Flue Gas Circulating Sintering Based on Biomass Fuel on Reduction of NO_x and SO₂ Emission

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In order to reduce the emission concentration of sintered flue gas pollutants, the source control technology and process control technology of iron ore sintering were adopted to reduce the emission concentration of flue gas pollutants. In this paper, the experiments of flue gas circulating sintering pot with charcoal instead of partial coke was carried out. The effects of O₂ content, temperature, SO₂ content and NO_x content in circulating flue gas on sinter properties and emission concentration of flue gas pollutants were studied. The experimental results show that the suitable oxygen content in flue gas was 14.9%, and the maximum suitable concentration of SO₂ was 500 ppm based on charcoal instead of 40% coke circulating flue gas sintering. The NO_x had little effect on the sintering performance index. Under the conditions of flue gas temperature of 200°C and CO content of 0.85%, the content of charcoal instead of coke was increased from 40% to 50%. The emission reduction of sintering flue gas pollutants SO₂ and NO_x was more than 42.6% and 65.8%, respectively. The comprehensive utilization of sintering flue gas waste heat and the cooperative control of sintering flue gas pollutants were realized.

KEY WORDS: flue gas circulating sintering; biomass fuel; flue gas pollutants; sinter properties; energy-saving and emission-reduction.

1. Introduction

At present, people pay more and more attention to the problem of atmospheric environment. The emission of pollutants from sintering flue gas is large, which is the most important thing in environmental treatment. In this regard, China has formulated the “Iron and Steel Sintering, pellets Industrial Air pollution Emission Standard” and ultra-low emission limits, strictly control SO₂ and NO_x in sintered flue gas and other pollutants. The source of the pollutants in the sintering flue gas is closely related to the combustion of the fuel in the sintering process,^{1,2)} and more than 90% of the NO_x in the sintering process is derived from the organic nitrogen-containing compound in the fuel. The source of SO₂ in sintering flue gas is mainly produced by the reaction of FeS₂ and FeS in iron ore or S in fuel with oxygen. It is generally believed that the rate of S generating SO₂ can reach 85–95%.^{3,4)} The content of S and N in biomass fuel is low, and the source of sintering pollutants can be controlled by using biomass fuel sintering.^{5,6)} The circulating sintering process of flue gas can greatly reduce the flue gas emissions, and effectively use the waste heat of sintering flue gas to realize the process control of sintering flue gas pollutants.^{7–9)} Therefore, the protection of the environment and the comprehensive utilization of resources as the starting point, the flue gas circulating sintering based on biomass fuel is studied, and the friendly environment production of

iron ore sintering is realized through the source control and process control of sintering flue gas pollutants.

At present, the sintering process of biomass fuel instead of coke breeze and flue gas circulating sintering has been studied. Liu C. *et al.*^{10–12)} studied the preparation of biomass sintering fuel and the effect of biomass fuel instead of coke sintering on the sinter properties. The results showed that the suitable biomass fuel instead of coke did not affect the sinter properties. Chen X.L. *et al.*¹³⁾ studied the effects of flue gas recirculation ratio on sintering of different iron ores including haematite, magnetite and limonite. Gan M. *et al.*^{14,15)} studied on iron ore sintering process of flue gas recirculation together with using biochar as fuel, and the results show that the proper proportion of biomass replacing coke breeze had little hardness to the productivity and the quality of sinter, meanwhile, which could alleviate fossil fuel crisis and realize the comprehensive utilization of energy. However, the flue gas circulating sintering based on the biomass fuel co-control of flue gas pollutants is rarely reported. If the conventional flue gas circulating process is directly applied to biomass fuel sintering without selective utilization, it is bound to affect the sinter metallogenic properties, energy saving and emission reduction effect. In this paper, the effects of fuel gas temperature, and oxygen, SO₂ content and NO_x content on the properties and the emission of flue gas pollutants are studied by using charcoal instead of partial coke breeze in flue gas circulating sintering pot experiments. At the same time, the suitable substitution amount of charcoal under the condition of flue gas cycle is studied, which provides a theoretical basis for the reason-

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Table 1. The sintering experiment scheme (mass fraction/%).

Raw materials	TFe	FeO	SiO ₂	CaO	MgO	Al ₂ O ₃	S	N	LOI	Ratio
Iron ore	60.65	5.08	4.26	2.62	0.75	1.74	0.028	0.016	-2.29	83.20
Limestone	0.12	0.12	2.72	47.56	3.77	0.72	0.005	—	40.76	3.43
Lime	0.26	0.18	3.52	72.33	4.52	1.00	0.180	—	20.97	4.07
Dolomite	0.31	0.20	1.38	29.61	21.85	0.18	0.090	—	45.54	4.71
Coke	—	—	6.44	1.18	0.38	3.90	0.632	0.805	83.00	2.70
Charcoal	—	—	—	—	—	—	0.03	0.16	—	1.80

able application of biomass fuel and flue gas cycle in the iron ore sintering process.

2. Materials and Methods

2.1. Raw Materials

The experimental raw materials were from a steel sintering workshop in Tangshan, the basicity of the sintering mixture was 2.0, the content of MgO was 2.0%, the Al₂O₃ content was 1.5%, and more than 80% the fuel particle size is larger than 3 mm. According to the experimental results of sintering pot, 40% charcoal and 60% coke breeze were used as sintering fuel for flue gas cyclic sintering.^{10–12)} The composition and proportion of experimental raw materials were shown in **Table 1**, and the particle size distribution of raw material was shown **Table 2**.

2.2. Flue Gas Circulating Sintering Pot Experiments

The sintering raw material was granulated by cylinder mixer, and the mixing time was 3 minutes, raw material water content was 7.5%. After granulation, it was put into the sintering pot by rotating cloth method. The flue gas circulating sintering pot equipment was composed of gas distribution system, hot blast stove and sintering pot, in which the gas distribution system is composed of 40 L seamless cylinder (N₂, O₂, CO₂, CO, SO₂ and NO) and air compressor. The concentrations of O₂, SO₂ and NO in sintered fuel gas were controlled by adjusting the flow rate in each cylinder, the concentration of flue gas in sintering pot was detected by testo 350 flue gas analyzer, and the mixed gas was pre-heated to the specified temperature by the hot-blast stove. The effects of oxygen content in circulating flue gas, flue gas temperature, SO₂ and NO_x content in flue gas on sintering index and metallogenic properties were studied in experiments. the schematic diagram of flue gas circulating sintering equipment was shown in **Fig. 1**.

2.3. The Calibration Experiments of O₂, SO₂ and NO_x Output Pressure

Nitrogen is added to a sintered pot filled with the mixture and the oxygen content was reduced to 18.9%, 16.9%, 14.9% and 12.9% by adjusting the output pressure of nitrogen, which studied the effect of oxygen content in flue gas on sintering indexes and metallogenic properties in flue gas circulating sintering process. **Figure 2** showed the oxygen content of flue gas under different N₂ output pressure.

According to SO₂ emission characteristics of sintering flue gas, the effect of SO₂ content in circulating flue gas on sintering index and metallogenic properties were studied.

Table 2. The particle size distribution of raw material (mass fraction/%).

Raw materials	<0.25 mm	0.25–1 mm	1–2.5 mm	2.5–5 mm	>5 mm
Iron ore	10.91	15.71	29.97	21.09	22.32
Limestone	19.07	19.42	46.44	14.00	1.07
Lime	53.37	15.12	31.15	0.36	0.00
Dolomite	31.00	17.62	36.76	14.62	0.00

Fig. 1. Schematic diagram of flue gas circulating sintering equipment. (Online version in color.) **Fig. 2.** Relationship between N₂ output pressure and oxygen content in flue gas. (Online version in color.)

The SO₂ content in circulating flue gas was controlled by adjusting the output pressure of SO₂, where **Fig. 3** showed the corresponding SO₂ content in circulating flue gas under different SO₂ output pressure.

Fig. 3. Effect of oxygen content in flue gas on sinter properties. (Online version in color.)

Fig. 4. Effect of flue gas temperature on sinter properties. (Online version in color.)

According to NO_x emission characteristics of sintering flue gas, the influence of NO_x content on sintering index and metallogenic properties was studied by adjusting the output pressure of NO gas cylinder. The NO content in circulating flue gas was set to 0 ppm, 100 ppm, 300 ppm, 500 ppm and 700 ppm, respectively. The NO content in flue gas under different NO output pressure was shown in Fig. 4.

3. Results and Discussions

3.1. Effect of Oxygen Content in Flue Gas on Sinter Properties

According to the sintering index obtained by sintering pot experiment under different oxygen content conditions, the effects of oxygen content in flue gas on vertical sintering rate, yield, drum strength and FeO content were studied. The sintering index and metallogenic performance were shown in Fig. 5.

As can be seen from Fig. 5, with the decrease of oxygen content in sintered flue gas, the fuel burnout time in sintered mixture were prolonged with the constant oxygen consumption, which lead to the continuous increase of sintering time

Fig. 5. Effect of biomass addition on sinter properties under circulating flue gas. (Online version in color.)

and the decrease of vertical sintering rate. Especially when the oxygen content of flue gas was less than 14.9%, the vertical sintering rate decreased significantly, which seriously affected the sintering production efficiency. When the flue gas content decreased from 20.9% to 18.9%, the yield increased from 77.61% to 79.5%, and sinter strength also increased slightly from 61.35% to 62.11%. The reason for this result may be due to the decrease of oxygen content in flue gas, the slow sintering rate and the prolongation of the whole sintering process, resulting in the broadening of sintering combustion layer, the increase of sintering temperature and the increase of low melting point liquid content, and the particle size and strength index of sinter increased. However, with the decrease of oxygen content in flue gas to 14.9%, the yield and strength index of sinter decreased, the yield decreased to 75.22%, and the strength index decreased to 59.67%. When the oxygen content in flue gas was reduced to 12.9%, the sinter strength and yield decreased obviously. The reason for this result may be that the oxygen content of flue gas was too low, the fuel in sintered mixture can not be fully burned in time, resulting in low combustion layer temperature, low melting point mineral liquid content, low sinter strength and low yield. With the decrease of oxygen content in flue gas, the content of FeO in sinter increased. The reason for this result was that with the decrease of oxygen content in flue gas, the reduction atmosphere inside the sinter layer increased, and the iron oxide in sinter was reduced step by step. Finally, the content of FeO in sinter increased gradually.

In summary, when the oxygen content of circulating flue gas was less than 14.9% based on 40% charcoal and 60% coke were used for sintering, the vertical sintering rate, the sinter strength and yield decreased obviously, meanwhile, the content of FeO in sinter increased, which seriously affected the sinter properties and production. Therefore, it was recommended that the minimum oxygen content of the circulating flue gas was 14.9%.

3.2. Effect of Flue Gas Temperature on Sinter Properties

According to the temperature characteristics of sintered flue gas, the gas is heated to 200°C, 250°C and 300°C by a hot blast stove respectively, in which the sintered flue gas

contains 0.85% CO and 14.9% O₂. The effects of flue gas temperature on sinter properties were studied by the sintering pot experiments, and the experimental results were shown in Fig. 6.

Figure 6 showed that the vertical sintering rate slowed down with the increase of flue gas temperature under the condition of injecting 0.85% CO in fuel gas. According to the Ergun Eq. (1), it can be seen that the temperature of the gas involved in the sintering reaction was higher than that of the conventional sintering under the same sintering negative pressure, and the viscosity of the gas increased, which increased the volume of the gas per unit mass and the oxygen content of the sintered flue gas was low, and the effective air volume entering the sinter layer decreased. Meanwhile, the high temperature gas brought the extra heat under the agglomerating agent is constant, the thickness of the sintering combustion layer increased, the sintering liquid phase amount increased, and the porosity of the sintering layer decreased accordingly, which increased the resistance of the gas passing through the sintering layer, and the higher the flue gas temperature, the lower the vertical sintering rate was, the lower the sintering efficiency of iron ore powder was.

$$\frac{\Delta P}{H} = 150 \frac{(1-\varepsilon)^2}{\varepsilon^3} \frac{\mu u}{d_v^2} + 1.75 \frac{(1-\varepsilon)}{\varepsilon^3} \frac{\rho_f u^2}{d_v} \dots\dots\dots (1)$$

Among, ΔP : Sintering pressure drop, Pa. H : Sinter layer thickness, m. ε : Porosity of sinter layer, %. μ : Fluid viscosity, Pa·s; u : Superficial velocity, m·s⁻¹. d_v : Equivalent diameter of sintered mixture, m. ρ_f : Fluid density, kg·m⁻³.

The sintering yield increases with the increase of flue gas temperature. The reason for the result was that the high temperature flue gas can replenish the heat shortage of the upper layer and slow down the cooling rate of the surface sinter. The stress damage caused by edge effect and rapid cooling was weakened, especially the sinter strength of 80–100 mm on the surface of sintering layer was increased, and the yield was increased. However, the high temperature would lead to the formation of large sinter block, degrade the permeability of sinter layer and reduce the utilization coefficient.

The strength of sinter increased with the increase of flue gas temperature involved in sintering. The reason for the result was that the higher the flue gas temperature is, the more heat is in the sintered layer, the thicker the high temperature layer is, and the longer the duration of high temperature is, so the amount of liquid phase in sintering increased. The higher the flue gas temperature, the slower the cooling rate of sinter, which was beneficial to the precipitation and growth of sinter phase crystal, the increase of bonded phase in sinter and the improvement of sinter strength. Therefore, the high temperature flue gas could improve sinter strength.

With the increase of flue gas temperature, the content of FeO in sinter increased. The Eq. (1) showed that the gas viscosity increases with the high temperature of the gas involved in the sintering reaction, the increase of gas volume per unit mass, so the oxygen content in the unit volume of flue gas was reduced, and the sintering bed temperature was increased, which were beneficial to the step-by-step reduction reaction of FeO_x, which lead to the increase of FeO content in sinter, and the formation of iron olivine phase was not conducive to the formation of calcium ferrate.

Fig. 6. The microstructure of sinter under different conditions. (a) conventional sintering, (b) flue gas circulating sintering + 40% charcoal, (c) flue gas circulating sintering + 50% charcoal, (d) flue gas circulating sintering + 60% charcoal.

The reducibility of sinter was degraded and the coke ratio of blast furnace in late smelting was increased.^{16,17)} Under the condition of flue gas circulating sintering, the higher the flue gas temperature was, the higher the FeO content

in sinter was.

Above all, on the basis of 0.85% CO in the flue gas, the higher flue gas temperature was, the more beneficial to improve the yield and strength of sinter, but it would reduce the vertical sintering rate and affect the sintering production efficiency. At the same time, the FeO content will be increased to degrade the sintering reduction property. On the premise of ensuring the sinter property and maximizing the emission reduction of flue gas pollutants, the flue gas cycle temperature was selected to be 200°C.

In order to make full use of the waste heat of flue gas, the addition of charcoal was further increased to 50% and 60% under the flue gas condition of 0.85% CO and 200°C, and the sintering indexes were shown in Fig. 7.

As shown in the Fig. 7, under the fuel gas condition of 0.85% CO and 200°C, the addition of charcoal was increased from 40% to 50%, the vertical sintering rate was increased, and the sinter yield, drum strength and FeO content are slightly decreased. However, all the indexes were basically the same as those of conventional sintering, and can meet the requirements of iron ore sintering. When the charcoal continued to increase to 60%, the vertical sintering rate continued to increase, the sinter yield, drum strength and FeO content continued to decrease, and the index values are worse than those of conventional sintering. Therefore, according to the effect of different amount of charcoal on sintering index, it was suggested that the suitable addition of charcoal was 50%.

The sinter obtained under different sintering conditions was treated by sample mosaic, polishing and gold spraying. The microstructure of sinter was observed by scanning electron microscope (SEM), and the results are shown in Fig. 8.

Figure 8(a) was a micromorphology photograph of sinter obtained by coke breeze under conventional sintering conditions. there were a certain amount of bonded phase in the sinter and the structure was uniform. Figure 8(b) was a micromorphology photograph of sinter obtained under cyclic sintering with 40% charcoal and 60% coke. Compared with Fig. 8(a), the sinter was overmelted to form a macroporous thin-wall structure. The sinter was brittle and easy to crack, and the strength properties of sinter were degraded. Figure 8(c) was the micromorphology photograph of sinter obtained by 50% charcoal and 50% coke under

the condition of flue gas circulating sintering, which was basically consistent with the microstructure of Fig. 8(a), indicating that increasing the amount of biomass fuel can prevent the overmelting of sinter in the sintering process under the condition of flue gas circulating. Figure 8(d) was a micromorphology photograph of sinter obtained by using 60% charcoal and 40% coke under the condition of flue gas circulating sintering. Due to the lack of heat, the internal liquid phase of sinter was insufficient and the bonding phase was less, which affected the sinter strength. It was difficult to meet the requirements of blast furnace burden. By comparing the microstructure of the sinter, in the production process of the flue gas circulating sintering, the addition amount of the charcoal can be appropriately increased to 50% under the premise of ensuring the performance of the sinter.

3.3. Effect of SO₂ Content in Flue Gas on Sinter Properties

There were a lot of SO₂ in flue gas and the content of SO₂ in different bellows varied greatly in the sintering process. The influence of SO₂ on sinter metallogenic properties determined the choice of circulating flue gas bellows. According to the SO₂ emission characteristics of flue gas, the SO₂ content in flue gas was adjusted to 0 ppm, 300 ppm, 500 ppm, 700 ppm and 900 ppm, respectively.

The influence of SO₂ content on sintering index was investigated by circulating flue gas with different SO₂ content. Based on the migration law of sulfur in sinter, the sulfur element in sinter at the lower layer of sinter pot was detected to determine the maximum amount of SO₂ in circulating flue gas. Table 3 was the sintering index and the sulfur content in sinter under different SO₂ content.

Through the comparison of sintering indexes, it was found that the SO₂ content in flue gas has little effect on the vertical sintering rate, and the sintering process needed to continue about 25.67 min. Meanwhile, the gas flow velocity through the material layer was measured by an anemometer, the average gas flow velocity was approximately 0.6 m/s, and the radius of the sintered pot was 100 mm, so the amount of gas was about 29 m³.^{11,18,19)} when the SO₂ content in flue gas increased to 700 ppm, the mass of SO₂ involved in sintering reaction is about 0.06 kg, and the drum

Fig. 7. Relationship between SO₂ output pressure and SO₂ content in flue gas. (Online version in color.)

Fig. 8. SO₂ emission curve in sintered flue gas. (Online version in color.)

Table 3. Sintering index and sinter sulphur content.

SO ₂ /ppm	Vertical sintering rate/ mm·min ⁻¹	Yield/%	Strength/%	S content/%
0	25.32	75.62	61.38	0.025
300	25.28	74.95	61.09	0.027
500	25.3	75.22	60.35	0.023
700	25.33	75.22	55.82	0.036
900	25.39	72.29	53.16	0.041

strength decreased obviously. When the SO₂ content in flue gas increased to 900 ppm, the sinter yield decreased from 75.56% to 72.29%. Through the detection of sulfur content in sinter, it is found that when the SO₂ content in flue gas increased to 700 ppm, the residual sulfur content in sinter increased significantly. The reason for this result might be that the flue gas was continuously pumped into the material layer under the action of negative pressure, the SO₂ of flue gas was constantly recycled and enriched in the material layer, the higher the concentration of SO₂, the greater the SO₂ content in the material layer. The SO₂ reacted with CaO to form CaSO₃ or CaSO₄, and the higher SO₂ content, the more CaO was consumed, which inhibited the formation of calcium ferrate phase in sinter, and reduced the amount of sintering liquid phase. Thus, the yield and drum strength of sinter were affected. Based on the above results, it was suggested that the SO₂ content should be less than 500 ppm in the flue gas circulating sintering process, and the SO₂ emission curves were obtained by using the flue gas analyzer to detect flue gas sintering with different SO₂ contents, as shown in Fig. 9.

From the SO₂ emission curve in sintering flue gas in Fig. 9, the distribution of SO₂ emission curve in flue gas was bimodal distribution. When the fuel burned and released heat at ignition, the permeability of the material layer was good, and the flux in the material layer was too late to absorb all the SO₂ in the flue gas, therefore, some SO₂ could enter the large flue, and the detection curve would appear the peak value. When there is a certain amount of SO₂ in the circulating flue gas, the SO₂ emission curve would have a peak value after ignition compared with conventional sintering, which was the SO₂ in the circulation flue gas enters the sintering layer to participate in the sintering reaction after ignition, which led to the instantaneous increase of SO₂ content in sintering flue gas, and the peak value of SO₂ emission increased with the increase of SO₂ content in circulation flue gas. With the progress of sintering, the SO₂ content decreased to a lower value and remained stable. The reason for this result was that the moisture in the raw material was enriched in the lower material layer to form an overwet layer under the suction action of negative pressure, so the permeability of the material layer became worse, which provided the reaction conditions for the absorption of SO₂ by the material layer. The higher the SO₂ content, the greater the amount of SO₂ absorbed by the material layer. Because the SO₂ content in flue gas was the sum of SO₂ in circulation flue gas and SO₂ produced by sintering, the content of unabsorbed SO₂ in flue gas increased, and the emission concentration of SO₂ in sintering flue gas increased. Near the end of sintering, due to the complete reaction of flux in

Fig. 9. The relationship between NO output pressure and NO content in flue gas. (Online version in color.)

the material layer and the decomposition of sulfate at high temperature, the SO₂ absorbed by the material layer was released again, resulting in the peak value of SO₂ emission curve. With the increase of SO₂ content in circulating flue gas, the peak value of SO₂ in sintering flue gas increased and the emission range widened. Due to the material layer could absorb SO₂, the concentration of SO₂ in sintering flue gas was consistent with the initial SO₂ content in circulating flue gas after sintering. The total emission was lower than the sum of SO₂ in the conventional sintering flue gas and the SO₂ content in the circulation flue gas, the emission reduction of SO₂ could be realized in the circulating flue gas sintering.

Conclusions As a result, when the SO₂ content in flue gas increased from 500 ppm to 700 ppm, the drum strength and yield decreased obviously, the residual sulfur content in sinter increased significantly, meanwhile, the emission reduction of SO₂ in flue gas increases with the increase of SO₂ content in circulating flue gas. Based on the effect of SO₂ content on sintering metallogenic properties and pollutant emission reduction, it was suggested that the suitable content of SO₂ in circulating sintering flue gas was 500 ppm.

3.4. Effect of NO_x Content in Flue Gas on Sinter Properties

There was also a large amount of NO_x in sintering flue gas, but different from SO₂, the NO_x content in each bellows was basically the same after ignition, so NO_x inevitably participated in the iron ore sintering reaction in flue gas circulating sintering process. The influence of NO_x content in flue gas on sintering metallogenic properties determined the amount of circulating flue gas, and the sintering index obtained under different NO_x content was shown in Table 4.

From Table 4, with the increase of NO_x content from 0 ppm to 700 ppm, the vertical sintering rate was basically maintained at 25 mm·min⁻¹, the yield was basically maintained at about 75%, and the drum strength was basically maintained at about 61%. By comparing the sintering index, it was found that the NO_x content in flue gas has little effect on the sinter properties. At the same time, the NO_x content was obtained by detecting sintering flue gas with different NO content, and the results were shown in Fig. 10.

According to the NO_x emission curve obtained by sintering at different NO content in Fig. 10, it could be seen

that the trend of NO_x emission curve in sintering flue gas was basically the same. With the increase of NO content, the emission concentration of NO_x in sintering flue gas increased. The concentration of NO_x in flue gas increased rapidly after sintering ignition. When NO was 0 ppm in the circulating flue gas, the NO_x in the sintering flue gas began to decrease with the end of the ignition stage. The reason was that after adding 50% biomass fuel, the total nitrogen content of fuel was low, so the NO_x in sintering flue gas showed a downward trend. When the NO gas was added into the circulating flue gas, the concentration of NO_x in sintering flue gas increased sharply by introducing circulating gas after ignition, and the fuel began to burn in large quantities to release NO_x . The NO_x emission curve presented an increased tendency, and then tended to be stable after stability. The higher the concentration of NO in circulating gas, the more obvious the decreasing trend of NO_x emission curve in sintering flue gas. The reason for this result was that the higher the amount of NO in circulating flue gas, the greater the amount of NO_x was reduced in the sintering process under the action of calcium ferrate phase and CO, which reduced NO_x emission concentration in sintering flue gas.^{20–22)} After approaching the end of sintering, the concentration of NO_x in flue gas decreased significantly and finally returned to the initial concentration of NO. The

reason was that the fuel burned completely near the end of sintering, and the fuel and sintering raw materials no longer produced NO_x . However, because the circulating gas contained NO, CO in flue gas and residual carbon in sinter would reduce part of NO in the cooling process of sinter. The higher the initial concentration of NO in circulating flue gas, the greater the reduction amount of NO_x . From the influence of NO in circulating flue gas on sinter metallogenic properties and NO_x emission concentration it could be seen that because NO has little effect on the sinter properties, the flue gas with high NO_x concentration could be selected for circulation sintering, so as to achieve the goal of maximizing the emission reduction of NO_x .

3.5. Effect of Flue Gas Cyclic Sintering on Sintering Pollutants Content

The influence of the addition amount of the charcoal and the circulating flue gas characteristic on the performance of the sinter were studied by the sintering pot experiments. The SO_2 and NO_x in the sintering flue gas obtained by the sintering of conventional, 40% charcoal and 60% coke and 50% charcoal and 50% coke were detected, respectively. The experimental scheme was as shown in Table 5, and the distribution curves of the SO_2 and NO_x in the sintering flue gas pollutants were shown in Fig. 11.

By comparing the distribution curves 1 and 2 of SO_2 and NO_x in sintering flue gas in Fig. 11, it could be seen that sintering with 40% charcoal instead of coke, the peak emission concentration of SO_2 in sintering flue gas decreased from 1 180 ppm to 820 ppm, and the peak emission concentration of NO_x decreased from 165 ppm to 120 ppm. Therefore, the SO_2 and NO_x emissions of flue gas could be reduced by 28.2% and 25.7% by using charcoal instead of coke sintering. The curve 3 in Fig. 11 was the emission curve of SO_2 and NO_x obtained by flue gas circulating sintering with 50% charcoal, where the SO_2 emission curve 3 in Fig. 11(a) was due to the SO_2 , containing 500 ppm in the circulating flue gas after the first peak value. Therefore, the SO_2 increased sharply after the introduction of flue gas, and the second peak value appeared, and then the SO_2 was gradually absorbed by flux in the material layer. The SO_2 emission curve was maintained at about 92 ppm during sintering. Because there were 500 ppm NO in circulating flue gas, the NO_x emission increased instantly after ignition of curve 3 in Fig. 11(b), and due to the reduction and decomposition of some NO_x in sintering process, the NO content in flue gas decreased gradually. The peak value of NO_x emission appeared at the beginning of sintering was about 549 ppm. After the sintering end point, the flue gas circulating sintering SO_2 was restored to the initial value, and the NO_x was continuously reduced and decomposed, and then the initial value was restored. Although the SO_2 and NO_x content in flue gas increased significantly after circulating

Table 4. Sintering performance index.

NO/ppm	Vertical sintering rate/mm·min ⁻¹	Yield/%	Strength/%
0	25.32	75.62	61.38
100	25.66	74.26	60.88
300	25.18	75.33	61.11
500	24.93	76.02	61.25
700	25.63	75.22	60.59

Fig. 10. NO_x emission curve in sintered flue gas. (Online version in color.)

Table 5. Experimental scheme for control of sintering flue gas pollutants.

No.	Charcoal/%	Oxygen content/%	SO_2 content/ppm	NO content/ppm	Sintering type
1	0	21	0	0	Conventional sintering
2	40	21	0	0	Conventional sintering
3	50	14.9	500	500	Flue gas circulating sintering

Fig. 11. Distribution curve of SO_2 and NO_x in sintering flue gas. (a) SO_2 distribution curve in flue gas, (b) NO_x distribution curve in flue gas. (Online version in color.)

sintering, the relative peak value (The calculation method was to subtract the content of SO_2 and NO_x contained in flue gas by using the peak emission of SO_2 and NO_x in flue gas circulating sintering) decreased from 1180 ppm and 165 ppm to 610 ppm and 49 ppm, respectively, which compared with conventional coke sintering. Based on charcoal circulating sintering, the enrichment of pollutants SO_2 and NO_x could be realized. Through the experiment of sintering pot, it could be seen that the end treatment amount of sintering flue gas pollutants was reduced, and the relative emission reduction of SO_2 and NO_x was more than 42.6% and 65.8% in the flue gas of sintering pot. Through the emission curve of flue gas pollutants, it could be seen that the cooperative control of sintering flue gas pollutants could be realized fuel gas circulating sintering process based on biomass fuel.

4. Conclusions

Through the experiments of biomass fuel flue gas circulating sintering pot, the influences of oxygen content, temperature, suitable amount of charcoal, SO_2 content and NO_x content on sintering metallogenic properties and flue gas pollutants emission were studied.

Based on the charcoal instead of 40% coke circulating flue gas sintering, the suitable oxygen content in flue gas was 14.9%, and the maximum suitable concentration of SO_2 was 500 ppm. The NO_x had little effect on the sintering performance index. The higher the concentration of NO_x in flue gas, the greater the reduction of emission. Under the conditions of flue gas temperature of 200°C and carbon monoxide content of 0.85%, the content of charcoal instead of coke breeze was increased from 40% to 50%, which ensured the sintering metallogenic properties. The emission reduction of sintering flue gas pollutants SO_2 and NO_x was more than 42.6% and 65.8% in the sintering pot experiments, respectively. At the same time, the end treatment amount of sintering flue gas pollutants was reduced, and the comprehensive utilization of sintering flue gas waste heat and the cooperative control of sintering flue gas pollutants were realized.

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