

Model of Iron Ore Sintering Based on Melt and Mineral Formation

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Abstract: A model of iron ore sintering was built with consideration of fuel combustion, catalysis of sinter mixture as well as formation of melt and mineral, which was verified via sintering pot tests and showed a good fit to the experimental results. The effect of bed depth on temperature was reflected by the residence time in high-temperature zone, rather than the top value of the temperature, which was weakened by melt formation as well as hematite decomposition. Moreover, the effect of bed depth, fuel content and distribution on sintering process was different, which was reflected by temperature profiles and the rule of calcium ferrite formation. The formation of melt as well as magnetite was a process which was decided by kinetic factors, while the formation of calcium ferrite was related to fuel blending conditions, which is determined by thermodynamics when the fuel ratio inside sinter granules is low or fuel content is high, otherwise, it is determined by kinetics.

Key words: sintering model; iron ore; melt; mineral composition; fuel combustion

Symbol List

A_s —Specific surface area, m^{-1} ;	I —Fuel distribution coefficient;
c_g —Specific heat of gas, $J \cdot kg^{-1} \cdot K^{-1}$;	k_{c1} —Rate constant of carbon complete combustion, $m \cdot s^{-1}$;
c_p —Specific heat, $J \cdot kg^{-1} \cdot K^{-1}$;	k_{c2} —Rate constant of carbon solution combustion, $m \cdot s^{-1}$;
c_s —Specific heat of bed, $J \cdot kg^{-1} \cdot K^{-1}$;	k_1 —Rate constant of calcite decomposition, s^{-1} ;
C_c —Carbon content of sinter mixture, %;	k_M —Rate constant of dolomite decomposition, s^{-1} ;
C_i —Gas concentration, $mol \cdot m^{-3}$;	k_{mo} —Rate constant of melt formation, s^{-1} ;
C_{O_2} —Oxygen concentration in gas, $mol \cdot m^{-3}$;	M_c —Molar mass of carbon, $kg \cdot mol^{-1}$;
C_{CO} —Carbon monoxide concentration in gas, $mol \cdot m^{-3}$;	M_C —Molar mass of magnetite, $kg \cdot mol^{-1}$;
C_{CO_2} —Carbon dioxide concentration in gas, $mol \cdot m^{-3}$;	M_1 —Molecular mass of calcite, $g \cdot mol^{-1}$;
C_{N_2} —Nitrogen concentration in gas, $mol \cdot m^{-3}$;	M_M —Molecular mass of dolomite, $g \cdot mol^{-1}$;
D_i —Gas diffusion coefficient, $m^2 \cdot s^{-1}$;	n_c —Number of carbon granules in unit volume, m^{-3} ;
f —Melt content, %;	n_1 —Number of calcite granules in unit volume, m^{-3} ;
ΔH_{mo} —Smelting heat of ore, $J \cdot kg^{-1}$;	n_M —Number of dolomite granules in unit volume, m^{-3} ;
ΔH_C —Decomposition enthalpy of hematite, $J \cdot mol^{-1}$;	p_{O_2} —Oxygen partial pressure;
ΔH_{c1} —Formation enthalpy of carbon dioxide, $J \cdot mol^{-1}$;	q_v —Inner heat source, $J \cdot m^{-3} \cdot s^{-1}$;
ΔH_{c2} —Formation enthalpy of carbon monoxide, $J \cdot mol^{-1}$;	R_2 —Binary basicity;
ΔH_1 —Decomposition enthalpy of calcite, $J \cdot mol^{-1}$;	r_c —Radius of carbon granule, m ;
ΔH_M —Decomposition enthalpy of dolomite, $J \cdot mol^{-1}$;	r_1 —Radius of calcite granule, m ;
ΔH_v —Evaporation enthalpy, $J \cdot mol^{-1}$;	r_M —Radius of dolomite granule, m ;
h_p —Convection heat transfer coefficient of gas-solid, $J \cdot m^{-2} \cdot s^{-1} \cdot K^{-1}$;	R_c —Overall combustion rate of carbon, $mol \cdot m^{-3} \cdot s^{-1}$;

R_C ——Rate of hematite decomposition, s^{-1} ;
 R_{c1} ——Rate of carbon complete combustion, $mol \cdot m^{-3} \cdot s^{-1}$;
 R_{c2} ——Rate of carbon solution reaction, $mol \cdot m^{-3} \cdot s^{-1}$;
 R_1 ——Rate of calcite decomposition, $mol \cdot m^{-3} \cdot s^{-1}$;
 R_M ——Rate of dolomite decomposition, $mol \cdot m^{-3} \cdot s^{-1}$;
 R_{mo} ——Rate of melt formation, s^{-1} ;
 R_w ——Rate constant of moisture evaporation, $mol \cdot m^{-3} \cdot s^{-1}$;
 t ——Time, s;
 T ——Temperature, K;
 T_g ——Temperature of gas, K;
 T_s ——Temperature of bed, K;
 u_x, u_y, u_z ——Gaseous velocity in x, y, z directions, $m \cdot s^{-1}$;
 w_C ——Magnetite content of sinter;
 w'_C ——Magnetite content of melt;

w_{SFCA} ——Calcium ferrite content of sinter;
 w'_{SFCA} ——Calcium ferrite content of melt;
 w_s ——Moisture content of bed, %;
 X ——Environmental influence coefficient;
 z ——Bed depth, m;
 Z ——Granulation influence coefficient;
 α ——Overall catalytic coefficient of sintering material;
 λ ——Coefficient of thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$;
 ϵ ——Porosity of bed;
 ϕ ——Heat dissipation, $J \cdot m^{-3} \cdot s^{-1}$;
 ρ ——Density, $kg \cdot m^{-3}$;
 ρ_b ——Apparent density of bed, $kg \cdot m^{-3}$;
 ρ_c ——Density of carbon granule, $kg \cdot m^{-3}$;
 ρ_g ——Density of gas, $kg \cdot m^{-3}$;
 ρ_1 ——Density of calcite granule, $kg \cdot m^{-3}$;
 ρ_M ——Density of dolomite granule, $kg \cdot m^{-3}$;
 ρ_s ——True density of sinter mix, $kg \cdot m^{-3}$.

Forecast on the sintering process has been realized to some extent through model simulation, and operating parameters could be adjusted in advance to achieve the goal of high yield at a low cost. Therefore, wide attention has been paid to the modeling of iron ore sintering process^[1-9].

The diversity and accuracy of models are determined by included sub-models or involved reactions. The semi-empirical model built by Li and Yang^[2] described the temperature field of sintering bed, and the rates of involved reactions were determined according to the measurement data about flow velocity and composition of tail gas; therefore, poor forecast was doomed for this model. Zhou et al.^[1] summarized characteristics of some models^[1,3-10], and difference between reactions involved as well as adopted algorithms were discussed in detail. Common reactions such as vaporization and condensation of moisture, carbon combustion and carbonate decomposition were generally considered, and estimation on melt formation based on thermodynamics was included in some models^[3,4,6-10]. With development of the sintering technology, higher requirements were put forward and details on the sintering process were concerned. The change of structural features for the sintering bed was described^[4,5,11-13], and progress in terms of forecast on sinter quality was made^[7].

Generally speaking, the fuel content of sinter mixture is in the range of 3.5 mass% to 4.5 mass%, which is equivalent to that of silica. High alkalinity around 2 is normally adopted in modern sintering process, that is, the content of alkaline flux in sinter mixture is approximately twice as that of fuel.

The catalysis of alkaline oxides on carbon combustion is well known^[14,15], and that of iron ores is also reported recently^[16]. Therefore, the catalysis of sintering mixture is necessary to be taken into account, which is good for the improvement of precision on describing fuel combustion in a model. Moreover, metallurgical properties of sinters greatly depend on their mineral composition, and prediction on mineral composition will be a new direction for modeling. In present work, some efforts were made to improve the precision of model simulation, and meanwhile, some new functions were given in the model:

(1) the catalysis of sinter mixture was considered to revise the rate of carbon combustion;

(2) melt formation was described from the viewpoint of kinetics;

(3) the formation of magnetite as well as calcium ferrite was involved, and it is possible to predict the change of mineral composition during sintering process.

1 Outline of the Model

1.1 Characteristics of the model

1.1.1 Reactions proceed in stages

The beginning temperature of each reaction was determined by the fundamental experiments or thermodynamic data. Based on this, reactions involved in sintering bed were thought to proceed in stages in present model, and the division of temperature intervals was given in detail as follows.

(1) The region of moisture evaporation (Below 773 K)

Moisture evaporation is a physical process,

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