Lower SO₂ Emissions in the Sintering Process Utilizing the Difference of Sulphur Contents of Iron Ores

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The current treatment of sintering flue gas pollutants is mainly focused on the end-of-pipe treatment, but some problems still exist. It will be more simple and efficient to start from the source to control the pollutants elements. In this paper, the iron ores are classified into two parts utilizing the difference of sulphur contents of iron ores and their adding ratio, “High Sulphur” iron ores and “Low Sulphur” iron ores. Both parts of the iron ores are located inside or outside of the tested pellet, respectively, by granulating with other sintering materials. The experiment results of SO₂ emissions reduction are similar in the tubular electric furnace experiment and the sinter-pot test. The sinter-pot test performed in this study reveals that about 41.02% and 34.20% of SO₂ are reduced, respectively, through the method in which the “High Sulphur” iron ores are located inside and outside of the tested pellet compared with the traditional method. The falling strength and tumbler strength of sinter decrease by 3.04% and 1.51% when the “High Sulphur” iron ores are located inside of the tested pellet, respectively. While the falling strength and tumbler strength increase by 5.44% and 0.08% when the “Low Sulphur” iron ores are located inside of the tested pellet, respectively. Reduction index (RI) decreases by 1.38% and 4.96%, respectively, while the characteristic value (S) decreases by 19.89% and 70.50%, respectively. The reducibility of sinter decreases, but the softening-melting properties of sinter improve obviously. Compared with the traditional method, the methods introduced in this article have some advantages from the perspective of SO₂ emissions reduction and the improvement of the softening-melting properties of sinter. In general, the method in which “High Sulphur” iron ores are located outside of the pellet would be more preferable than that of located inside.

KEY WORDS: sintering; SO₂; sulphur contents; iron ores.

1. Introduction

China is the world's largest steel producer. Its output of steel reached 804 million tons in 2015, accounting for about 50% of the world's steel output.¹⁾ The main steel production process in China is BF-BOF process. The BOF steel has accounted for up to 90% and the sinter has accounted for 70%–80% in blast furnace burden design.^{2,3)} The output of sinter in China reached 857 million tons in 2015.⁴⁾ The emissions of sintering flue gas pollutants increase significantly with the increase of the sinter output. The SO₂ emissions in the sintering process accounts for 60% in steel manufacturing process.⁵⁾ The SO₂ emissions in China reached 18.59 million tons in 2014, and the emissions reduction pressure is increasing gradually.⁶⁾

The SO₂ is one of the most important factors behind the formation of acid rain and haze, and it seriously affects human health and ecological environment.⁷⁾ Germany, Japan and other developed countries have taken the lead in

treating the sintering flue gas pollutants and issued national standards to limit the pollutants emissions in the sintering process. China began comparatively later for controlling the sintering pollutants. In 2012, China issued the national standard (GB28662-2012) to limit the pollutants emissions in the sintering process. Some emissions limits in GB28662-2012 are more stringent than the standards of other developed countries.^{8–10)}

Currently processing methods for SO₂ in the sintering process are mainly based on the calcium method, such as wet limestone/gypsum technology, circulating fluidized bed (CFB), spray drying adsorption (SDA), maximized emission reduction of sintering (MEROS), *etc.* All these techniques belong to the end-of-pipe treatment process and significant progresses have been made in the treatment of SO₂ in the sintering process, but some problems do exist, for instance, high investment cost, high running expense, large occupation of land and secondary pollution, *etc.*^{11–13)} The reasonable treatment for pollutants should not just focus on the end-of-pipe treatment and it has to incorporate with source treatment and process control. However, over a long period of time, for sintering flue gas pollutants treatment,

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we depend more on end-of-pipe treatment and neglect the research to source treatment and process control, especially to source treatment.¹⁴⁾ Hence, strengthening the study on source treatment for controlling the sintering flue gas pollutants has become important.

Iron ores in different regions vary dramatically in sulphur contents. The difference of sulphur contents of typical iron ores from Chinese and other countries is obvious (Fig. 1), especially between that of Chinese domestic iron ores and other countries iron ores.^{15,16)} The fuel and iron ores provide the main source of SO₂ in the sintering process.¹⁷⁾ Many researches are mainly focused on reducing pollutant emissions by utilizing fuel and fluxes in the sintering process.^{18,19)} However, we are not aware of utilizing the difference of sulphur contents of iron ores to reduce the generation of SO₂ in the sintering process. In this paper, we start from the source, making use of the difference of sulphur contents of iron ores to reduce the generation of SO₂, and meanwhile investigating the effect of different methods on the sinter quality through the tubular electric furnace experiment and the sinter-pot test.

2. Materials and Experiment Methods

There are some similarities between the tubular electric furnace and the sinter-pot, like the oxidizing atmosphere and negative pressure. It is practical to combine the sinter-pot test with the tubular electric furnace experiment to verify the effect of the methods on SO₂ and the sinter quality from the perspective of economy and practicability.

2.1. Raw Materials for Tubular Electric Furnace Experiment

The species and ratios of raw materials for tubular electric furnace experiment are shown in Table 1. In the experiment, we select five kinds of different sulphur contents iron ores (A, B, C, D and E), three kinds of fluxes (dolomite, quicklime and limestone) and take the coke powder as fuel. Meanwhile, considering the actual sintering raw materials, a part of return fines are chosen as raw materials. The chemical compositions of raw materials are shown in Table 2. The sulphur contents of iron ores are shown in Fig. 2.

The sulphur contents of iron ores B, C and E are more than 0.02% and higher than that of iron ores A and D (Fig. 2). Meanwhile, the adding ratio of iron ores B, C and E are equal to that of iron ores A and D. Based on these two characteristics, we define the iron ores B, C and E as “High

Sulphur” iron ores and the iron ores A and D as “Low Sulphur” iron ores. The “High Sulphur” and “Low Sulphur” in this case are a relative concept, and it just indicates that the sulphur contents of iron ores B, C and E are higher than that of iron ores A and D.

2.2. Preparation of Raw Materials for Tubular Electric Furnace Experiment

Preparation process of raw materials for testing is as follows: firstly, the fuel and fluxes (including return fines) are mixed well in a 300 mL conical flask and classified into two equal mass parts. Half of fuel and fluxes are mixed with “High Sulphur” iron ores well in the conical flask and then the materials are processed into pellet with 50%–70% water in a Φ100 mm culture dish. Another half of fuel and fluxes are mixed with “Low Sulphur” iron ores well in the conical flask and then the materials are processed as coating materials with 30%–50% water in another Φ100 mm culture dish. Then the pellet and coating materials are mixed together for testing, where the pellet is inside and the coating materials are outside (Fig. 3). Compared with this model, the traditional model in which all materials are mixed together, and another model in which the “Low Sulphur” iron ores are located inside of the tested pellet are prepared simultaneously (Fig. 3). The tested pellet that is processed by the traditional method is defined as Pellet a, and the corresponding method is Method A. The tested pellet where the “High Sulphur” iron ores are located inside is defined as Pellet a-1 (Method A-1) and the tested pellet

Table 1. Raw materials species and its ratios for tubular electric furnace experiment (wt%).

Raw materials	Ratios
A fine ore	19.29
B fine ore	15.44
C fine ore	7.72
D fine ore	19.29
E fine ore	15.46
dolomite	6.77
quicklime	2.97
limestone	8.01
Coke powder	5.05
Return fines (external)	24.77

Fig. 1. The sulphur contents of different typical iron ores from Chinese and other countries.

Table 2. The chemical compositions of raw materials (wt%).

Raw materials	TFe	CaO	SiO ₂	MgO	Al ₂ O ₃	Mn	TiO ₂	K ₂ O	S	P	LOI
A fine ore	61.26	0.16	3.93	0.049	2.07	0.28	0.11	0.023	0.006	0.074	5.53
B fine ore	59.27	0.14	3.85	0.041	1.34	0.035	0.062	0.012	0.021	0.033	9.66
C fine ore	58.18	0.08	3.92	0.14	2.08	0.65	0.20	0.055	0.048	0.11	8.89
D fine ore	65.17	0.11	2.59	0.12	1.42	0.48	0.09	0.023	0.008	0.029	2.24
E fine ore	64.56	0.24	6.58	0.37	0.58	0.01	0.097	0.120	0.021	0.014	−0.39
Return fines	54.28	10.14	5.35	2.02	2.07	0.22	0.14	0.092	0.046	0.054	2.26
dolomite	—	31.02	0.21	21.71	0.14	—	—	—	—	—	46.89
limestone	—	49.51	4.42	2.11	1.33	—	—	—	—	—	40.30
quicklime	—	75.23	5.82	1.93	1.34	—	—	—	—	—	12.57
Coke powder	5.59	8.69	42.94	1.36	28.06	—	1.22	0.68	1.23	0.15	—
Industrial analysis for coke powder						Fixed Carbon: 79.96%; Volatile: 2.59%; Ash: 17.45%

Fig. 3. Preparation progress of raw materials for Pellet a-1 and Pellet a-2 (Pellet a: all materials are mixed together and then granulation). (Online version in color.) **Fig. 2.** The sulphur contents of iron ores for tubular electric furnace experiment.

where the “Low Sulphur” iron ores are located inside is defined as Pellet a-2 (Method A-2).

To ensure the water content of the tested pellet is around 10% and the diameter is around 10 mm. The amount of the tested pellet for each experiment is 30 g.

The test equipment mainly includes the tubular electric furnace and the ECOM J2KN^{Pro} gas analyzer (Fig. 4). The tubular electric furnace is heated from room temperature to 1 200°C under the heating rate of 7°C/min. The tested pellet is positioned in a 100°C dry box for 10 min in case the corundum crucible cracks. Then the tested pellet is positioned in the corundum crucible and pushed into furnace. The pellet is remained in furnace for 10 min at 1 200°C. The gas volatilizes out of the pellet and then is pumped out by the gas analyzer which has a pumping rate of 2.6 L/min. The SO₂ is analyzed by the gas analyzer. The chemical

compositions of the pellet after the test are analyzed by chemical methods.

2.3. Raw Materials for Sinter-pot Test

According to the above sintering materials preparation methods (Method A, Method A-1 and Method A-2), the sinter-pot test is carried out to investigate the effect of the methods on the SO₂ emissions and the sinter quality.

The species and ratios of raw materials for sinter-pot test are shown in Table 3. The raw materials in the sinter-pot test are similar with that of in the tubular electric furnace experiment. A new iron ore A' is selected and its chemical compositions is shown in Table 4. The sulphur contents of iron ores for sinter-pot test are shown in Fig. 5.

The sulphur contents of iron ores B, C and E are more than 0.02% and higher than that of iron ores A' and D (Fig. 5). Meanwhile, the adding ratio of iron ores B, C and E are equal to that of iron ores A' and D. Likewise, we define the iron ores B, C and E as “High Sulphur” iron ores and the iron ores A' and D as “Low Sulphur” iron ores.

2.4. Preparation of Raw Materials for Sinter-pot Test

The preparation process of raw materials for sinter-pot test is similar with that for tubular electric furnace experiment. The disc pelletizer is adopted to mixing and granulation. The main technical parameters of the disc pelletizer are as follows: diameter, 1 000 mm; side height, 250 mm; rotational speed, 20 r/min; dip, 45°; linear velocity, 1.05 m/s. Preparation process of raw materials for sinter-pot test is as follows: firstly, the fuel and fluxes (including return fines) are mixed well in the disc pelletizer for 2 min and classified

Fig. 4. The diagram of test equipment for tubular electric furnace experiment.

Table 4. The chemical compositions of iron ore A' (wt%).

Raw materials	TFe	CaO	SiO ₂	MgO	Al ₂ O ₃	Mn	TiO ₂	K ₂ O	S	P	LOI
A' fine ore	61.79	0.16	3.57	0.061	2.03	0.10	0.09	0.019	0.018	0.088	5.37

Table 3. Raw materials species and its ratios for sinter-pot test (wt%).

Raw materials	Ratios
A' fine ore	15.46
B fine ore	12.37
C fine ore	6.19
D fine ore	15.46
E fine ore	12.39
dolomite	5.43
quicklime	2.38
limestone	6.42
Coke powder	7.00
Return fines	16.9

Fig. 5. The sulphur contents of iron ores for sinter-pot test.

Table 5. Operation parameters of the sinter-pot test.

Parameter	Value
Ignition temperature	1 100°C
Ignition time	180 s
Ignition suction	4 000 Pa
Sintering suction	6 000 Pa
Bed height	320 mm
Diameter	100 mm
Water content	8%–10%
Sinter basicity	2.10

Fig. 6. The diagram of test equipment for sinter-pot test (1, Combustion fan; 2, Liquid gas storage tank; 3, exhaust gas temperature indicator; 4, insulation layer; 5, sinter-pot; 6, ignition temperature indicator; 7, ignitor; 8, negative pressure meter; 9, gravity dust collector; 10, muffler; 11, exhaust fan; 12, ECOM J2KN^{Pro} gas analyzer).

into two equal mass parts. Half of fuel and fluxes are mixed with “High Sulphur” iron ores well in the disc pelletizer for 1.5 min, and then the materials are processed into pellet with 60%–80% water. Another half of fuel and fluxes are mixed with “Low Sulphur” iron ores well in the disc pelletizer for 1.5 min and the materials are processed as coating materials with 20%–40% water. Then the pellet and coating materials are mixed together for 2 min, the pellet is inside and the coating materials are outside.

Likewise, compared with the traditional preparation method (Method A', all materials are mixed together for 2 min and then granulation for 3 min in the disc pelletizer), two new ways of preparation (Method A'-1 and Method A'-2) for sintering raw materials are developed. The difference between Method A'-1 and Method A'-2 is that the “High Sulphur” iron ores are located inside or outside of the tested pellet.

The water content of the tested pellet is around 8% and the diameter is around 5–7 mm. The amount of the tested pellet for each sinter-pot test is 5 Kg. The test equipment of the sinter-pot test and its operation parameters are shown in Fig. 6 and Table 5, respectively.

When putting the sintering materials into the sinter-pot, a hearth layer of about 30 mm consisting of sinter with a size of 10–16 mm is placed onto the bottom of the pot. Afterwards the sintering materials are put into the pot. At the beginning of the sinter-pot test, the exhaust fan is started and the ignitor is placed over the sinter-pot. For the ignition of raw materials the natural gas-fired burner is in operation for 180 seconds at 1 100°C. After that the ignitor is removed from the sinter-pot. From the start of ignition the SO₂ is recorded. After the sinter-pot test, the sinter produced is removed from the pot and conducted a series of test, including the chemical compositions, falling strength, tumbler strength, reduction index and softening-melting properties of sinter. The sinter produced, that the raw materials are processed by Method A', is defined as Sinter a'. Sinter a'-1 and Sinter a'-2 are defined with the same way.

3. Results and Discussion

3.1. Sulphur Distribution in Tested Pellet and Gas of the Tubular Electric Furnace Experiment

The chemical compositions of Pellet a, Pellet a-1 and Pellet a-2 heated for 10 min at 1 200°C are shown in Table 6. The sulphur contents of Pellet a-1 are higher than that of Pellet a and Pellet a-2. The sulphur contents of Pellet a-1 are 1.16 times as much as that of Pellet a (Fig. 7).

The SO₂ emission concentration of Method A-1 is lower than that of Method A and Method A-2 (Fig. 8). The integral of SO₂ emission concentration curve can be represented as the SO₂ emissions over a period of time. The SO₂ emissions of Method A-1 are reduced by 50.83% compared with that of Method A (Fig. 9).

From the above, we find that more sulphur in raw mate-

rials of Pellet a-1 is remained rather than volatilized into gas. It is probable that there are four chief causes for this phenomenon. One possible cause is that the “High Sulphur” iron ores are located inside of the tested pellet, and the chance for the sulphur to make contact with oxygen is less, so the formation volume of SO₂ is reduced. The other possible cause is that pre-granulation increases the compactness of the pellet (Pellet a: 351.2 kg/m³; Pellet a-1: 407.1 kg/m³; Pellet a-2: 452.3 kg/m³), and it is also helpful to reduce the contact between sulphur and oxygen. Another possible cause is that the temperature distribution of the pellet is not uniform, the internal temperature is lower than the external temperature, and this also can reduce the formation of SO₂. The last possible cause is that the CaO contained in raw materials has certain effect on sulphur fixation ($2\text{CaO} + 2\text{SO}_2 + \text{O}_2 = 2\text{CaSO}_4$, the equilibrium temperature ranges from 1 600°C to 1 700°C), the CaSO₄ is difficult to decompose under the sintering temperature condition ($\leq 1\,500^\circ\text{C}$), hence the sulphur can be remained in the tested pellet.

Fig. 8. The SO₂ emission concentration of Method A, Method A-1 and Method A-2. (Online version in color.)

Fig. 7. The sulphur contents of Pellet a, Pellet a-1 and Pellet a-2. (Online version in color.)

Fig. 9. The integral area of the SO₂ emissions of Method A, Method A-1 and Method A-2.

Table 6. The chemical compositions of Pellet a, Pellet a-1 and Pellet a-2 (wt%).

	TFE	FeO	MgO	Al ₂ O ₃	CaO	SiO ₂	K ₂ O	Na ₂ O	MnO	TiO ₂	S
Pellet a	58.26	39.08	2.46	2.11	11.02	5.77	0.091	0.055	0.38	0.16	0.063
Pellet a-1	58.90	47.55	2.40	2.30	10.37	5.75	0.084	0.055	0.32	0.14	0.073
Pellet a-2	59.34	47.99	2.37	2.29	10.27	5.76	0.089	0.054	0.33	0.14	0.068

3.2. The Sinter-pot Test

3.2.1. Sulphur Distribution in Sinter and Gas

The sulphur contents of Sinter a'-1 are higher than that of Sinter a' and Sinter a'-2 (Table 7). The sulphur contents of Sinter a'-1 are 2.00 times as much as that of Sinter a' (Fig. 10).

The SO₂ emission concentration of Method A'-1 is lower than that of Method A' and Method A'-2 (Fig. 11). The SO₂ emissions of Method A'-1 are reduced by 41.02% compared with that of Method A' (Fig. 12).

Based on the sinter-pot test results of sulphur distribution in sinter and gas, the sulphur balance chart is established (Fig. 13).

From the above results, we find a similar phenomenon between the sinter-pot test and the tubular electric furnace experiment that more sulphur in raw materials is remained in Sinter a'-1 and Pellet a-1 rather than volatilized into gas.

Table 7. The chemical compositions of Sinter a', Sinter a'-1 and Sinter a'-2 (wt%).

	TFe	FeO	CaO	SiO ₂	S	R
Sinter a'	57.06	15.83	9.81	4.80	0.016	2.04
Sinter a'-1	56.44	13.87	10.23	4.70	0.032	2.18
Sinter a'-2	56.18	11.73	10.09	4.95	0.024	2.04

Fig. 10. The sulphur contents of Sinter a', Sinter a'-1 and Sinter a'-2. (Online version in color.)

Fig. 11. The SO₂ emission concentration of Method A', Method A'-1 and Method A'-2. (Online version in color.)

Fig. 12. The integral area of the SO₂ emissions of Method A', Method A'-1 and Method A'-2. (Online version in color.)

Fig. 13. The sulphur balance chart of the sinter-pot test. (Online version in color.)

(Figs. 14, 15). The analysis result about FeO content in sinter is in agreement with their chemical compositions (Table 7). Meanwhile, the content of calcium ferrite in Sinter a'-2 increases and its structure changes from the branch shape to the lath shape, while the content of calcium ferrite in Sinter a'-1 is relatively less (Figs. 14, 15).

The falling strength and tumbler strength are two important indexes for evaluating the sinter strength at room tem-

Fig. 14. XRD patterns of Sinter a', Sinter a'-1 and Sinter a'-2. (Online version in color.)

Fig. 15. Optical microstructures of Sinter a', Sinter a'-1 and Sinter a'-2. H—Hematite; M—Magnetite; CF—Calcium ferrite (a. Sinter a'; b. Sinter a'-1; c. Sinter a'-2). (Online version in color.)

perature. The falling strength and tumbler strength of Sinter a'-1 are lower than that of Sinter a' and Sinter a'-2 (Fig. 16). Studies have shown that the sinter strength at room temperature would improve with the increasing content of FeO in sinter.^{20,21)} However, when the content of FeO in sinter exceeds 12%, which will decrease the sinter strength at room temperature.²²⁾ In the experiment, the content of FeO in Sinter a', Sinter a'-1 and Sinter a'-2 is 15.83%, 13.87% and 11.73%, respectively. Meanwhile, the content of calcium ferrite in Sinter a'-2 increases (Figs. 14, 15). It may help to explain why the strength of Sinter a'-2 at room temperature is higher than that of Sinter a' and Sinter a'-1.

The CaO contained in raw materials has certain effect on sulphur fixation. For Sinter a'-1, there would be more CaO participates in sulphur fixation reaction, the SO₂ emissions are reduced, while the binding phase of sinter is decreased which can decrease the sinter strength at room temperature (Figs. 14, 15). It may be the cause that the strength of Sinter a'-1 is lower at room temperature.

Reduction index (RI) is an important index for evaluating the metallurgical property of sinter. RI is used to simulate the condition under which the burden is fed into high temperature region from the top of blast furnace. It can show the difficult degree that the gas reducing agent captures the oxygen combined with iron in sinter. RI is diminishing from Sinter a' to Sinter a'-2 (Fig. 17). Compared with Sinter a', RI of Sinter a'-1 decreases by 1.38%, while that of Sinter a'-2 decreases by 4.96%.

Generally, decreasing the content of FeO in sinter can not only reduce fuel consumption in the sintering process, but

Fig. 17. Reduction index of Sinter a', Sinter a'-1 and Sinter a'-2. (Online version in color.)

Fig. 16. The falling strength and tumbler strength of Sinter a', Sinter a'-1 and Sinter a'-2. (Online version in color.)

also improve the metallurgical property of sinter. It creates conditions for reducing the coke ratio of blast furnace.^{22,23)} Decreasing FeO content leads to the increase of hematite (Fe_2O_3) and calcium ferrite ($\text{Ca}_2\text{Fe}_2\text{O}_5$, CaFe_2O_4 , etc.) in sinter under certain carbon content (Figs. 14, 15), and the hematite and calcium ferrite are relatively easily reduced. Meanwhile, the amount of magnetite (Fe_3O_4), SiFe (silicate iron) and fayalite ($\text{CaO}\cdot\text{FeO}\cdot\text{SiO}_2$) decreases as the content of FeO in sinter decreases, and the magnetite, SiFe and fayalite are relatively hard to be reduced.²²⁾ The reduction rate of hematite and calcium ferrite (Fe_2O_3 (49.9%), $\text{Ca}_2\text{Fe}_2\text{O}_5$ (49.9%) and CaFe_2O_4 (40.1%)) are much higher than that of other materials (e.g. Fe_3O_4 (26.7%)) in sinter.²⁴⁾ It means that the decrease of FeO in sinter is helpful to improve RI of sinter.

However, in the experiment, RI of sinter decreases with the decrease of FeO. The likely reason is that the reducing atmosphere is weak and the amount of heat is less in the sintering process for increasing the compactness of the pellet that will weaken the burning of fuel, while the reducing atmosphere is helpful to the growth of calcium ferrite, and the formation amount of calcium ferrite will be decreased as the sintering reaction is insufficient. In addition, it would result in more unreacted iron ores are remained in sinter, and the unreacted iron ores are denser and hard to be reduced which would also decrease RI of Sinter.²³⁾ Compared with Sinter a'-2, there are more Fe_2O_3 is remained in Sinter a'-1 and it results in RI of Sinter a'-1 is higher than that of Sinter a'-2 (Figs. 14, 15).

The softening-melting properties of sinter have a significant impact on the reduction process and the permeability of the burden. The softening-melting properties of sinter contain dozens of indexes, such as softening temperature, dropping start temperature, dropping end temperature and so on. In general, the characteristic value of the softening-melting property of sinter (S , $\text{kPa}\cdot^\circ\text{C}$) is mainly used to evaluate the softening-melting properties of sinter, the smaller the S value, the better of the softening-melting properties of sinter.

The softening-melting properties of Sinter a', Sinter a'-1 and Sinter a'-2 are shown in **Table 8**. The melting point of Fe_2O_3 and $\text{Ca}_2\text{Fe}_2\text{O}_5$ is higher (1536°C and 1436°C , respectively), and the melting point of CaFe_2O_4 (1216°C) is lower than that of Fe_2O_3 and $\text{Ca}_2\text{Fe}_2\text{O}_5$.²⁴⁾ Hence, the amount of high melting point materials in sinter will increase with the increase of the content of Fe_2O_3 and $\text{Ca}_2\text{Fe}_2\text{O}_5$ and the decrease of the content of CaFe_2O_4 . As mentioned above, decreasing FeO content leads to the increase of hematite (Fe_2O_3) and calcium ferrite ($\text{Ca}_2\text{Fe}_2\text{O}_5$, CaFe_2O_4 , etc.). So in the experiment, the $T_{40\%}$, ΔT_1 and T_5 would increase. Meanwhile, the increase of T_5 leads to the increase of ΔH_5 . The primary slag forms with the temperature increases, as the content of FeO is diminishing from Sinter a' to Sinter a'-2,

the slag viscosity increases and mobility decreases. Hence the slag would be hard to drop off and the T_d increases. Although the T_d increases slightly, the ΔH and ΔT_2 decrease significantly.

The melting zone is the most influential factor of pressure difference of gas in blast furnace. Narrower droplet temperature range (ΔT_2) and smaller thickness of melting zone (ΔH) are beneficial to blast furnace operation. It means that the decrease of ΔH and ΔT_2 can improve the softening-melting properties of sinter.

According to the expression of the characteristic value S , $S = (\Delta P_m - 0.49) \times \Delta T_2$, the decrease of ΔP_m and ΔT_2 would help to decrease the S value and improve the softening-melting properties of sinter. In the experiment, both ΔP_m and ΔT_2 decrease. The S value is diminishing from Sinter a' to Sinter a'-2 (**Fig. 18**), and it indicates that the softening-melting properties of sinter get better. Compared with Sinter a', the S value of Sinter a'-1 decreases by 19.89%, while that of Sinter a'-2 decreases by 70.50%.

3.2.3. Comparison of Different Methods to the Sinter-pot Test

Method A'-1 and Method A'-2 are preferable compared with Method A', which is used as a reference and adopts the traditional raw materials preparation method, from the

Fig. 18. The characteristic value (S) of Sinter a', Sinter a'-1 and Sinter a'-2. (Online version in color.)

Table 9. Comparison of Method A', Method A'-1 and Method A'-2 to the sinter-pot test.

Index \ Method	A'	A'-1	A'-2
SO_2 emission reduction (%)	0	41.02	34.20
Falling strength change (%)	0	-3.04	5.44
Tumbler strength change (%)	0	-1.51	0.08
RI change (%)	0	-1.38	-4.96
S value change (%)	0	-19.89	-70.50

Table 8. The softening-melting properties of Sinter a', Sinter a'-1 and Sinter a'-2.

Sinter	$T_{10\%}$ $^\circ\text{C}$	$T_{40\%}$ $^\circ\text{C}$	ΔT_1 $^\circ\text{C}$	T_5 $^\circ\text{C}$	ΔH_5 %	ΔP_m kPa	T_d $^\circ\text{C}$	ΔT_2 $^\circ\text{C}$	ΔH mm	S $\text{kPa}\cdot^\circ\text{C}$
a'	1 215	1 362	147	1 289	25.89	12.65	1 423	136	24.20	1 654
a'-1	1 232	1 386	154	1 294	26.89	10.76	1 425	129	22.10	1 325
a'-2	1 195	1 434	239	1 374	34.56	5.97	1 463	89	11.30	488

perspective of SO₂ emissions reduction and the improvement of the softening-melting properties of sinter (**Table 9**). In general, Method A'-2 is better than Method A'-1, although its reduction effect on SO₂ is less significant than that of Method A'-1.

4. Conclusions

From the perspective of SO₂ emissions reduction, based on the difference of sulphur contents of iron ores and their adding ratio, the iron ores are classified into two parts, "High Sulphur" iron ores and "Low Sulphur" iron ores. The classification of iron ores means that the sulphur contents of a part of iron ores in the same batch of iron ores are higher or lower than that of others. Different from the traditional preparation method that all materials are mixed together and then granulation, pre-granulation for "High Sulphur" iron ores and "Low Sulphur" iron ores is adopted in the methods described in this paper to change the sulphur distribution in the pellet and increase the pellet compactness.

The sinter-pot test results show that 41.02% and 34.20% SO₂ are reduced, respectively. The new methods have little effect on the sinter quality, and even some indexes are improved. The reduction mechanism of SO₂ of the new methods is considered to be associated with the following reasons: the contact between sulphur and oxygen is reduced; the compactness of the pellet is improved through pre-granulation that is also helpful to reduce the contact between sulphur and oxygen; the temperature distribution of the pellet is not uniform, and the internal temperature is lower than the external temperature; the CaO contained in raw materials has certain effect on sulphur fixation.

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