Effect of Coke Powder Ratio on Particle Emission and Sinter Quality in Sintering Process

Hui Wang¹,²*, Pu Zhang¹,²
¹Central Research Institute of Building and Construction Co. Ltd. MCC, Beijing 100088, China
²Energy-saving and Environmental Protection Co. Ltd. MCC, Beijing 100088, China
*Corresponding author’s e-mail: wanghui@cribc.com

Abstract. Starting from the perspective of source reduction, the emission characteristics of particulate matters in sintering flue gas and sinter quality were studied by a sintering cup based on the fixed carbon 3.6% conditions in sintering raw materials. The particles were sampled by an Andersen 8-stage impactor at the coke powder ratios at 100%, 75%, 50% and 0%. The results showed that the particles in the sintering flue gas were mainly fine particles below 2.63 µm. When the coke powder ratio was 100%, the removal efficiency reached the maximum value of 34.37%. The effects of coke powder ratio on the sinter index were reflected in: (1) the sintering speed decreases; (2) the solid fuel consumption increases; (3) the drum index improves. Compared with comprehensive indicators, the 100% coke powder was the most conducive condition to the production of enterprise sintering process.

1. Introduction
Sintering process is one of the most serious pollution processes in steel production. The concentration of untreated sintering flue gas dust can reach about 10 g/m³. Particle size was mainly concentrated in 100 µm and 10 µm. PM₁₀ accounts for 51.23% of total suspended particulate (TSP). PM₁₀ is dominated by PM₂.₅ (85.36%). Terminal particulate purification facilities are electrostatic precipitator and bag filter. In normal operation, the precipitator has high removal efficiency for coarse particles, but cannot remove PM₁₀ and PM₂.₅.

Current emission standard adjusts the particle emission limit of sintering machine and pellet roasting equipment to 20 mg/m³, which greatly improves the processing capacity requirements of the purification devices of the sintering system, making it a new research direction to reduce the total amount of PM₂.₅ and PM₁₀ from the perspective of source emission reduction [1-3].

Most of sintering plants use pulverized coal and coke as solid fuels. With the cost decrease of coke powder in recent years, many iron and steel enterprises have increased the proportion of coke powder in sintered fuel or even completely replaced the use of coal powder [4, 5]. The change in the proportion of coal powder and coke powder will directly affect the change of pollutant concentration in the sintering flue gas [6]. Therefore, according to the changes of TSP, PM₁₀ and PM₂.₅ concentration in sintering flue gas, this research studied the influence of coke powder ratio on the emission of particles in sintering flue gas and sinter performance through sintering cup experiment.
2. Experimental and sampling system

2.1. Materials and Instruments
The sintering cup experiment used the actual sintering raw material of a sintering plant. Under the condition that the total calorific value (target carbon content was 3.6%) was constant, the ratio of coal powder and coke powder is changed to make the ratio of coke powder reach 0%, 50%, 75% and 100% of the total calorific value of fuel, respectively, as shown in Table 1. The dry weight of the cup was slightly lost; the mass was about 75 kg. The carbon content of coke powder is higher than that of coal powder, therefore, the total weight of fuel increased slightly as the proportion of coal powder increased.

Table 1. List of Ingredients.

| Composition of coke powder (100%) | Dosage (kg) |
|----------------------------------|-------------|
| Iron powder                      | 49.30       |
| Dust and electric field dust     | 3.70        |
| return mine                      | 18.60       |
| Quicklime, Limestone             | 8.73        |
| coke powder                      | 2.79        |

| Dry amount                        | 80.60       |
| Total amount                      | 83.12       |
| C content (%)                     | 3.668       |

| Amount of coke powder (0%, 50%, 75%, 100%) and pulverized coal |
|---------------------------------------------------------------|
| Set               | Coke powder(kg) | Pulverized coal(kg) | Total weight(kg) | C content (%) |
|-------------------|-----------------|---------------------|-----------------|---------------|
| 1                 | 0               | 3.00                | 3.00            | 3.668         |
| 2                 | 1.40            | 1.49                | 2.84            | 3.650         |
| 3                 | 2.10            | 0.74                | 2.89            | 3.639         |
| 4                 | 2.79            | 0                   | 2.79            | 3.650         |

Andersen 8-stage impact particle sampler was used to study the mass concentration of particles in different particle size ranges of PM$_{10}$ in the sintering flue gas. The particle sizes obtained by calculation were 0.53 µm, 0.88 µm, 1.52 µm, 2.63 µm, 3.94 µm, 5.22 µm and 7.22 µm, respectively. This equipment met the requirements of EPA particle Method 5 and 17. High purity quartz fiber membrane (PALL, America) was selected for particulate filtration. Due to the different aerodynamic particle sizes, particles impacted on the sampling membrane of each sampling panel under the action of inertia, respectively, to achieve the particle size grading effect.

2.2. Sintering Cup Experiment
The scale of the sinter cup equipment was 100 kg per cups. 2 kg sinter with particle size of 10–16 mm was first laid at the bottom of the sintering cup as the bottom layer. Then the mixed granulated sinter was loaded into the sintering cup, making the total layer thickness reach 750 mm (including the bottom layer). Coal gas was used as heat source. Sintering ignition temperature was 1050 ± 50°C. Ignition time was 3 minutes. Ignition pressure was 6 kPa. During the combustion process, the sintering flue gas was extracted from the bottom of the sinter cup, passing through the cyclone dust collector and the booster fan, finally discharged. Figure 1 shows the structure of sintering cup system. Two sampling points were located before and after the cyclone separator, respectively. Due to the filtration effect of fixed bed platform material layer and cyclone separator, the particles in the flue gas were mainly PM$_{10}$, which is closer to the actual production situation.
3. Results and Discussions

3.1. Particulate emission in sintering cup experiment

Table 2 indicates the particle emission from the sampling points. In point 1, the TSP emission mass concentrations in flue gas with different coke powder ratios at 100%, 75%, 50% and 0% were 134.04, 98.66, 111.04 and 116.38 mg/m$^3$. There was no obvious rule with the change of coke powder ratio. At point 2, the mass concentrations of coke powder ratios at 100%, 75%, 50% and 0% were 112.34, 68.49, 88.27 and 82.43 mg/m$^3$. Both point 1 and 2, the TSP emission mass concentrations of 100% coke powder had the highest data. The TSP removal efficiency of the cyclone separator from high to low were 30.59%, 29.17%, 20.51% and 16.19%, respectively, while the ratios were 75%, 0%, 25% and 100%. The sintering raw materials were composed of materials with different particle sizes and proportions. They were broken and separated during combustion with a large number of broken particles extracted from the material layer under a strong negative pressure environment, causing high TSP concentration in flue gas. The particles removal efficiency was low, because of little coarse particles and lots of fine particles in the sintering flue gas. The fine particle pollutant in flue gas was PM$_{10}$.

Sintering process was a static combustion process. Materials layer did not move on the platform. So it could be regarded as a filter. Large particles were retained and small particles were pulled out in the gap of the layer under the negative pressure. Figure 2 shows particle size distribution and removal efficiencies of mass concentration. The mass concentration diameter distribution of particulates is uniformly expressed in accordance with $D_p$=d$M$/d$log(D_p)$ method [7]. The specific calculation formula is as follows:

$$\frac{dM_i}{d \log D_p} = \frac{M_i}{\log D_{p,\text{upp}} - \log D_{p,\text{low}}}$$  \hspace{1cm} (1)

Where, $D_p$ is the aerodynamic diameter of particulate matter, m; $M_i$ is the mass concentration of particulate matter, mg/m$^3$. Up and Low are the upper and lower limits of particle size. The particle size concentration in the sintering flue gas showed a single peak distribution. The peak value was near 0.88 µm. The concentration of particles with aerodynamic diameter below 2.63 µm accounted for 75~90%. With the decrease of coke powder ratio, the total mass concentration increased gradually. When the coke powder ratio is 100 %, the whole particulate removal efficiency reached the maximum value of 34.37%. With the coke powder ratio decreased, the removal efficiency decreased by 6~18%.
Figure 2. Particle size distribution and removal efficiencies of mass concentration. 
(a) coke 100%; (b) coke 75%; (c) coke 50%; (d) coke 0%.

3.2. Effect of coke powder ratio on sinter quality
The performance indexes of the sinter with 100%, 75%, 50%, 25% and 0% coke ratios were studied in order to analyze the influence of fuel composition change on the sinter. Table 2 shows the results. When coke ratio was 100%, sinter performance was the best. The burning loss rate of sinter was the lowest, 18.80%. The utilization coefficient was 1.53 t/m²h. The total firing time was the shortest, 35.89 minutes. These indexes were beneficial to the increase of the sinter production and the production efficiency of the enterprises.

When the coke powder ratio changed, the vertical sintering velocity changed a little. The vertical sintering velocity has influence on the permeability of sintering. Therefore, change of coke powder ratio does not affect the air permeability of sintering and has no effect on sintering mixture pelletizing. The yield ranged from 84% to 86%. The drum index increased slightly, between 67% and 69%. Solid fuel consumption increased slightly, ranging from 44 to 46 kg/t.

Table 2. Sinter test results

| Coke powder | Burn out rate (%) | Solid fuel loss (kg/t) | Yield rate (%) | Drum index (%) | Vertical sintering speed (mm/min) | Utilization coefficient (t/m²·h) | Total firing time (min) |
|-------------|------------------|-----------------------|----------------|----------------|-----------------------------------|---------------------------------|-----------------------|
| 100%        | 18.80            | 45.03                 | 84.74          | 68.27          | 28.83                             | 1.53                            | 35.89                 |
| 75%         | 19.66            | 45.40                 | 85.01          | 68.07          | 27.49                             | 1.44                            | 37.50                 |
| 50%         | 19.94            | 45.28                 | 86.15          | 68.67          | 28.90                             | 1.52                            | 36.85                 |
| 25%         | 19.23            | 46.06                 | 84.49          | 68.87          | 27.50                             | 1.44                            | 37.70                 |
| 0%          | 18.85            | 46.15                 | 85.18          | 69.73          | 27.56                             | 1.50                            | 37.55                 |

Figure 3 indicates the grain size composition of sinter. When the coke powder ratio gradually decreased, the proportions of sinter particle size between 5~10 mm and <5 mm were relatively stable. The main influences of the coke powder ratio change on the sinter index were reflected in: (1) the
sintering speed was slightly slow after the coke powder ratio reduced; (2) the solid fuel consumption was increased; (3) the drum index was improved. Compared with comprehensive indicators, the 100 % coke powder, that is, when all sintered fuel was coke powder, was the most conducive to the production of enterprise sintering process.

![Figure 3. Comparison of particle size composition of sinter](image)

4. Conclusion
During the sintering process, the concentrations of particulate matter in flue gas were 98.66~134.04 mg/m³. The analysis of particle size mass concentration showed that: (1) particle size mass concentration in sintered flue gas had a single peak distribution; the peak value was around 0.88 µm. The concentration of particles with aerodynamic diameter below 2.63 µm accounted for 75~90% of the total particles. (2) with the coke powder proportion 100%, the removal efficiency reached the maximum value of 34.37 %.

The effects of coke powder ratio on the sinter index were reflected in: when the coke powder ratio reduces, (1) the sintering speed decreases; (2) the solid fuel consumption increases; (3) the drum index improves. Compared with comprehensive indicators, the 100 % coke powder was the most conducive to the production of enterprise sintering process.

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