Study on Effect of Material Layer Thickness on Pollutant Emissions from Sintered Flue Gas

Chen Zhang[a], Yutao Cui[b], Yun Shu[c], Li Yang*[d] and Jinwei Zhu*[e]
Chinese Research Academy of Environmental Sciences, Beijing 100012, China

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Abstract: Herein, a 210-m^2 sintering machine was tested under different material layer thickness conditions to investigate the effect of the thick layer sintering technology on the emissions of flue gas pollutants from the sintering machine. The relationship between the material layer thickness and pollutant emission concentration, sinter output and drum index was studied using a flue gas analyser (MH3200). The results show that the discharge of gaseous pollutants has a positive linear correlation with the material layer thickness during the sintering process of SO_2, NO and CO. Furthermore, the emission of pollutants per tonne of product decreases as the layer thickness increases. When the thickness of the material is increased from 550 to 650 mm, the emissions of SO_2, NO and CO per tonne of the sintered ore can be reduced by 0.22, 0.07 and 1.7 kg/t, respectively.

1 INTRODUCTION

As a major steel country, China's steel industry output has ranked first in the world for many years. According to statistics from the China Iron and Steel Association, China's steel output exceeded 900 million tonnes in 2018, accounting for 50% of the world's steel output. The iron and steel industry is an industry with high energy consumption and high pollution. Besides, environmental pollution has received much attention. With the continuous deepening of pollution control work requirements in China's iron and steel industry, the industry has shifted from the traditional mode of re-production and high-efficiency to the direction of production and environmental protection. However, the steel industry has become the largest source of gaseous pollutants due to several companies, the large amount of pollutant emissions and the uneven level of corporate management and environmental protection. In 2017, sulphur dioxide (SO_2), nitrogen oxide (NOx) and particulate matter (PM) emissions from the iron and steel industry accounted for 7%, 10% and 20% of the total national emissions (Li 2018, Yan 2015, Yu 2017). For this reason, in 2019 the 'Opinions on Promoting the Implementation of Ultra-Low Emissions in the Iron and Steel Industry' jointly issued by the Ministry of Ecology and Environment and other five ministries and commissions included access to new reconstruction and expansion projects of iron and steel enterprises, the promotion of ultra-low emission transformation, the elimination of outdated production capacity and the strengthening of pollution emission monitoring and monitoring new corresponding requirements put forward in other aspects.

The iron and steel industry mainly adopts the conventional blast furnace converter technology in China. The sintering process, which is an important link in steel production and also the main process for emitting gaseous pollutants in iron and steel enterprises (Liao 2018, Wang 2013, Zhu 2014), provides more than 70% of the charge to the blast furnace. Sintering flue gas has the characteristics of large flue gas volume and high pollutant concentration. According to relevant literature reports, the emission of SO_2, NOx and PM in the sintering process can account for ~60%, 50% and 20% of the total emissions of iron and steel enterprises (Wang 2017, Chen 2015, Taira 2019). Among them, SO_2 in the flue gas of the sintering

[a] https://orcid.org/0000-0003-1347-1824
[b] https://orcid.org/0000-0003-0091-7612
[c] https://orcid.org/0000-0002-7575-5956
[d] https://orcid.org/0000-0003-0021-0166
[e] https://orcid.org/0000-0003-4034-736X

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machine mainly comes from the sulphides (such as FeS_2 and $CuFeS_2$) and sulphates (such as $BaSO_4$ and $CaSO_4$) in the iron ore, and partly comes from the elemental and organic sulphur in the fuel. Note that the elemental sulphur is the main component. Sulphide reacts with organic sulphur and oxygen to generate SO_2, which is released after sulphate decomposition. The NO_x from the combustion process is mainly divided into three types: thermal, fuel and fast types. (1) Thermal-type nitrogen oxides are generated by the reaction of N_2 and O_2 in air during combustion. (2) Fuel-type nitrogen oxides are generated by the oxidation of N in the fuel during combustion. (3) Rapid nitrogen oxides are produced by the reaction of N_2 in air with hydrocarbon groups in the fuel to generate HCN, CN and other NO precursors, which are then further oxidised. During sintering, the combustion temperature is <1500°C, and the thermal NO_x is minute. Therefore, the NO_x in the flue gas of the sintering machine mainly comes from the combustion process of solid fuel, that is, fuel-based NO_x, usually >90% of NO_x. CO generation mainly comes from the incomplete combustion of solid fuels in the sintering process, mainly in the combustion zone and the preheating drying zone. Also, the reaction of C with CO_2 and Fe will also generate CO (Liu 2013, Williams 2012, Li 2014).

Presently, treatment technology for sintering machine flue gas is mainly divided into three categories: raw material control, sintering process control and end flue gas treatment technology (Chun 2017, Xing 2014). The end treatment technology mainly adopts the FGD + SCR denitrification technology. Among them, the desulphurisation technology mainly applies to wet desulphurisation and semi-dry desulphurisation. A few companies adopt the activated carbon adsorption-integrated flue gas purification technology. These treatment technologies can effectively control the SO_2 and NO_x emission in the flue gas. However, with the implementation of ultra-low emission standards in the steel industry, the ultra-low emission of sintering flue gas through the upgrading and transformation of desulphurisation and denitrification facilities will significantly increase the production of enterprises. Operating costs are not conducive to the long-term development of enterprises (Long 2016, Wang 2020, Cheng 2019). Faced with dual pressures of production and environmental protection, several new sintering technologies for energy saving and emission reduction have emerged, such as thick material layer sintering technology, combustible gas auxiliary combustion technology, fuel distribution technology, material surface steam injection technology and low-temperature sintering technology, Hot air circulation sintering technology has been widely used in the actual production (Huang 2019, Zhang 2019, Fan 2014, Lu 2015). Herein, the influence of the material layer thickness changes on the emission of pollutants is studied using the actual flue gas. The current research in this direction is mainly focused on the impact of the material layer thickness on the production cost of the sintering machine and the improvement of the quality of the sintered ore. However, few studies exist on the gaseous pollutant emission of the sintering machine, and the research is mainly limited to the sinter cup test—actual on-site monitoring. To deeply analyse the influence of the material layer thickness on the air pollutant emission from the sintering machine, a sintering machine with a scale of 210 m^2 of a certain enterprise was selected as the experimental platform, and the NO, SO_2, CO and other pollution in the airbox and sintering flue of the sintering machine. The changes in the concentration of the substances and O_2 before and after the changes in the material layer thickness are monitored and analysed to clarify the changing law of gaseous pollutant emissions from the sintering machine under different material layer thicknesses and provide data support for the subsequent environmental protection of the flue gas of sintering machines.

2 MATERIALS AND METHODS

2.1 Sintering Machine Parameters

Herein, a 210-m^2 sintering machine was selected as the research object for industrial testing. The composition analysis of 22 wind boxes and sintering flue gas on one side of the sintering machine was performed. Figure 1 shows the monitoring points. By changing the material layer thickness of the sintering machine (550 mm × 600 mm × 650 mm), the pollutant emission was analysed. Table 1 presents the main chemical components of the sintering raw materials.

Table 1: Chemical composition of main raw materials.

Raw material	TFe	SiO_2	CaO	Al_2O_3	MgO	H_2O
Iron sheet	71.00	0.80	-	0.00	-	8.00
Dolomite powder	-	2.50	30.00	-	20.00	3.00
Limestone powder	0.00	3.00	47.00	0.00	4.50	3.00
Miscellaneous	50.00	6.60	12.80	2.60	2.80	6.00
Mixed return mine	54.60	5.40	10.60	2.60	2.80	2.00
Steel slag	35.00	12.00	35.00	-	9.93	6.00
Coke breeze	0.00	40.00	7.00	1.60	-	10.00

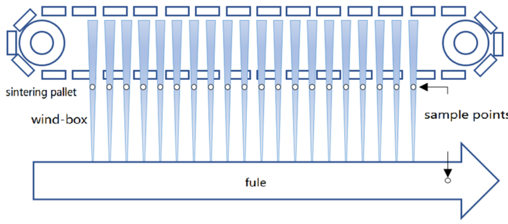

Figure 1: Schematic of monitoring locations.

2.2 Detection Equipment and Methods

Qingdao Minghua Electronic Instrument Co., Ltd. MH3200 ultraviolet differential method flue gas analyser was was used. It adopts ultraviolet differential absorption spectroscopy measurement. The principle is thermal wet method, the whole process of the gas chamber-heating design, the flue gas is extracted from the flue after several grades of filtration, enter the optical detection gas chamber, the entire gas path is heated at high temperature, and the water vapour is completely vaporised, avoiding the interference of moisture on the gas adsorption.

3 RESULTS & DISCUSSION

3.1 Regular Distribution of Pollutants in Wind Boxes

The material layer thickness of the sintering machine as 600-mm (daily conditions) is selected as the reference-working condition. Next, the distribution law of the air box pollutants is analysed. Using the same monitoring programme, under the premise of maintaining a constant raw material ratio, the wind box and sintering flue gas under the working conditions of 550 and 650 mm material layer thickness were detected. Figure 2 shows the change in the wind box.

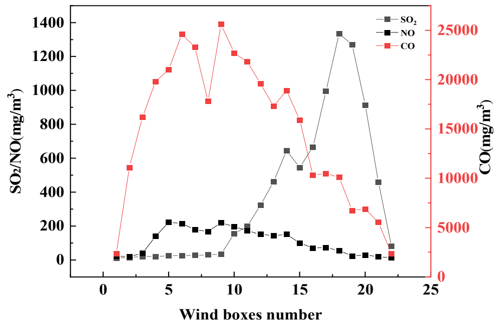

Figure 2: Distribution of smoke components in wind boxes.

3.1.1 SO_2 Emission Regular Analysis

Figure 2 shows that SO_2 emissions can be divided into three distinct characteristic intervals during the entire sintering process. The first interval is before the 9th wind box, and the SO_2 emission concentration in each wind box is low, all below 35 mg/m^3. The second interval started from the 10th wind box; the SO_2 emission concentration increased obviously, after nine wind boxes, it culminated at the 18th wind box position 1335 mg/m^3). Afterwards, there comes the third interval, where the SO_2 emission concentration decreased rapidly. After passing through four wind boxes, the concentration decreased to 100 mg/m^3. This trend can be ascribed to the fact that SO_2 is mainly generated in the combustion and dry preheating zones (Figure 3 shows the schematic of the change in the sintered material layer), and its formation mechanism is the oxidation reaction of sulphide, elemental sulphur and sulphate. After preheating and decomposition, SO_2 will be absorbed again, forming sulphate and sulphide due to the joint action of alkaline flux and moisture when passing through the over-humid zone as the flue gas moves from top to bottom. During sintering, the over-humidity zone gradually disappears, and SO_2 is released into the flue gas again. When the combustion zone disappears, the SO_2 emission concentration decreases rapidly, thus forming this emission characteristic. The results are consistent with those of previous studies (Wang 2019, Fan 2019).

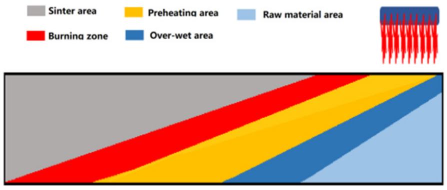

Figure 3: Schematic diagram of material layer changes.

3.1.2 NO Emission Regular Analysis

The emission concentration of NO_2 in each wind box was <5 mg/m^3, so the emission characteristics of NO_x and NO were consistent. Thus, the emission characteristics of NO needed to be analysed only. Figure 2 shows that NO emissions have three distinct characteristic intervals. The first interval is before the 4th wind box, and the NO emission concentration is below 40 mg/m^3. Afterwards, the second interval starts from the 4th wind box. The concentration increased significantly and culminated at 219.8 mg/m^3 in the 9th bellows, and the third interval comes afterwards, and the NO concentration decreased slowly. On reaching the 22nd bellows, its emission concentration was close to 10 mg/m^3. This emission law is caused because NO produced during the sintering process is basically the fuel-type NO, and the concentration depends on the combustion state. At the beginning of sintering, the combustion zone is small, so the NO emission concentration is low. As the sintering progresses, the combustion zone gradually stabilises, and NO emission concentration tends to stabilise after increasing. Towards the end of the sintering process, the combustion zone gradually decreases, and the NO emission concentration gradually decreases (Min 2016, Zhou 2016).

3.1.3 CO Emission Regular Analysis

Figure 2 shows that the first characteristic interval of CO emissions occurs before the 5th wind box. At this stage, the CO concentration in the flue gas rapidly increases above 20000 mg/m^3. The second characteristic interval occurs from the 5th–11th box. In this interval, the CO concentration is above 20000 mg/m^3, and the concentration of the 9th bellows is the highest at 25600 mg/m^3. Afterwards, there comes the third characteristic interval. Starting from the 12th bellows, the CO concentration decreases rapidly, and when it reaches the 22nd bellows, the concentration becomes as low as 1500 mg/m^3 or less. This trend occurs because CO is mainly formed by the incomplete combustion of solid fuels. Therefore, the CO concentration increases rapidly after ignition. When the combustion zone is stable, the CO emission concentration is relatively stable. The CO emission concentration decreases considerably when the sintering process approaches the endpoint (Pei 2019, Wang 2019, Zhu 2006). The CO emission trend is similar to that of NO, which comprises the characteristic rapid increment in the concentration of the head of the sintering machine, the stable concentration of the middle section, and the rapid decrease in the concentration of the tail of the sintering machine.

3.1.4 Response Relationship Analysis between Material Layer Thickness and Pollutant Discharge Concentration

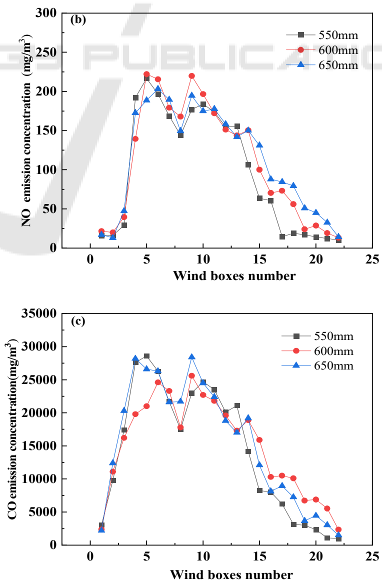

Figure 4: Comparison of air box pollutant concentration under different material thicknesses.

Figure 4 (a)–(c) compare the concentration of SO_2, NO and CO of each wind box under different material layer thicknesses. As the thickness of the sintering material layer increases, the pollution distribution curve significantly shifts to the right. This trend occurs because the material layer thickness increases as the air resistance increases. When the wind speed and air volume passing through the material layer decrease, the vertical sintering speed also decreases. In Figure 4, the concentrations of SO_2, NO and CO increase as the material layer thickness increases, which is mainly caused by the following two reasons. First, as the material layer thickness increases, the air resistance increases, and the flow rate of the flue gas in the sintering flue decreases. Second, the main sources of SO_2, NO and CO are related to fuel combustion, and the increase in raw materials and fuel will inevitably increase the total amount of pollutants produced. Under the combined action of the two, the increase in the material layer thickness leads to a rise in the pollutant emission concentration.

Table 2: Emission concentrations of sintered flue gas of different layer thicknesses.

Material layer thickness (mm)	Test points	SO_2 (mg/m^3)	NO (mg/m^3)	CO (mg/m^3)	O_2 (%)	Average flow rate (m^3/h)
550		414.6	107.1	9156.2	17.0	1043965
600	Sintering flue	421.9	107.6	9408.8	17.0	1082944
650		441.4	109.1	10660.8	17.6	1074708

Table 2 compares the emission concentrations of pollutants in the flue gas of the sintering flue with different material layer thicknesses. The concentration of NO and SO_2 of the sintering machine is similar under different material layer thicknesses. As the material layer thickness increases, the CO emission concentration is slightly >the other two cases when the material layer thickness is 650 mm. This trend occurs because CO generation is closely related to the incomplete combustion of the fuel. Table 2 shows that the standard flow rate of the flue gas is inversely proportional to the material layer thickness. Under the condition of the material layer thickness of 650 mm, the sintering machine experiences a higher resistance of the material layer, the oxygen participating in the reaction is reduced, and the incomplete combustion of the fuel is aggravated, so CO is sintering. The concentration in the flue gas of the large flue increases significantly. From Table 2, it can be calculated that with a material layer thickness of 550 mm, the SO_2, NO and CO emission rates are respectively 432.8, 111.8 and 9558.8 kg/h, respectively. With the material layer thickness as 600 mm, the SO_2, NO and CO emission rates are 456.9, 116.5 and 10189.2 kg/h, respectively. Finally, with the material layer thickness as 650 mm, the SO_2, NO and CO emission rates are 474.4, 117.3 and 11457.3 kg/h. Figure 5(a)–(c) are the linear relationship diagrams of SO_2, NO and CO emissions versus the material layer thickness, respectively. The material layer thickness positively affects the emission of the main pollutants of the flue gas—linear correlation.

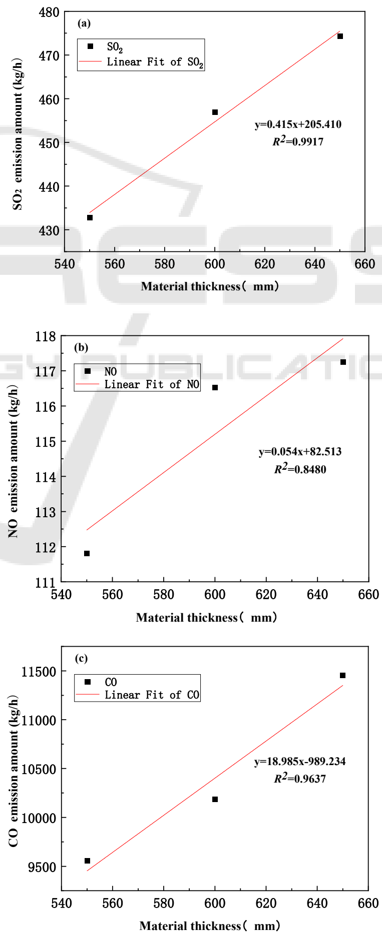

Figure 5: Linear relationship between pollutant emissions and layer thickness.

3.1.5 Effect of Material Layer Thickness on Pollutant Discharge

Table 3 shows the relevant parameters of sintering machine products under different material layer thickness conditions. As the material layer thickness continuously increases, the sinter output and utilisation factor of the sintering machine are significantly improved. This trend occurs due to the increment in the total batching amount after the material layer thickness is increased. The drum index has a small increase, which may be related to the enhancement of the heat storage effect of the sintering machine after the material layer thickness of the sintering machine increases. Figure 5 shows that as the material layer thickness increases, the emissions of various pollutants also increase. However, after converting the concentration of each pollutant to the emissions per tonne of the sintered ore, the thickness of the sintered material layer increases, and the amount of SO_2 emissions decreases from 1.79-kg/t to 1.57-kg/t-sintered ore. Meanwhile, NO emissions decrease from 0.46-kg/t to 0.39-kg/t-sintered ore, and CO emissions decrease from 39.6-kg/t to 37.9-kg/t-sintered ore. As the thickness of the sintered material layer increases, the concentration of pollutants in the sintering flue gas changes slightly. However, the emissions per tonne values of the products are significantly reduced, indicating that increasing the thickness of the sintered material positively affects the sintered material significantly, and the promotion effect also positively affects the emission reduction of the sintering flue gas pollutants (Qie 2019).

Table 3: Production of sintering machines with different layer thicknesses.

Material layer thickness (mm)	Output per unit (t/h)	Drum index (%)	Utilisation factor ($t/m^2 \cdot h$)
550	241.5	76.99	1.15
600	268.8	77.23	1.28
650	302.4	77.66	1.44

4 CONCLUSIONS

(1) The emission of SO_2 in the air box is low in the middle and later stages of the sintering process, and an obvious peak occurs in the middle and later stages of sintering. Consequently, as the over-humidity zone disappears, SO_2 is precipitated again, and the emission increases rapidly. When the combustion zone gradually disappears, the emission concentration of SO_2 decreases rapidly.

(2) The CO emission characteristics are similar to those of NO, in that the concentration of the sintering machine head increases rapidly, the emission concentration of the middle sintering stage is stable, and the emission concentration of the sintering machine tail decreases rapidly. Both are directly related to the change in the combustion zone during the fuel combustion process of the sintering machine. As the initial combustion zone thickens and its emission concentration increases rapidly, the mid-term combustion zone tends to stabilise, and its emission concentration is relatively stable. The later combustion zone shrinks until it disappears, its emission concentration decreases rapidly.

(3) SO_2, NO and CO in the sintering flue gas have a positive linear correlation with the material layer thickness. The higher the material layer thickness and the larger the batching amount, the higher the emissions of pollutants in the sintering flue gas. Comparing the production status of the sintering machine under three material layer thicknesses showed that the sintering machine has a high utilisation factor and a large product output under the high material layer thickness. The sinter drum index is slightly increased, and the SO_2, NO and CO emissions can be reduced by 0.22-kg/t, 0.07-kg/t and 1.7-kg/t-sintered ore, which indicates that the thick material layer sintering is more conducive to improving the output and quality of sintering, and has a positive effect on pollutant emission reduction.

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REFERENCES

Chen Wangsheng, Luo Jing, Qin Linbo, et al. Selective autocatalytic reduction of NO from sintering flue gas by the hot sintered ore in the presence of NH3[J]. Journal of Environmental Management, 2015, 164 (DEC.1): 146-150.

Chun Tiejun, Long Hongming, Di Zhanxi,et al.Novel technology of reducing SO2 emission in the iron ore sintering[J]. Process Safety & Environmental Protection, 2017,105: 297-302.

Cheng Zhengming, Ning Wenxin, Pan Wen, et al. Research and application of ultra-deepbed homogeneous sintering technology[J].Sintering and Pelletizing, 2019(4).

Fan Xiaohui,Yu Zhiyuan, Gan Min,et al. Appropriate Technology Parameters of Iron Ore Sintering Process with Flue Gas Recirculation[J].ISIJ International, 2014, 54(11):2541-2550.

Fan Xiaohui, Wong Guojing, Gan Min,et al.Establishment of refined sintering flue gas recirculation patterns for gas pollutant reduction and waste heat recycling[J]. Journal of Cleaner Production,2019.

Huang Jianping. Application effect of steam spraying technology on sintering surface[J]. Ferro-Alloys, 2019(6):22-25.

Li Heping, Wu Shengli1, Han Jiayou. Application of sintering flue gas cleaning technology with method of"ozone oxidation and circulating fluidized bed"[J]. Sintering and Pelletizing,2018,43(06):6-11+23.

Liao Jiyong, He Guoqiang. Progress and development of sintering technologies during the last five years[J]. Sintering and Pelletizing, 2018, 43(05):5-15+23.

Liu Chen. Research on Behavior of SO2/NOx/COx in the Process of Flue Gas Circulation Sintering of Iron Ores[D].Central South University, 2013.

Li Yuran,Yan Xiaomiao,Ye Meng,et al. Summary and evaluation for the desulfurization technologies applied in iron-steel sintering flue gas[J].Environmental Engineering,2014, 32(11):82-87.

Long Hongming, Chen Xiaolong, Chun Tiejun,et al.Sulfur balance calculation of new desulfurization technology in the iron ore sintering process[J].Metallurgical Research & Technology,2016,113(1):107.

Lu L, Ooi T C,Li X.Sintering emissions and their mitigation technologies[J].Iron Ore,2015:551-579.

Min Gan, Fan Xiaohui, Lv Wei,et al.Fuel pre-granulation for reducing NOx emissions from the iron ore sintering process[J]. Powder Technology, 2016: 478-485.

Pei Yuandong, Liao Jiyong, Zhang Junjie, et al. Discussion on CO emission reduction in iron ore fines sintering process[J]. Sintering and Pelletizing, 2019, 44(01): 73-77.

Qie J M,Zhang C X,Guo Y H,et al. Reducing the Sintering Flue Gas Pollutants Emissions Based on the Accumulation Heat Effect in Iron Ore Sintering Process[J].Transactions of the Indian Institute of Metals,2019.

Taira Kenji. NOx emission profile determined by in-situ gas monitoring of iron ore sintering during packed-bed coke combustion[J]. Fuel,2019, 236(JAN.15):244-250.

Wang Suping, Bi Xuegong, Weng Deming. Study on a New Technology of Flue Gas Desulfurization in Sintering Process [J]. Advanced Materials Research, 2013, 726-731: 2284-2290.

Wang Shijie, Zhang Qi, Zhang Gu, et al. Effects of sintering flue gas properties on simultaneous removal of SO2 and NO by ammonia-Fe(II)EDTA absorption[J]. Journal of the Energy Institute, 2017.

Williams A, Jones JM, Ma L, Pourkashanian M. Pollutants from the combustion of solid biomass fuels. Prog Energy Combust Sci 2012; 38:113–37.

Wang Jie,Zhong Wenqi. Simultaneous desulfurization and denitrification of sintering flue gas via composite absorbent[J].Journal of Environmental Sciences 96 (2020) 64–71.

Wang Feng,Zhang Jun, Qie Junmao,et al. Emission law and analysis of flue gas in sinter wind boxes[J].Iron & Steel,2019(6).

Wang Yaozu, Liu Zhengjian, Zhang Jianliang, et al. Study of stand-support sintering to achieve high oxygen potential in iron ore sintering to enhance productivity and reduce CO content in exhaust gas[J]. Journal of Cleaner Production,2019.

Xing Fangfang, Jiang Qi, Zhang Zhiya, et al.The analysis of multi-pollutant collaborative control technologies of sinter flue gas in iron and steel industry[J]. Environmental Engineering, 2014,32(004):75-78.

Yan Xiaomiao, Li Yuran, Zhu Tingyu,*et al*. Review of Emission and Simultaneous Control of Multiple Pollutants from Iron-steel Sintering Flue Gas

Yu Zhiyu, Fan Xiaohui, Gan Min,*et al*.NOx Reduction in the Iron Ore Sintering Process with Flue Gas Recirculation[J].JOM,2017, 69(9):1570-1574.

Zhu Tingyu, Liu Qing,Li Yuran,*et al*. Emission Characteristics of Multiple Pollutants from Iron- steel Sintering Flue Gas and Review of Control Technologies [J].Science & Technology Review, 2014(33): 53-58.

Zhang Xiaohui,Feng Peng,Xu Jiarui,et al.Numerical research on combining flue gas recirculation sintering and fuel layered distribution sintering in the iron ore sintering process[J].Energy,192(2019).

Zhou Hao,Zhou Mingxi, Liu Zihao,et al. Modeling NOx emission of coke combustion in iron ore sintering process and its experimental validation[J]. Fuel, 2016, 179(sep.1): 322-331.

Zhu Dewang, He Aoping, Pan Jian, et al. Rule of Greenhouse Gas COx Emission in Iron Ore Sintering Process[J]. Iron & Steel,2006(2).