments. Most work in the past has been performed to find the relationships between input (operating parameters) and output (sintering performance) of the sintering "black box", rather than to get direct information and explain the process. In this paper, in order to have a better understanding of sintering "black box", the key parameters of flame front are extracted and analysed based on eight temperature-time profiles in different axial positions. The peak temperature, DTHT and FFS

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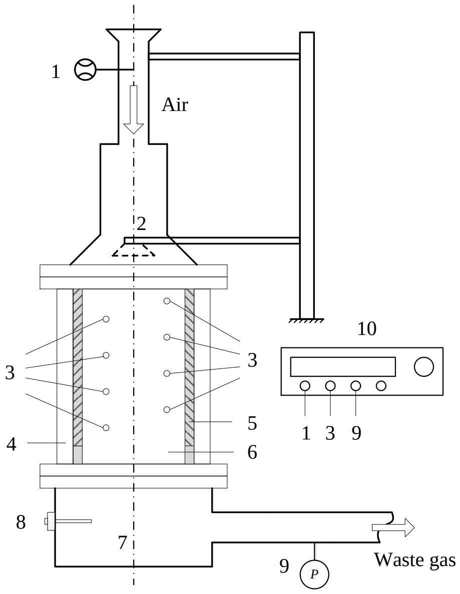
are carefully compared, and the differences are tried to explain in a view of heat and mass transfer. In addition, the effects of suction pressure and fixed carbon content on the local changes are also examined.

2. Experimental method

2.1 Introduction to experimental device

The experimental setup is illustrated in Figure 1. Eight S-type thermocouples are positioned in the axis of reactor at equal intervals of 40 mm. A K-type thermocouple is inserted in the wind box to monitor the waste gas temperature. In addition, to improve the air flow uniformity, the iron ores bigger than 5 mm are removed. For every test, 350 g hearth ore and approximate 10 kg micro pellets after granulation are fed into the sintering reactor with a diameter of 142 mm and a height of 400 mm.



1-Flowmeter; 2-Ignitor; 3-S type thermocouples; 4-Insulator; 5-Iron ore fines; 6-Raw sinter mixture; 7-Wind box; 8-K type thermocouple; 9-Pressure transmitter; 10-Data acquisition system.

Figure 1: Schematic diagram of the lab-scale iron ore sintering system

2.2 Experimental procedures

In the present study, raw sinter materials contain three kinds of iron ore fines, return fine and flux, as listed in Table 1. All the materials are carefully mixed and granulated by adding water to achieve the final moisture content in the granulation drum for 5 min. And then, feeding the micro pellets after granulation into the reactor and arranging thermocouples are completed in order. Finally, the reactive micro pellets are ignited by the liquefied petroleum gas (LPG) burner for 90 s. Other operating parameters are shown in Table 2. Then the burner is lifted off from the above of reactor, and air flow rate measurement system is quickly installed and sealed. The sintering process is not completed until the waste gas temperature reaches the peak value. After cooling for 3 min, the suction fan is shut down.

Table 1: Blending ratio of sinter mixture used in the experiments

Components	VMS iron ore	WPF iron ore	Brazilian iron ore	Return fine	Hydrated lime
Mass fraction (%)	26.88	26.88	13.44	21.64	11.16

Table 1: Major operating parameters in the experiments

Parameters	Units	Sintering conditions
Hearth layer depth	mm	20
Ignition temperature	K	1,373 ± 10
Ignition suction	kPa	5, 6, 7
Sintering/Cooling suction	kPa	10, 12, 14

2.3 Parameters identification

As presented in Figure 2, all the definitions of the parameters used in the analysis are given below.

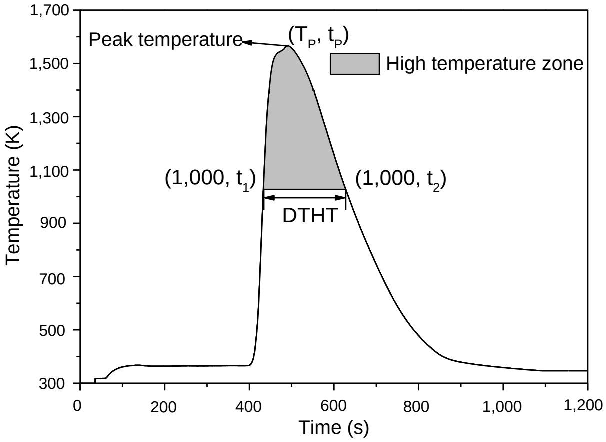


Figure 2: Definitions of major parameters

(a) Peak temperature – is the peak value of the temperature-time profile recorded by the thermocouple.

(b) Duration time of high temperature (DTHT) – is the residence time of temperature above 1,000 K (coke ignition temperature (Won et al., 2006)) in the temperature-time profile.

(c) Flame front speed (FFS) – is determined by dividing the distance (40 mm) between neighbouring thermocouples by propagating time of high temperature zone front (1,000 K isosurface).

3. Result and Discussion

Before sintering, with the aim of obtaining mix moisture for sufficient granulation, the influence of moisture content on bed permeability was performed, as shown in Figure 3. The bed permeability curve indicates that the optimum moisture content required for granulation is approximately 10.02 %.

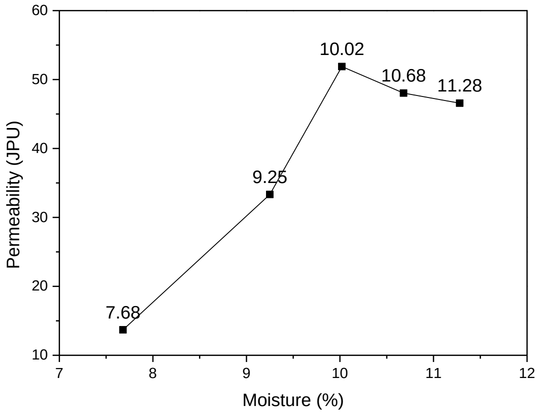


Figure 3: Effect of moisture content on bed permeability

The typical behaviour of sintering process is shown in Figure 4. It is obvious that the temperature profiles become higher and wider as sintering process progresses. These can be reasonably explained by the advantages of porous medium combustion: solid porous matrix serves a means of recirculating heat from the high temperature zone to the incoming reactants in preheating zone. With the high temperature zone moving downwards, the longer preheat time and less heat loss enhanced the preheat effect of fresh air. As a consequence, both of the combustion condition and efficiency were improved. Peak temperature, DTHT and FFS are carefully extracted from the Figure 4, as indicated in Table 3. The local temperatures, DTHTs and FFSes show an increasing trend in the axial direction. The increasing of local FFSes may be caused by the increased air flow rate due to evaporation of large amount of water film condensed on the micro pellets and coke particles consumption.

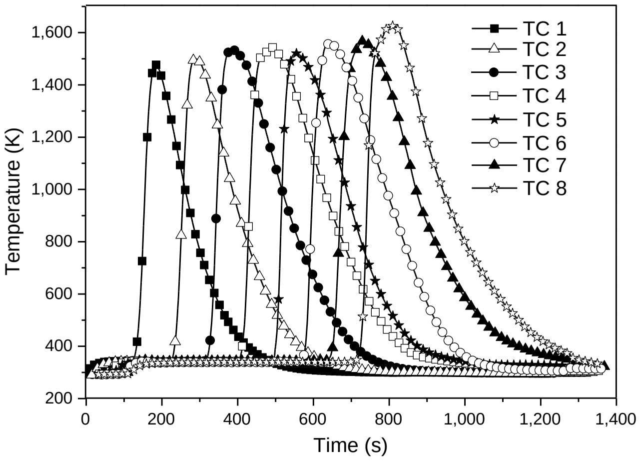


Figure 4: Temperature evolutions of the sintering bed

Table 3: Main results of the reference case

Position (mm)	40	80	120	160	200	240	280	320
Peak temperature (K)	1,477	1,498	1,533	1,539	1,517	1,556	1,561	1,622
DTHT (s)	102.98	128.22	167.54	167.25	168.25	193.00	194.50	197.56
FFS (mm/min)	15.07	24.59	26.31	27.89	28.05	29.85	31.52	33.53

3.1 Effect of suction pressure

In this part, experiments are conducted at three suction pressures of 10 kPa, 12 kPa and 14 kPa. Figure 5 shows increasing the suction pressure applied across the sintering bed from 10 kPa to 14 kPa reduces the local peak temperatures and DTHTs in different axial positions. In the previous work of Pironi et al. (2009) similar peak temperature trends were found in smouldering combustion of NPAL. And the similar DTHTs were also found in the work of Won et al. (2006). The increased air flow rate in sintering bed not only accelerates the convective heat transfer from high temperature zone to the downstream unburnt reactive micro pellets but also enhances the cooling effect of hot sinters in the upstream of high temperature zone. They adversely affect the energy accumulation in high temperature zone leading to the decrease of peak temperature and DTHT.

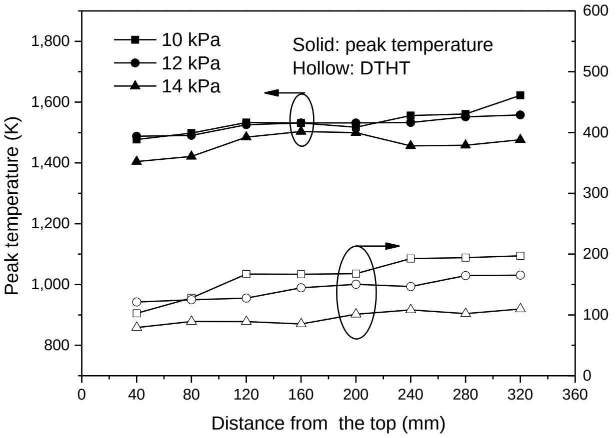


Figure 5: Effect of suction pressure on peak temperature and DTHT

FFS is also a critical parameter which determines the sintering productivity. As indicated in Figure 6, within the studied range of suction pressures, higher suction pressure results in faster local FFSes. Basically, the flowing gas plays dual role of supplying oxidiser (O_2) as well as transferring heat through convection in sintering bed. FFS may be controlled by both of reaction speed and heat transfer speed. Reaction speed is strongly dependent on the rate of oxidiser (O_2) supply. Therefore, for a fixed amount of fuel in sintering bed, higher combustion and convective rate at higher suction pressure contribute to the faster local FFSes.

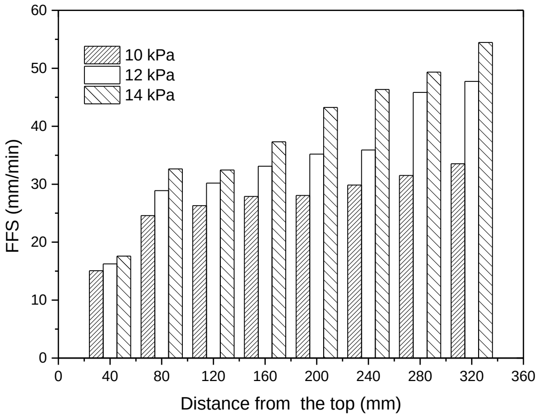


Figure 6: Effect of suction pressure on FFS

3.2 The effect of fixed carbon content

In this part, three experiments are arranged to study the effect of total energy input on sintering process at fixed carbon content of 3.26 %, 3.48 % and 3.70 %. Figure 7 presents increasing the fixed carbon content from 3.26 % to 3.70 % raises the local peak temperatures and DTHTs in different axial positions. Fuel combustion is the most important source of energy input in sintering bed, so the rising trend of local peak temperatures and DTHTs with fixed carbon content is quite easy to accept. However, as Figure 7 noted, the increments of both local peak temperatures and DTHTs are very small when fixed carbon content increases from 3.48 % to 3.70 % due to the limited oxygen supply.

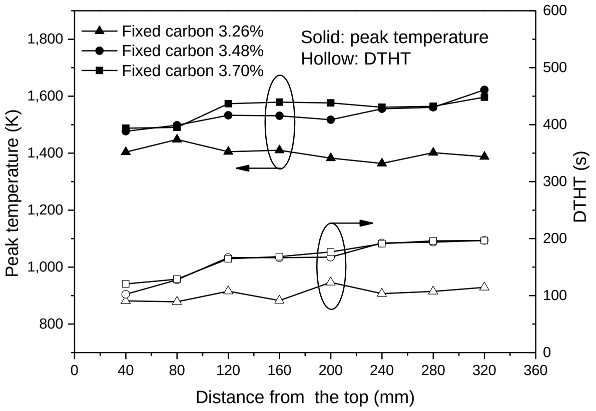


Figure 7: Effect of fixed carbon content on peak temperature and DTHT

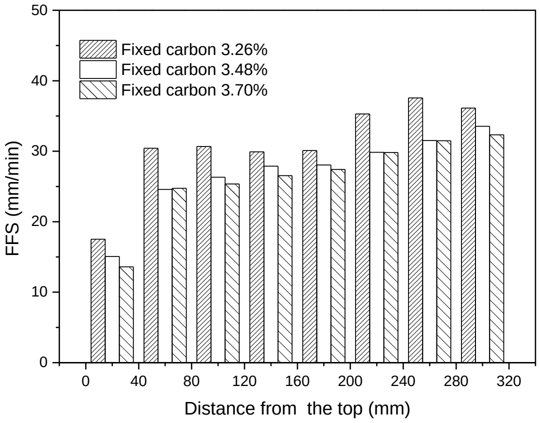


Figure 8: Effect of fixed carbon content on FFS

Figure 8 indicates that increasing fixed carbon content decreases the local FFSes. Wider high temperature zone and higher temperature at high fixed carbon content actually increase the flow resistance in sintering bed. The decreased air flow rate at higher fixed carbon content weakens the convective heat transfer from high temperature zone to the unburnt reactive micro pellets in the downstream. As a consequence, the decreased bed permeability contribute to the fact that local FFSes decrease with the increasing of fixed carbon content in sintering bed.

4. Conclusions

Key parameters of high temperature zone in different axial positions are carefully extracted and compared in the present study. The new findings are reasonably explained in a view of flow, heat and mass transfer in the reactive porous medium. And the major findings are summarised as follows:

1) During the iron ore sintering process, both of the improving bed permeability and enhancing preheat effect result in the increase of local peak temperatures, DTHTs and FFSes in axial direction.
2) Increasing the suction pressure results in the decrease of local peak temperatures and DTHTs. Moreover, the enhanced convection accelerates the heat and mass transfer in the front of high temperature zone, which increases the FFSes.
3) Increment of local peak temperatures and DTHTs are more pronounced when fixed carbon content is increased from 3.26 % to 3.48 % than from 3.48 % to 3.70 %, which is probably because of the limited oxygen supply and increased resistance in high temperature zone at high level of fixed carbon content.

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