Preparation Technologies of Straw Char and Its Effect on Pollutants Emission Reduction in Iron Ore Sintering

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Influences of preparation technologies on properties of straw char (corn) and its use as a supplementary fuel for coke breeze in iron ore sintering were investigated. By means of one-stage carbonisation, produced straw char achieved similar volatile and fixed carbon contents to coke breeze, where recommended carbonisation temperature was 700°C, heating rate was 10–25°C/min, and carbonisation time was 30 min. Two-stage carbonisation, consisting of one low temperature stage and the other high temperature stage, facilitated the further removal of volatile matters, and making straw char increased in yield and fixed carbon content. Recommended one-stage carbonisation benefited reducing combustibility difference between straw char and coke breeze since densified structure was achieved. Compared with one-stage carbonisation, two-stage carbonisation made straw char more densified in structure and less difference in combustibility to coke breeze. For straw char prepared from one-stage and two-stage carbonisation, recommended replacement ratio to coke breeze were 20% and 40% respectively. The emission reduction of SO_x for replacement ratio 20% and 40% were 10.98% and 38.15% respectively, and that of NO_x were 12.67% and 22.53% respectively.

KEY WORDS: agglomeration; iron ore sintering; bio-energy; straw char; carbonisation; pollutants emission reduction.

1. Introduction

As the chief iron-bearing burden of blast furnace for iron-making in China, sinter makes up a ratio exceeding 75%.¹⁾ Sintering process is also energy-intensive that consumes 9–12% of the total energy in integrated steelworks. 75–80% of the energy consumed is solid fuels, including coke breeze, anthracite etc.²⁾ Greenhouse gas CO₂, polluting gases SO_x, NO_x etc. have been proved to mainly come from the combustion of fossil fuels during sintering process.³⁾ Therefore, substituting fossil fuels with clean and renewable bio-energy in sinter making contributes to clean sinter production. CSIRO exhibited a great interest in employing charcoal into sintering field,^{4–6)} while Corus mainly put its focus on researching olive residues, sunflower husk pellets etc.^{7,8)} Both of them indicated that biomass fuels replacing fossil fuels benefited emissions reduction of CO_x, SO_x, NO_x etc. However, their findings also indicated that biomass fuels combusted faster than coke, which degraded sinter quality mainly for accelerated sintering speed. Uncarbonised raw biomass fuels like sunflower husk pellets had a lower level of fuel utilisation since volatile matters were not used before combustion front approached. For introducing biomass fuels into sinter making in China, our group has investigated the properties and sintering behaviours of charcoal, charred straw and molded sawdust. Emissions of CO_x, SO_x, NO_x

etc. have been reduced, while sinter quality decreased markedly when excessive coke breeze was replaced.^{9,10)}

Therefore, it is necessary to prepare desirable biomass fuels for iron ore sintering process. However, no research about the preparation technologies of biomass fuels for iron ore sintering purpose is found. Fuels needed for sinter making are supposed to be lower in volatile matters and to have proper combustion rate.¹¹⁾ Coke breeze has been proved to be a typical kind of fuels that well match heating transfer speed for sinter making.¹¹⁾ This investigation focused on searching proper preparation technologies for producing expected biomass fuels. 17% of the world total straw resources is distributed in China,¹²⁾ while its availability is less than 45% for open burning and being abandoned.^{13,14)} For environmental and economic purposes, raw straw therefore was applied to prepare desired supplemental fuel-straw char for coke breeze by means of carbonisation processing. A laboratory-scale sinter pot was used to evaluate its applying effect during sinter making.

2. Materials and Methods

2.1. Properties of Materials

For making sinter, iron ores, fluxes (dolomite, limestone and quick-lime), fuels and return fines were all provided by an integrated steelwork in China. According to ore blending scheme adopted in the sinter plant, mass contents of Fe, SiO₂, and MgO in sinter were kept at 56.38%, 4.92%, and 2.0% respectively. Basicity (CaO/SiO₂, mass%), which was

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adjusted through changing flux levels, in sinter was kept at 1.9. The chemical composition and proportions of raw materials are given in **Table 1**. Since the influence of different fuels on chemical composition of mixtures mainly depended on their ash composition, this influence was neglected in our investigation for lower fuel ratio in mixture and lower ash ratio in fuel.

Coke breeze and raw corn straw were employed in this investigation. Raw corn straw used to prepare straw char had been briquetted into pellets of 10 mm diameter $\times$ 20 mm long by a briquetter working at a maximum pressure of 180 MPa and maintained for 1 min without any binder at room temperature. The density of raw straw was then increased from 0.25 kg/m³ to 1.22 kg/m³. Coke breeze was a typical kind of sinter fuels, which had a size range of mainly 0.5 mm–3 mm. By means of Automatic Proximate Analyser, model SDTGA5000 (Sundy, China) and CHNOS Elemental Analyser, model Vario EL III (ELEMENTAR, Germany), proximate and ultimate analyses of raw straw and coke breeze illustrated in **Table 2** showed that raw straw mainly consisted of volatile matters, which accounted for 82.37%, and its calorific value was lower than coke breeze. Since coke breeze came from coking plant, its major part was fixed carbon.

Table 1. Chemical composition and proportion of individual raw material in mixture.

Sorts of raw materials	Chemical composition							Proportion
	TFe	SiO ₂	CaO	MgO	Al ₂ O ₃	FeO	LOI ^a	
Mixed iron ores	60.74	4.65	1.9	1.54	1.92	9.24	2.64	64.93
Dolomite	0.21	0.87	31.57	19.68	0.22	0.13	46.91	0.53
Limestone	0.14	1.31	50.19	3.30	0.32	0.10	42.27	3.05
Quick-lime	0.40	2.85	77.92	3.64	0.75	0.23	11.29	4.56
Return fines	56.38	4.92	9.36	2.00	2.07	8.58	0.00	23.08 ^b
Fuel	—	—	—	—	—	—	—	3.85

^a LOI = loss on ignition; ^bProportion of return fines will be changed when do the experiments of return fines balance

Table 2. Proximate and ultimate analyses of fuels (dry basis).

Fuel types	Ultimate analyses (mass%)					Proximate analyses (mass%)			Calorific value (MJ/kg)
	C	H	O	N	S	Ash	Volatile	Fixed carbon	
Raw straw	44.69	5.10	45.49	0.27	0.089	4.36	82.37	13.27	18.80
Coke breeze	76.33	2.29	0.96	0.67	0.209	19.54	4.88	75.68	28.06

Table 3. Factors and their levels for one-stage and two-stage carbonisation.

Carbonisation processes	Factors	Levels			
One-stage	Carbonisation temperature (°C)	500	600	700	800
	Heating rate (°C/min)	10	25	100	200
	Carbonisation time (min)	10	20	30	60
	Reaction atmosphere	N ₂ with flow rate 0.1 L/min			
Two-stage	Carbonisation temperature of stage-1 (°C)	400	500	600	
	Carbonisation temperature of stage-2 (°C)	700			
	Reaction atmosphere	N ₂ with flow rate 0.1 L/min			

2.2. Experimental Methods

2.2.1. Straw Char Preparation and Properties Examination

Corn straw char was prepared in an electrically heated shaft furnace, depicted in **Fig. 1**. For each run, 200 g straw pellets were initially loaded into a quartz tube, and then moved the tube into the furnace. Two types of carbonisation processes, one-stage carbonisation and two-stage carbonisation, were employed to prepare straw char. During one-stage carbonisation, variable factors like heating rate, carbonisation temperature, carbonisation time, and reaction atmosphere, and their levels were given in **Table 3**. When determining the influences of one factor, other factors were remained constant. Two-stage carbonisation described in more detail

Fig. 1. Schematic diagram of carbonisation equipment. 1-gas bottles; 2-reducing valve; 3-flowmetre; 4-gas mixing bottle; 5-thermocouple; 6-electronic balance; 7-computer; 8-temperature regulator; 9-quartz reactor; 10-raw material cup; 11-shaft heating furnace.

elsewhere¹⁶⁾ consisted of two sequential one-stage carbonisation processes. However, in this investigation, carbonisation process was directly moved from lower temperature stage-1 to the higher temperature stage-2 without any cooling between these two stages. Factors and their levels for two-stage carbonisation are also given in Table 3. Heating rate and carbonisation time for stage-1 and stage-2 were the same, which were determined by the selected values in one-stage carbonisation.

After carbonisation, straw char was cooled to room temperature in N₂ with a flow rate of 0.1 L/min, and its weight was measured. Equation (1) was used to calculate the yield of straw char, which was an important factor to assess carbonisation effect. Optical microscope, model DMRXP (Leica, Germany) and CHNOS Elemental Analyser were employed to examine microstructure and chemical composition of straw char.

$$W = \frac{M_1}{M_2} \cdot 100\% \quad \text{..... (1)}$$

Where W is the yield (%), M_1 is the mass of final solid product (g), M_2 is the mass of dried straw charged for carbonisation (g).

According to analysed yield and C, H, and O levels of straw char, Eq. (2) was used to calculate the removal ratio of C, H and O during carbonisation, where P is the removal ratio of C(H, or O), w_1 is the level of C(H, or O) in raw straw, w_2 is the level of C(H, or O) in straw char, W is the yield.

$$P = \frac{w_1 - Ww_2}{w_1} \cdot 100\% \quad \text{..... (2)}$$

Isothermal weight loss rate was measured with the same equipment shown in Fig. 1 to describe the combustibility of straw char. 25 g straw char with size range of 3–5 mm was loaded into a quartz tube, and only N₂ with a flow rate of 5 L/min was supplied. The combustion reaction started at

900°C in simulated air atmosphere, of which flow rate was 5 L/min. During the whole combustion process, weight change of straw char was collected by a computer. According to the data recorded, fuel conversion rate x_c used to evaluate fuel burning speed was calculated by Eq. (3).

$$x_c = \frac{m_0 - m}{m_0} \cdot 100 \quad \text{..... (3)}$$

Where x_c is fuel conversion rate (%), m_0 is initial mass (g), m is the mass at time t (g).

2.2.2. Description of Sintering Trials

Sintering trials were conducted in a 700 mm deep × 180 mm diameter sinter pot, and its schematic diagram was given in Fig. 2. Raw materials introduced ahead were blended manually together according to their proportions, during which water was added to achieve prescribed moisture content. After that, mixed materials were charged into an electrically powered drum for granulation. The drum was 1 400 mm deep × 600 mm diameter, and granulation was conducted at 15 r/min for 4 min. Before charging granulated mixtures, 1 kg sinter of size range 10 mm–16 mm was charged as hearth layer. An ignition hood was employed to ignite the fuel in the surface layer with natural gas fuelled and a set of downdraught system was used to sustain combustion front to move downwards. Ignition period involved 1 min at 1 050°C ± 50°C and a pressure drop of 5 kPa. The pressure drop was changed to 10 kPa for sintering, and then to 5 kPa for cooling. The total sintering time was measured from the start of ignition to the point where the sinter waste gas had reached a maximum temperature. During the whole sintering process, infra-red flue gas analysers, model DELTA 65-3 and Vario Plus (MRU Corporation, Germany), were adopted to measure the concentration of O₂, CO, CO₂, NO_x, and SO₂ in flue gas.

During sinter quality tests, RFB (return fines balance) was regarded as an important index to validate the test of

Fig. 2. Schematic diagram of laboratory sinter pot.

sintering speed, yield, tumble index, productivity. Only when RFB ranged within 1 ± 0.05 (mass ratio), the following tests were conducted. Sintering speed was the ratio of layer height and sintering time. Yield was the percentage of sinter above 5 mm after screening, and the mass of hearth layer was deducted. Productivity reflected the quantity of sinter produced unit area and unit time. Tumble index reflected sinter strength, which was based on the methodology outlined in ISO3271-711.

3. Results and Discussion

3.1. Influences of Preparation Technologies on Basic Physiochemical Properties of Straw Char

3.1.1. One-stage Carbonisation

Results on influences of main factors of one-stage carbonisation on changes in yield, fixed carbon content, volatile content and ash content are described in **Table 4**. With carbonisation temperature increasing, where heating rate and carbonisation time were kept at 25°C/min and 30 min, yield and volatile matters tended to decrease, the results were similar to that described by Shigeru.¹⁷⁾ Possible reason was the deep removal of O and H in raw straw at higher temperature for greater carbonisation intensity. Increased fixed carbon content was then the result that more carbon was entered into solid products at higher carbonisation temperature. When carbonisation temperature was 500°C, fixed carbon content had reached 75.11%. However, volatile content was much higher than coke breeze, which was reduced to be close to coke breeze after increasing carbonisation

temperature to 700°C. As further increased temperature just changed yield, fixed carbon, and volatile matter moderately, 700°C was selected as proper carbonisation temperature to prepare straw char.

Keeping carbonisation temperature and carbonisation time at 700°C and 30 min, increasing heating rate gave rise to the decrease in yield and fixed carbon content, and was adverse to the removal of volatile matter. Especially when heating rate increased from 10°C/min to 200°C/min, yield, fixed carbon content dropped from 25.85%, 78.60% to 21.52%, 77.07%, while volatile content increased from 3.76% to 6.82%. Potential explanation was that raw straw was heated to 700°C within a short time under excessively high heating rate, which was detrimental to the sufficient removal of O and H. Besides, excessively high heating rate would lead to the intense decomposition of organics, and potential carbon or inorganic mineral components were removed with flow gas. When heating rate ranged within 10–25°C/min, straw char achieved desired fixed carbon contents and volatile matter to that of coke breeze.

Keeping carbonisation temperature and heating rate at 700°C and 25°C/min. Both yield and volatile content achieved a decrease with carbonisation time prolonging, while fixed carbon content achieved an increase. Possible explanation of this behavior was described as longer carbonisation time contributed to the further removal of O and H, and more carbon was left to achieve higher fixed carbon content. When carbonisation time stood at 30 min, contents of volatile matter and fixed carbon for straw char had met that of coke breeze.

3.1.2. Two-stage Carbonisation

Single stage carbonisation is generally adopted method during biomass or coal carbonisation process, while two-stage or other multistage carbonisation is scarcely used. However, multistage carbonisation influenced characteristics of prepared biochar in terms of yield, reactivity and inner structure.^{15,16)} Influences of carbonisation temperature of stage-1 on characteristics of prepared straw char are given in **Table 5**, it was found that two-stage carbonisation tended to produce straw char of greater yield, and even lower volatile and higher fixed carbon than one-stage carbonisation when temperature of stage-1 exceeded 400°C. However, when increasing the temperature to 600°C, both fixed carbon content and volatile content changed moderately. Consequently, we selected 500°C as proper temperature for stage-1.

Potential reason for superiority of two-stage carbonisation was as follows: cellulose and lignin in raw straw decomposed with competing reactions of de-H₂O, de-CO₂,

Table 4. Influence of carbonisation factors on proximate analyses (dry basis).

Carbonisation factors		Yield	Fixed carbon	Volatile	Ash
Carbonisation temperature (°C)	500	31.40	75.11	11.06	13.83
	600	25.50	77.01	6.84	16.15
	700	24.42	77.91	4.39	17.70
	800	24.02	78.01	3.71	18.28
Heating rate (°C/min)	10	25.85	78.6	3.76	17.64
	25	24.42	77.91	4.39	17.70
	100	22.28	77.16	6.26	16.58
	200	21.52	77.07	6.82	16.11
Carbonisation time (min)	10	25.38	76.56	7.93	15.51
	20	25.15	77.44	6.15	16.41
	30	24.42	77.91	4.39	17.70
	60	23.59	78.22	3.83	17.95

Table 5. Influences of carbonisation processes on physicochemical characteristics of straw char.

Carbonisation processes	Temperature of stage-1 (°C)	Temperature of stage-2 (°C)	Yield (mass%)	Fixed carbon (mass%)	Volatile (mass%)	Ash (mass%)
One-stage	700	—	24.42	77.91	4.39	17.70
	400	—	26.81	76.75	6.84	16.40
Two-stage	500	700	26.37	79.28	2.82	17.90
	600	—	26.01	79.38	2.41	18.21

^a heating rate was 25°C/min, carbonisation time was 30 min.

Table 6. Chemical composition of straw char.

Carbonisation products	Ultimate analyses (mass%)		
	C	H	O
One-stage	78.30	1.45	2.25
Stage-1 (500°C) of two-stage	77.65	3.03	4.89
Stage-2 (700°C) of two-stage	79.65	0.86	1.18

Table 7. Removal characteristics of C, H and O during carbonisation.

Carbonisation process	Removal percents of elements (mass%)			Removal molar number of 100 g raw straw		
	C	H	O	H ₂ O	CO ₂	CH ₄
One-stage	57.21	93.06	98.79	0.463	1.174	0.956
Stage-1	45.16	87.50	96.07	0.800	0.965	0.715
Two-stage Stage-2	7.84	8.05	3.25	-0.143	0.116	0.174
Total	53.00	95.55	99.32	0.657	1.081	0.889

and de-CH₄,¹⁷⁾ the comprehensive effect of which determined the yield, fixed carbon and volatile contents of straw char. **Table 6** gives the ultimate analyses of C, H, and O in straw char, according to which the removal percents of C, H, and O were figured out by Eq. (2) described ahead. Based on their removal ratios, the removal molar ratio of C, H, and O were easily obtained as C_xH_yO_z, according to which the removal molar number of H₂O, CO₂, and CH₄ during carbonisation were figured out by molar balance. Results are shown in **Table 7**, where can be observed that during two-stage carbonisation process, de-H₂O reaction played a more important role in removing H, O than that during one-stage carbonisation since higher removal molar number of H₂O was achieved in two-stage carbonisation. However, the lower removal molar number of CO₂, CH₄ showed that de-CO₂, de-CH₄ reactions during two-stage carbonisation process were inferiorly developed compared with one-stage carbonisation. Therefore, two-stage carbonisation benefited remaining more C in solid products. In combination with the removal molar percents of H₂O, CO₂, and CH₄ during two-stage carbonisation, stage-1 mainly served as the stage to remove major part of H, O through de-H₂O, de-CO₂ and de-CH₄ reactions; stage-2 mainly acted as the stage to deep remove H, O by means of de-CO₂, de-CH₄ reactions. The removal molar number of H₂O in stage-2 showed a negative value, the possible reason of which was that the removal of H, O was not in the form of de-CO₂, de-CH₄ rigorously. The comprehensive effect of stage-1 and stage-2 made two-stage carbonisation superior to one-stage carbonisation in terms of higher yield and fixed carbon content, and lower volatile matters.

3.2. Influences of Preparation Technologies on Combustibility of Straw Char

From the results shown in **Fig. 3**, increasing carbonisation temperature from 500 °C to 700°C, carbonisation time from 10 min to 30 min, or decreasing heating rate from 200°C/min to 25°C/min reduced the difference of fuel conversion rate between straw chars and coke breeze. Particularly when carbonisation temperature, heating rate and carbonisation

Fig. 3. Influences of carbonisation factors and processes on combustion conversion rates of straw char.

time were in proper values of 700°C, 25°C/min and 30 min, fuel conversion rate differences between two kinds of fuels got further narrowed. Compared with one-stage carbonisation, a closer conversion rate between coke breeze and straw char prepared from two-stage carbonisation was observed.

Different microstructures of straw char (**Fig. 4**) possibly served as an explanation for changed fuel conversion rates. Compared with straw char prepared under the proper one-stage carbonisation factors (**Fig. 4(d)**), the inner structure of straw char shown in **Fig. 4(a)** (carbonisation temperature 500°C), **Fig. 4(b)** (heating rate 200°C/min), and **Fig. 4(c)** (carbonisation time 10 min) was looser, and more pores were observed. Therefore, straw char prepared under these factors had a larger reaction area with air when combusting under high temperature, which made straw char burn up within a shorter period. Structure of straw char prepared in two-stage carbonisation (**Fig. 4(e)**) achieved further densification compared with that shown in **Fig. 4(d)**. The changed structure coincided with the reduced fuel conversion rate difference shown in **Fig. 3**. The formation of this structure was related to lower temperature stage-1, which made organics parolysed mildly and less damage to straw inner structure when removing parolysed gas or oil. However, when heating raw straw to 700°C without any transition, organics were then directly exposed to high carbonisation intensity. The pressure formed by parolysed gas or oil inside straw would be larger than lower carbonisation temperature, more potential pores in straw char therefore were left. However, further research in terms of the mineral changes in ash should be done to clarify in details the changes of combustibility, since inorganic matter correlated with fuel reactivity.^{15,18)}

3.3. Application of Straw Char in Iron Ore Sintering

3.3.1. Influences on Sintering Indices

For examining the influences of prepared fuels on sintering indices, straw char prepared from proper factors of one-stage carbonisation and two-stage carbonisation were selected. The weight of straw char for each run was calculated on the basis of heat balance, which meant that straw char provided equal amount of heat that the coke breeze replaced released. Prior to sintering trials, straw char was crushed and screened. The

C- carbon; P- pore

Fig. 4. Influences of carbonisation processing on microstructures of straw char. (a) one-stage carbonisation (500°C, 25°C/min, 30 min); (b) one-stage carbonisation (700°C, 200°C/min, 30 min); (c) one-stage carbonisation (700°C, 25°C/min, 10 min); (d) one-stage carbonisation (700°C, 25°C/min, 30 min); (e) two-stage carbonisation (500°C, 700°C); (f) coke breeze.

Table 8. Influence of carbonisation processes on sintering indexes.

Fuel types	Carbonisation processes	Replacement ratio (mass%)	Sintering speed (mm·min ⁻¹)	Yield (mass%)	Tumble Index (mass%)	Productivity (t·m ⁻² ·h ⁻¹)	Reduction of SOx (mass%)	Reduction of NOx (mass%)
Coke breeze	—	0	21.94	72.66	65.00	1.48	—	—
	One-stage	20	23.05	69.78	64.62	1.47	10.98	12.67
	One-stage	40	25.12	65.53	62.25	1.40	—	—
Straw char	Two-stage	20	22.18	71.79	64.85	1.47	—	—
	Two-stage	40	23.20	71.05	64.55	1.48	38.15	22.53
	Two-stage	60	25.86	64.09	60.22	1.41	—	—

fraction with the same size range as coke breeze was preferred. Proper moisture content on individual run was determined when sintering indexes were optimal. **Table 8** shows the results of sintering trials.

When straw char prepared from one-stage and two-stage carbonisation replaced coke breeze by 20%, 20–40% respectively, sintering indices changed slightly compared with base run where only coke breeze was applied. However, sinter strength degraded remarkably after replacing coke breeze excessively. Potential explanation was that greatly increased sintering speed decreased the top temperature required to form adhesive phase that guaranteed sinter quality as the balance between combustion front and heat transfer front was damaged.^{11,19)} Therefore, recommended ratio for replacing coke breeze for straw char prepared from one-stage carbonisation was 20%, and for two-stage carbon-

isation was 40%.

3.3.2. Influences on Emissions Reduction

Equation (4) was employed to calculate reduced emission of SOx, NOx, where $R_{SOx/NOx}$ is the reduction ratio of SOx or NOx, Q_0 is sampled total flue gas flow in base run, t_0 is the total sintering time in base run, c_t is the concentration of SOx or NOx at time t in base run; Q_1 is sampled total flue gas flow, t_1 is the total sintering time, and c_t is the concentration of SOx or NOx at time t when coke breeze was replaced. The Emission reduction of SOx, NOx in flue gas for each run was described in Table 8.

$$R_{SOx/NOx} = \frac{Q_0 \int_0^{t_0} c_t dt - Q_1 \int_0^{t_1} c_t dt}{Q_0 \int_0^{t_0} c_t dt} \cdot 100 \quad \text{..... (4)}$$

Fig. 5. Nitrogen and sulphur levels in fuels.

As can be clearly observed, the concentrations of SO_x, NO_x in sintering flue gas was reduced with coke breeze partially replaced. The lower levels of sulphur and nitrogen in straw char given in Fig. 5 explained emissions reduction of SO_x, NO_x since they mainly came from the conversation of sulphur and nitrogen in fuels. When 20% of coke breeze was replaced by straw char prepared from one-stage carbonisation, emission reduction of SO_x, NO_x achieved 10.98%, 12.67% respectively. As straw char prepared from two-stage carbonisation could replace coke breeze by 40%, emissions of SO_x, NO_x were accordingly reduced by 38.15%, 22.53% respectively.

4. Conclusions

An investigation was carried out regarding preparation technologies of corn straw char and its application as an alternative fuel for iron ore sintering. It concluded:

(1) In this investigation, recommended conditions for one-stage carbonisation include carbonisation temperature of 700°C, heating rate of 10–25°C/min, and carbonisation time of 30 min. Two-stage carbonisation facilitates the further removal of volatile matters, and making straw char increased in yield and fixed carbon content, where recommended carbonisation temperature for stage-1 is 500°C

when stage-2 is 700°C. Straw char yielded under recommended conditions has similar volatile and fixed carbon contents to coke breeze.

(2) Straw char prepared from the recommended conditions shows close combustibility to coke breeze as densified structure is achieved. Compared with one-stage carbonisation, two-stage carbonisation makes straw char more densified in structure and less difference in combustibility to coke breeze.

(3) Straw char prepared from recommended one-stage carbonisation and two-stage carbonisation is able to replace coke breeze by 20%, 40% respectively, where emission reduction for SO_x is reduced by 10.98%, 38.15% respectively, and for NO_x is reduced by 12.67%, 22.53% respectively.

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