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Heat Efficiency Improvement of Iron Ore Sintering Bed by Spraying Steam

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Sintered iron ore is the primary raw material in the ironmaking process of a blast furnace. The sinter is made from the mixture of iron ore fines, coke breeze, fluxes, and water. The coke breeze is burned during sintering to release heat for the iron ore fines and fluxes being partially melted together into agglomeration. Decreasing fuel consumption, reducing carbon emission, and improving the properties of sintered ore are always the main goals in developing the iron ore sintering process. In general, the oxygen concentration decreases to about 10% at the combustion region of the sinter bed. Under deficient oxygen conditions, coke tends to have incomplete combustion, resulting in the generation of partial CO instead of CO_2. In this study, a series of experiments were conducted to investigate the effect of steam spray on the combustion efficiency of coke breeze during the iron ore sintering process. We used a sinter pot equipped with the functions of observing, temperature measurement, and pressure drop measurement to investigate the sintering behavior. The area and movement speed of the red-hot combustion region, the temperature profile, and the change of pressure drop along the vertical direction of the sinter bed were able to be recorded during the sintering process. Furthermore, the off-gas compositions were in-situ detected by a gas analyzer for investigating the reactions among O_2, H_2O, CO, and CO_2.

Comparing to the conventional sintering experiment, we discover that when spraying 4.2Kg/hr steam on 115Kg of raw material of the sinter bed, the duration time of sintering in the temperature range of 1200-1400°C was much longer and the movement speed of the combustion front was faster. Gas analysis shows that O_2 and CO concentrations were lower and CO_2 concentration was averagely higher in the off-gas. Noted that H_2O is helpful for improving further CO combustion under low O_2 concentration inside the sinter bed, implying that the carbon combustion efficiency can be enhanced by spraying steam on the sinter bed. When intermittently spraying 3-15Kg/t-s or continuously spraying 21Kg/t-s steam on the sinter bed, the carbon consumption was not only lowered 0.5-1.9Kg/t-s but also the sinter productivity was increased 2-5%. In addition, the properties of the sinter with steam spraying retained nearly the same performance as that of the sinter without steam spraying.

Keywords: Iron ore sinter, steam, combustion efficiency, ironmaking process

1. INTRODUCTION

Sintered iron ore is the primary raw material in the ironmaking process of a blast furnace. Generally, sintering is part of the process in ironmaking work and the sintered ore is used as the raw material by feeding it into its corresponding blast furnace. The sinter is made from a mixture of iron ore fines, coke breeze, fluxes, and water. Through coke combustion to release heat to temperatures of 1100 to 1400°C, the iron ore fines and fluxes are partially melted together to form a strong agglomeration. Due to the high-temperature heating and then cooling down to room temperature, sintering is considered a high fuel consumption process. Moreover, because of coke combustion, the sintering process emits combustion gases of CO_2 and CO. It is also seen as a high carbon rate process.

Improving sinter productivity, decreasing fuel consumption and carbon emission, whilst retaining the properties of the sinter are always the priority. Recently, the pressure for reducing the energy consumption and CO_2 emission has significantly intensified in all operating units of the ironmaking process. Therefore, many technologies for low carbon and fuel consumption in the sintering process are being developed. Adding a combustion intermediate or fuel gas on the top of the sinter bed was effective for decreasing the fuel rate and for improving the sinter properties. Oyama et al.(1) reported that when the hydrogen-based fuel gas was introduced on the top of the sinter bed, the properties of the sinter of porous structure and strength were improved, and the fuel rate for producing sinter was decreased. In the early 1980s, Nippon Steel(2) had investigated the effect of steam spraying on the top of the sinter bed. The result showed that steam was able to increase the yield of sinter and to improve the efficiency of coke combustion.

Recently, Shougang Co.[3] and Sail Co.[4] reported their practices of steam spraying on the top of the sinter bed in Jingtan and Bokaro sinter plants, respectively. Shougang Co. intermittently installed the steam pipes above the sinter strand for spraying steam on the top of the sinter bed. In order to achieve the uniformity of steam coverage on the sinter bed, a pipe with 5 nozzles distributed across the width of the sinter bed at intervals of approximately 6 meters along the moving length was required. The steam flow rate was about 2,000Kg/hr in a 550m^2 sinter bed. It showed that the CO concentration was lowered, the gas main temperature was increased by 5 to 7°C, and the Temperature Rising Point (TRP) and Burn Through Point (BTP) were shifted ahead. The characteristics of TRP and BTP indicated that the vertical combustion speed was increased. Concluding that the fuel rate was 1.64Kg/t-s decrement without deteriorating the properties of sintered ore.

References confirmed that the steam spraying was beneficial to sintering. However, there are hardly any studies on the combustion region inside the sinter bed. In this study, we designed a sinter pot equipped with the functions of observing, temperature measurement, and pressure drop measurement to investigate the sintering behavior. Meanwhile, the off-gas compositions were also detected to propose the reaction sequence between CO and H_2O. In addition, to find out the proper condition of steam spraying for practicing in the sinter plant, the experiments of the presumed scenarios were also conducted.

2. EXPERIMENTAL METHOD

2.1 Preparation of raw material

The weight of raw materials for a one batch sinter experiment is shown Table 1. Iron ore fines are from Australia, Brazil, and Canada. The return fines are from the sinter fines of the previous experiment. The proper amount of burnt lime was used for improving the granulation of fine particles. And the adjustment of the addition of coke breeze to achieve a return fines balance in the range of 100+/-5% for each experiment. Usually, the coke breeze rate was about 5% to the sintered product. Meanwhile, serpentine, dolomite, and marble were utilized to adjust the CaO, SiO_2, and MgO content close to the designed ratio. All raw materials together with about 7.5% water were adequately mixed and then were put into a drum of 600mm diameter for granulation. The well mixed and granulated mixture was transferred to a sinter pot of 330mm diameter to a bed height of 700mm. The weight of the raw mixture was about 115Kg.

2.2 Experimental procedure

Fig.1 shows the diagram of the sinter pot with the ability to observe the red-hot combustion region through the transparent window, as well as to measure the temperature and pressure drop inside the sinter bed. Thermocouples and pressure tubes were inserted into the sinter bed of 50mm depth in the radius direction. Fig.2 shows the schematic diagram of the experimental apparatus. The sintering experiment started by using a hood burner to ignite the coke breeze on the top of the sinter bed for 90sec. Meanwhile, suction by a fan was at a pressure of 1000mmAq to keep air passing through the sinter bed. After the ignition of the sinter bed, the hood remained above the sinter pot for 90sec and then the suction pressure was increased to 1300mmAq. The 3.0Kg/cm^2 of steam was constantly sprayed on the top of the sinter bed during the indicated period of sintering. The movement of the red-hot combustion region band from the top to the bottom of the sinter bed was filmed by a camera, and the changes of temperature and pressure drop during sintering were recorded. A small amount of off-gas was continuously pumped out to the gas analyzer MRU VARIOluxx for sensing the content

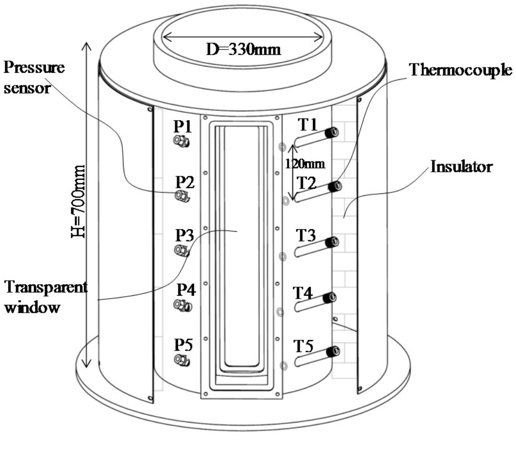

Fig.1. Sinter pot equipped with transparent window, thermocouple and pressure sensor.

Table 1 Weight of raw materials for one batch experiment.

Raw material	AUS F-ore-A	AUS F-ore-B	AUS F-ore-C	AUS F-ore-D	AUS L-ore-A	BRA F-ore-A	BRA F-ore-B	CAN F-ore-A	Return fine	Burnt Line	Coke fine
Weight (kg)	12.90	13.60	4.76	6.12	4.76	4.76	6.80	6.12	27.20	0.72	4.15

of CO, CO_2, CH_4, H_2, O_2, and N_2, respectively. As the gas temperature beneath the sinter pot reached it's peak, the sintering time was extended an additional 10% before the fan was turned off. The as-sintered ore was then subject to the typical evaluation process and property tests such as particle size distribution, chemical composition, strength, Reducibility index test, and Reduction degradation index.

3. RESULTS AND DISCUSSION

3.1 Effect of steam spray sintering

The experimental condition of steam spray in this section is at a constant flow rate of 4.3Kg/hr on the top of the sinter bed started from the tenth minute after the ignition and shut off at the thirtieth minute. The experimental apparatus used here is capable of filming the red-hot combustion region of the sinter bed from top to bottom, measuring the changes of temperature and the pressure drop inside the sintering bed, sensing the gas temperature underneath the sinter pot, analyzing the composition of compounds in off-gas, and calculating the flow rate of air passing through the sinter bed. According to the combination of the above information, the difference of behavior between conventional sintering and steam spraying sintering was investigated.

3.1.1 Visual observation of red-hot combustion region

Visual observation is the most straightforward way to understand the behavior of the red-hot combustion region. Fig.3 shows the image comparisons between conventional sintering and steam spray sintering of the red-hot combustion region at position 1 to 4 which is the

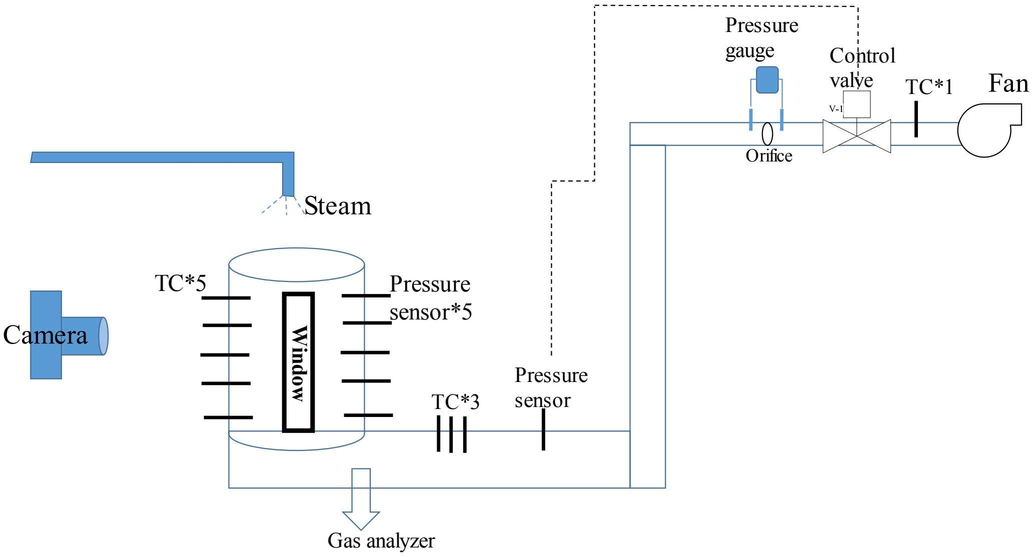

Fig.2. The schematic diagram of the experimental apparatus.

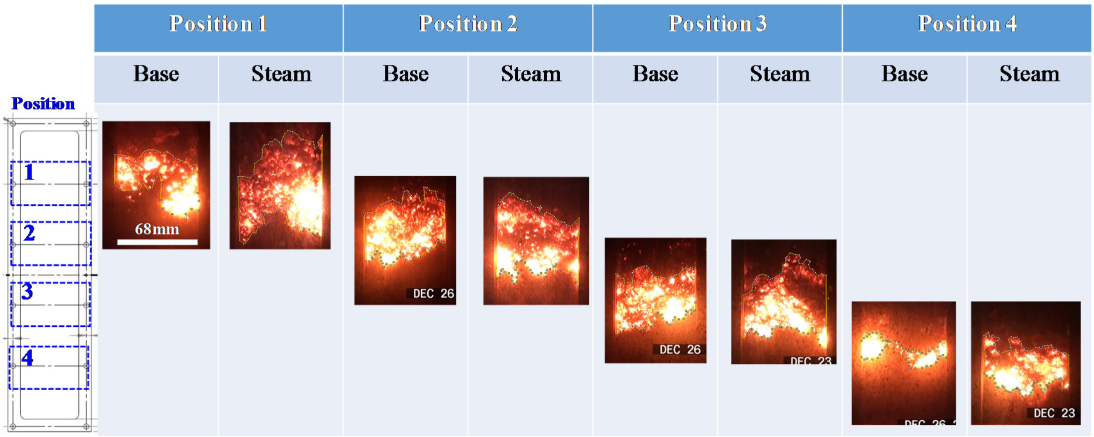

Fig.3. The pictures of red-hot combustion region from top to bottom of the sinter bed.

sequence from top to bottom of the sinter bed. It is obviously that the red-hot areas of the steam sprayed method are all larger than that of the conventional ones. To precisely identify the area difference between them, an imaging software was introduced to calculate the red-hot area. The calculation results are in Fig.4, from top to bottom the red-hot areas are larger in the steam spray sintering. Especially at position 1 and 4, the red-hot region are 77% and 151% bigger, respectively.

3.1.2 Characteristic of temperature and pressure changes inside sinter bed

Fig.5 shows the comparison of temperature changes measured at position T2, T3 and T4 of Fig.1. Noted that the temperature profiles and its time frame at the same measured position are various. In the ore sintering, the high temperature duration is more important. Generally, as the raw materials are heated to the range of 1200 to 1400°C, ore particles and fluxes are partially melted

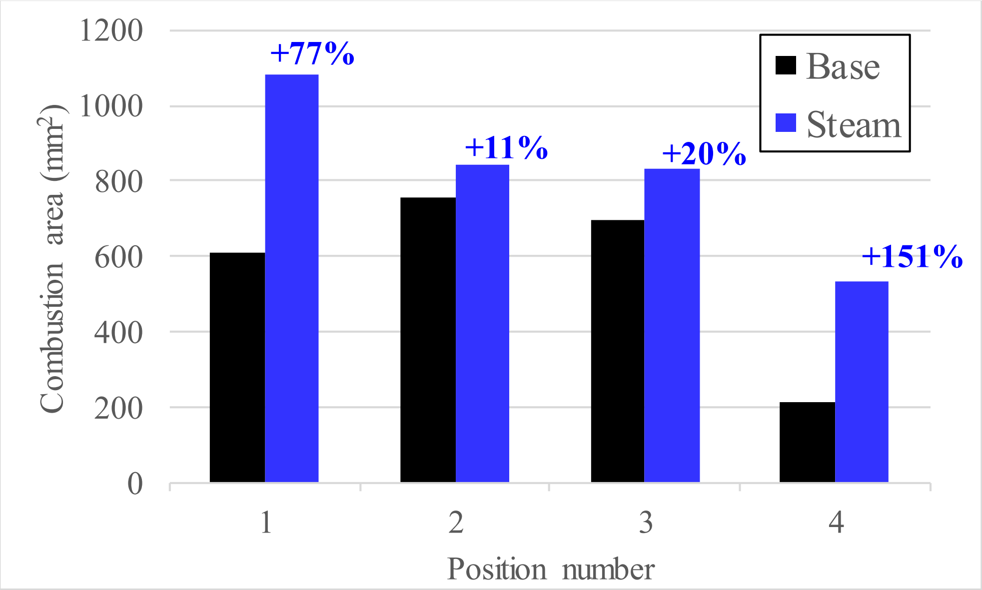

Fig.4. Comparison of red-hot combustion region between conventional sintering and steam spray sintering from top to bottom of the sinter bed.

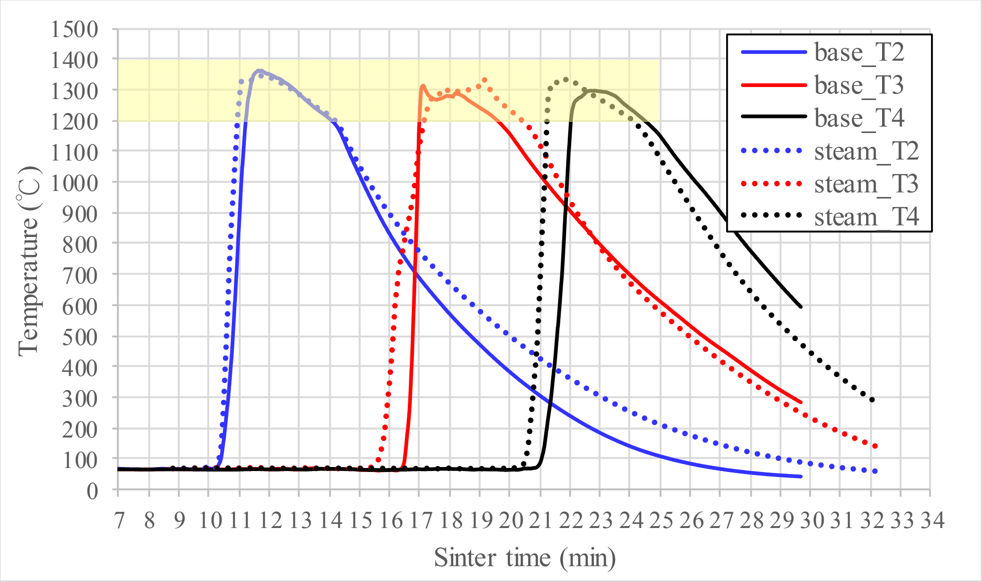

Fig.5. Comparison of temperature changes measured at position T2, T3 and T3.

together into agglomeration. In other words, the occurrence of ore sintering is mainly in the temperature range of 1200 to 1400°C. The longer the duration at this temperature range, the higher the degree of ore sintering, and it further suggests higher strength sinter and higher production. To quantify the degree of high-temperature duration, we calculated the coverage area and its difference in this temperature range as shown in Table 2. It indicates that the coverage area of steam sintering was higher than that of conventional sintering and the corresponding ratio of area difference was 13.8%, 26.5%, and 18.5%. Furthermore, the flame front speeds from T2 to T3, T3 to T4, and T2 to T4 were estimated by their distances over time between temperature peaks. It appeared that the flame front speed of steam sintering was 14.3 % faster from position T2 to T3 but was 7.1% slower from position T3 to T4. Overall, from position T2 to T4, steam sintering was still 4.6% faster. Faster sintering speed along the vertical direction of the sinter bed suggests higher production rate.

Fig.6 shows the changes of pressure drop between position P2 and P3. During the early stage of sintering, coke combustion has not reached the depth of P2 position. Supposedly the pressure drop between conventional and steam sintering is not too much different. When the sintering region came to position P2, the pressure drop rapidly surged. It appeared that the pressure drop of the conventional sinter was higher than that of the steam one. After the sintering region passed position P3, the pressure drop went down. The duration of the high-pressure drop was about 7 minutes which is coincidental with the period of temperature peaks between position T2 and T3. The lower pressure drop suggests better permeability and a higher sintering speed.

3.1.3 Characteristics of off-gas temperature and compositions

Fig.7 shows the changes in off-gas temperature underneath the sinter pot. A slight temperature increment was observed during the steam spraying period in the zoomed-in figure. The TRP shifted early by about half a minute as well. It means the sintering speed is faster, coordinating with the result in Fig.5.

Fig.8 is the changes of O_2, CO, CO_2 concentration, and $CO_2/(CO+CO_2)$ ratio measured in the off-gas. During the sintering period from the tenth minute to the thirtieth minute, the O_2 and CO_2 concentrations in the steam spraying sintering were averagely lower and higher than that in the conventional sintering, respectively. Particularly, the CO concentration was significantly much

Table 2 Coverage area in the temperature range of 1200 to 1400℃ and difference ratio of flame front speed.

Position	Base area (°C *min)	Steam area (°C*min)	Area difference ratio (%)	Difference ratio of flame front speed (%)		
T2	3,692	4,203	13.8	14.3		4.6
T3	3,283	4,153	26.5		-7.1	
T4	3,081	3,650	18.5			

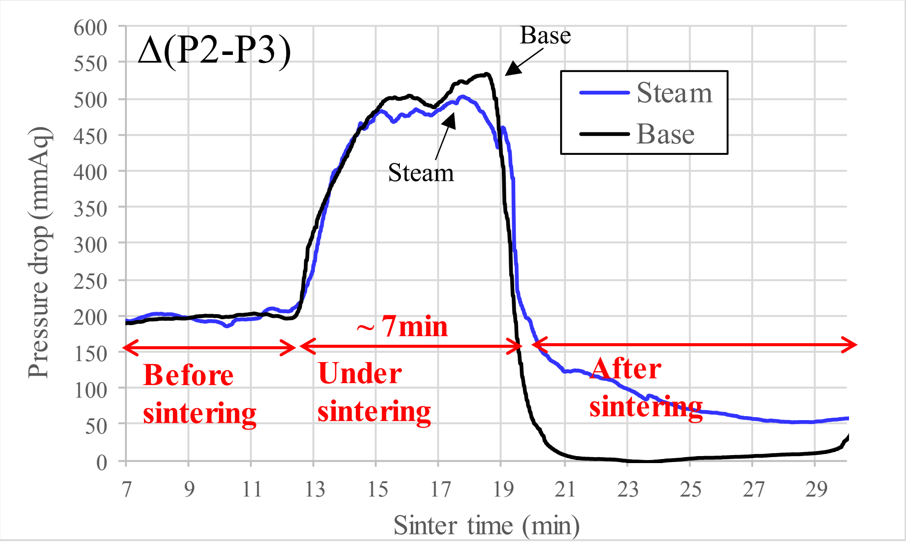

Fig.6 Changes of pressure drop between position P2 and P3.

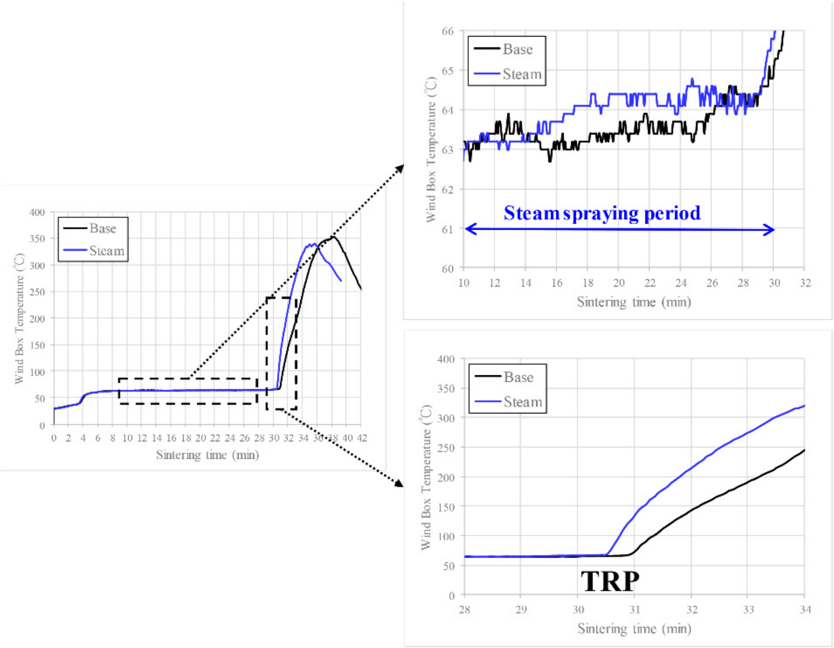

Fig.7 Changes in off-gas temperature underneath sinter pot.

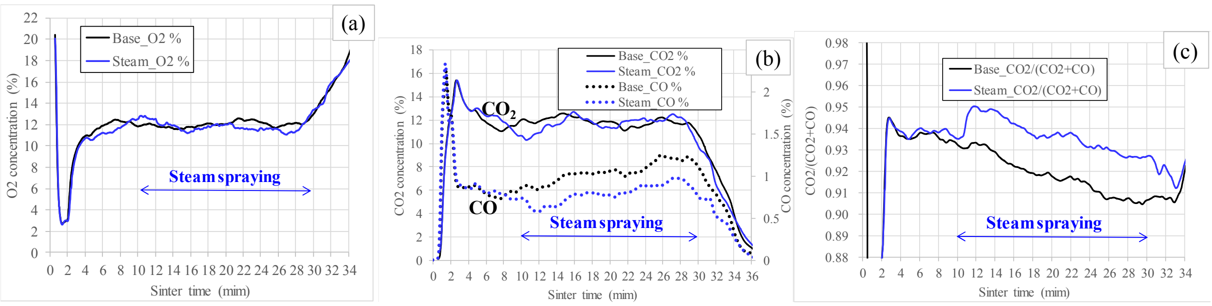

Fig.8 Changes of O_2, CO, CO_2 concentration, and $CO_2/(CO+CO_2)$ ratio during sintering.

lower. Therefore, the difference in $CO_2/(CO+CO_2)$ ratio was obvious. On the other hand, after the thirtieth minute, the steam was turned off, the difference tended to be small thereafter.

Referring to the reaction equation (1) to (4). Under the circumstance of low O_2 concentration, carbon combustion is usually insufficient to generate CO as shown in Equation (1). The situation is similar to the red-hot combustion region inside the sintering bed. As long as there is a relevant H_2O addition, it is helpful for further combustion of CO. According to the gas analysis results here, we suggest that H_2O from steam improves the combustion with CO to release CO_2, H_2, and heat as shown in Equation (2). Moreover, on the basis of thermodynamic equilibrium, delta Gibbs free energy of reaction Equation (3) is much lower than zero. The reaction occurs spontaneously very easily under low oxygen concentration. Both Equations (2) and (3) are exothermic. They released additional heat caused the temperature to rise both inside the sintering bed and in the off-gas. The significant decrement of CO concentration and increment of $CO_2/(CO+CO_2)$ ratio measured in the off-gas supported the proposal of the reaction between CO and H_2O took place as well. Equation (4) is the combination of Equation (1) to (3). The H_2O showing on both sides is not exactly identical. In this study, we suggested that the H_2O on the left side is from steam addition on the top of the sinter bed, whereas, the H_2O on the right side is the production from the reaction between H_2 and O_2. Hence, the H_2O was indicated as intermediate.

$2C + O_2 = 2CO + 9{,}797$ kJ/kgC .... Equation (1)

$CO + H_2O_{(g)} = CO_2 + H_2 + 41$ kJ/mol.. Equation (2)

$2H_2 + O_2 = 2H_2O_{(g)}$.............................. Equation (3)

$C + H_2O + O_2 = CO_2 + H_2O$................. Equation (4)

3.2 Effect of steam spraying on coke rate and sinter productivity

3.2.1 Scheme of steam spraying

The results shown in Section 3.1 demonstrates the fact that spraying steam on the top of the sinter bed is effective for further combustion and heat release. To facilitate in the sinter plant, it is necessary to establish a scheme for steam spraying on the sintering bed. Fig.9 shows two experimental schemes of steam spraying. CE-07 experiment was continuously spraying steam from the fifth minute to the thirtieth minute of sintering time. CE-11 experiment was pulse sprayed, being open for 20 seconds and closed for 40 seconds until the thirtieth minute in the sequence. The steam flow rate for both of them was 3.7 Kg/hr. Also, a conventional experiment was carried out as a benchmark. The major reason for pulse spraying was to reduce the total amount of addition. Meanwhile, the full fresh air circulation was remained to pass through the sinter bed.

The experiment results are shown in Table 3, Fig. 10, and Fig.11. The amount of steam added in CE-07 was 21.1 Kg/t-s about three-fold of CE-11. The off-gas temperature, shown in Fig.10, is higher for the steam sintering. The intermittent spraying experiment was about 1°C higher than the conventional one, but about 1°C

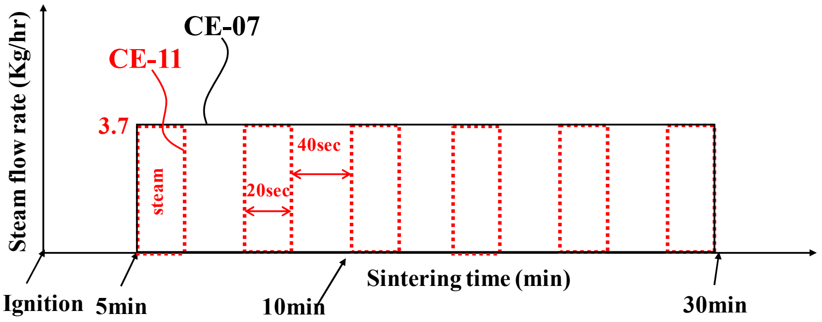

Fig.9 Scheme of steam spraying.

Table 3 Sintering characteristics, coke rate, and sinter productivity of steam spraying scheme.

Sample No.	Steam Spray type	Steam spray rate (Kg/hr)	Steam Kg/t-s	Wind Box Temp (°C)	Air Flow Flux ($Nm^3/(min*m^2)$)	Coke rate (Kg/t)	Coke Reduce (Kg)	Productivity ($t/24h*m^2$)	Productivity Improvement(%)	TI(%)
Base 04	No Steam_B04	0	0	64.5	30.9	54.5	-	26.52	-	70.1
CE-11	Intermittent 20sec-On 40sec-Off	3.7	7.1	65.5	31.5	53.22	-1.28	27.36	3.17%	70.7
CE-07	Continuous 5-30 min	3.7	21.1	66.2	31.9	53.16	-1.34	27.92	5.28%	70.5

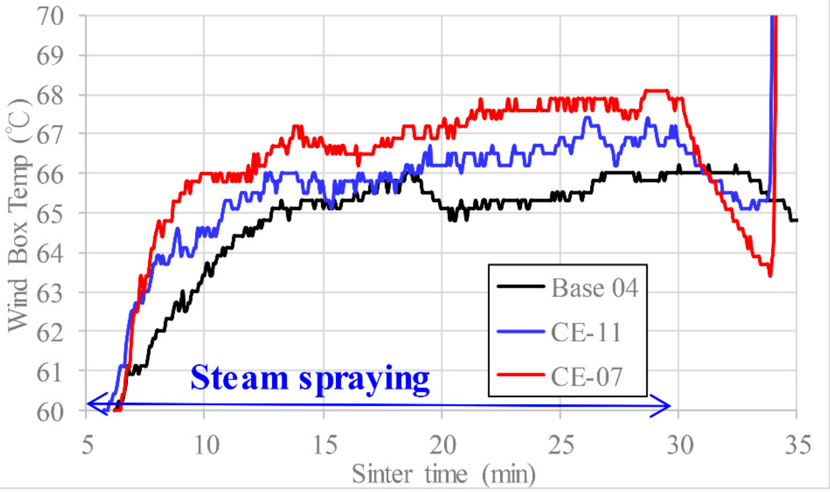

Fig.10 Temperature changes in the off-gas.

lower than the continuous spraying one. The index of airflow flux was more or less different but not significantly. The steam spraying schemes saved 1.28 Kg and 1.34Kg of coke per ton of sinter, individually. Moreover, the sinter productivity was 3.2% and 5.3% improved, respectively . In addition, the properties such as strength (Tumbler Index), Reducibility Index, and Reduction Degradation Index of sintered ore were not degraded.

The changes in $CO_2/(CO+CO_2)$ ratio are again shown in Fig.11. The $CO_2/(CO+CO_2)$ ratio in off-gas was very sensitive to the steam addition. For the CE-11experiment, when steam was turned on, the ratio immediately increased. On the contrary, when closing the steam, the ratio went back to normal. On the other hand, when continuously adding steam, the ratio remained at a high level.

3.2.2 Effect of steam flow rate

The steam spraying rate of 5.0, 6.0, and 9.0Kg/hr was also carried out. Fig.12 shows the results of off-gas temperature, airflow flux, coke rate, and sinter productivity at various steam spraying rates. The temperature and airflow were proportional to the steam rate. It results from better combustion efficiency and good permeability inside sinter bed. The sinter productivity had a 2 to 4% increment. The Coke rate also can be reduced. However, it should be done with regard to the proper amount of added steam.

3.3 Discussion of potential influence in the sintering process

Herein, H_2O is added from the top of the sinter bed and then is brought out underneath the sinter bed. Therefore, H_2O is suggested as the intermediate. It indicates that the H_2O content would be increased in the wind box as well as the main gas pipe of the sinter machine. Increased H_2O content would lower the dew point, causing the precipitation of H_2O easily. Liquid H_2O has a high potential to corrode the equipment of wind boxes and pipes. Therefore, to prevent hardware corrosion, the

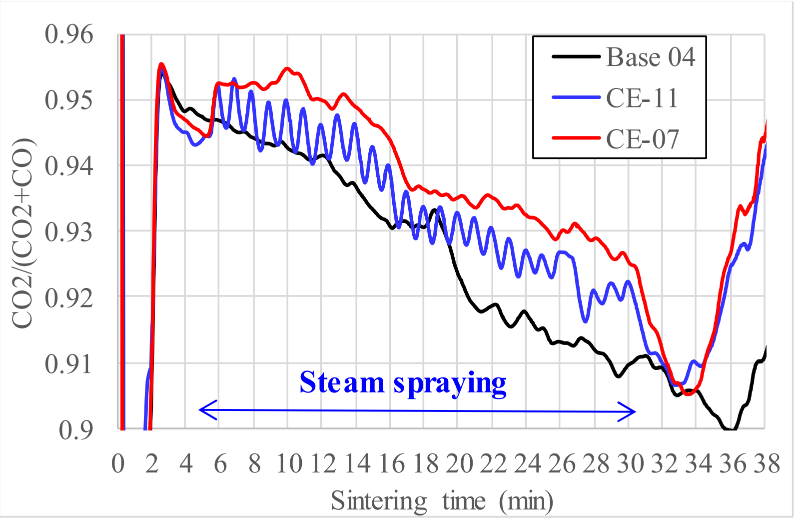

Fig.11 Changes of $CO_2/(CO+CO_2)$ ratio.

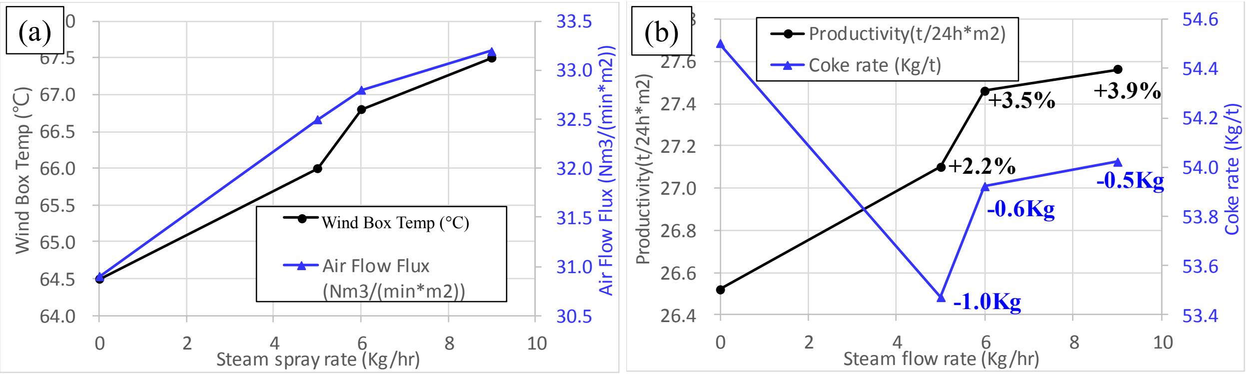

Fig.12 (a) Off-gas temperature and air flow flux through sintering bed, (b) coke rate and sinter productivity, in different steam spraying rate.

estimation of the dew point is recommended when adding steam on the top of the sinter bed.

4. CONCLUSIONS

The main raw material for the blast furnace is sintered ore. Decreasing the carbon rate and increasing the sinter productivity is always the challenge in developing the iron ore sintering process. This study used a sinter pot, which is able to measure the temperature, pressure drop, airflow rate inside the sinter bed, and off-gas composition, to investigate the effects of the steam sprayed on the top of the sinter bed. The experiment results are shown below.

(1)When spraying steam of 4.3Kg/hr, the sintering duration in the temperature range of 1200 to1400°C was longer by 13 to 27% than the conventional sintering. The red-hot combustion speed along the vertical direction was faster by 4.6%. The pressure drop of the red-hot combustion region was decreased and the off-gas temperature was increased by 1 to 2°C.

(2)The O_2 and CO concentration were lower; CO_2 concentration was averagely higher; $CO_2/(CO_2+CO)$ ratio was significantly improved in off-gas when under steam sintering. It is suggested that steam was effective to further combusting CO and releasing heat. The carbon combustion efficiency was accordingly enhanced.

(3)When intermittently spraying 3-15Kg/t-s or continuously spraying 21Kg/t-s steam on the sinter bed, the carbon consumption was lowered 0.5-1.9Kg/t-s and the sinter productivity was also increased by 2 to 5%. In addition, the properties of the sinter with steam spraying were kept nearly the same performance as that of the sinter without steam spraying.

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