Influence of Preformation Process on Combustibility of Biochar and its Application in Iron Ore Sintering

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A study was carried out into the use of preformation process to prepare biochar for replacing coke breeze in iron ore sintering. Two types of preformation process, thermo-compression process (TCP) and normal temperature process (NTP), were adopted. Results show that preformation contributed to improving the density of both raw biomass and biochar. Recommended preformation parameters for TCP were 200°C, 1 min and 120 MPa respectively, while the recommended preformation pressure for NTP was 180 MPa. Compared with non-preformed biochar, the specific surface area and porosity of preformed biochar were considerably reduced. The inner structure of biochar was therefore compacted to close to that of coke breeze. These changes bridged the differences in terms of combustion properties between biochar and coke breeze. Laboratory-scale sintering tests showed that the proper replacement percentage of biochar to coke breeze was increased from 20% to 40% after preformation process, and the emission reduction of SOx and NOx were correspondingly increased from 18.37% and 15.88% to about 38.00% and 27.00% respectively.

KEY WORDS: iron ore sintering; biochar; preformation process; combustibility; emissions reduction.

1. Introduction

Sintering process is an energy-intensive and pollution-intensive process in integrated steelworks. About 9–12% of the total energy in integrated steelworks was consumed in this stage, 75–80% of which is consumed in the form of solid fuels, including coke breeze, anthracite etc.1) The combustion of fossil fuels has been widely known as the main source of CO2, SOx, NOx etc.2) Current studies have verified that substituting fossil fuels with clean and renewable bio-energy in sinter making was an effective strategy to reduce the emissions of CO2, SOx, NOx etc.3–6) However, the application of biomass fuel would also exert adverse influences on sinter quality mainly resulted from the significant differences in terms of combustion speed and reactivity between biomass fuels and fossil fuels.5,7) Besides, most of the mass of solid biomass fuels would be lost by devolatilization before its combustion in sintering process if raw biomass rather than biochar was utilized, which would give rise to poor fuel utilization and potential hazard to electrostatic precipitator.5)

Therefore, how to apply bio-energy into iron ore sintering process reasonably is the bottle-neck problem. Oxygen enrichment, increased air flow rates and adding more reactive iron ores (e.g. goethitic, porous hematite ore types and martitic ores) or a reduction in unreactive ores (e.g. dense hematite) during sintering process had been proposed to solve the problem.5,7) Unfortunately, no research regarding regulating the characteristics of biomass fuels via developing proper preparation technologies were found with the exception of our previous research.8,9) According to our research, controlling the carbonization process was able to bridge the differences between biomass fuels and fossil fuel, while only afforded less information about the effect of preformation process, which also played a significant role in biochar preparation. Biomass from plants is a cellular material of high porosity,10) preformation is able to reduce the volume and improve the energy density of biomass fuel through briquetting the raw biomass into regular particles with the help of mechanical pressure. Since the preformed biomass fuel characterizes easy storage and lower transportation cost, which has achieved wide concern.11–13)

In this investigation, raw biomass was initially preformed, and then carbonized into biochar. To our knowledge, this study is the first to describe the influences of preformation on the characteristics of biochar, which is prepared for iron ore sintering. A laboratory-scale sinter pot was used to evaluate its application in sinter making.

2. Materials and Methods

2.1. Properties of Raw 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 the chemical composition and proportions of raw materials given in Table 1, the mass contents of Fe, SiO2, and MgO in sinter...
could be kept at 56.38%, 4.92%, and 2.00% respectively. The basicity (CaO/SiO\textsubscript{2} mass ratio), which was adjusted through changing flux levels, in sinter was kept at 1.9. 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 biomass were employed in this investigation. Raw biomass, which was corn straw, was used to prepare biochar. Coke breeze was a typical kind of sintering fuels. 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 were tested, and the average value of which was regarded as the effective results.

### 2.2. Experimental Methods

#### 2.2.1. Biochar Preparation and Properties Examination

The preparation of biochar consisted of the preforming process and the following carbonization process. During the preforming stage, raw biomass ground to 0–2 mm was molded into cylindrical pellets of diameter 10 mm using a forming machine. Two types of preformation processes were applied to briquette the raw biomass, which were thermo-compression preformation (TCP) process and normal temperature preformation (NTP) process. As for TCP process, a heater was afforded to meet the prescribed temperature during the mechanical compression process. During the NTP process, no heating was provided, and the biomass particles were preformed with the help of high mechanical pressure. The designated factors and levels for TCP and NTP processes are described in Table 3. After that, preformed raw straw pellets underwent a two-stage carbonization process, which consisted of one lower temperature process and another higher temperature process, to prepare straw char. During carbonization process, raw straw pellets were firstly heated to 500°C under the heating rate of 25°C/min, and kept 30 min. After that, partially-carbonized straw pellets were heated to 700°C under the heating rate of 25°C/min, and kept 30 min.

#### 2.2.1.2. Evaluation Indexes

The density of preformed raw biomass and biochar were selected to evaluate the preformation process. Equation (1) was used to calculate the apparent density of biomass or biochar, and Eq. (2) was used to calculate the energy density of biochar. During the examining process, 20 individual pellets were tested, and the average value of which was regarded as the effective results.

\[
D_0 = 4m_0 / (3.14d^2 L) \quad (1)
\]

\[
D_E = D_0 C \quad (2)
\]

In Eq. (1), \(D_0\) is the apparent density of raw biomass or biochar (g/cm\(^3\)), \(m_0\) is the mass of raw biomass or biochar (g), \(d\) is the diameter of raw biomass or biochar (cm), \(L\) is the length of raw biomass or biochar (cm); In Eq. (2), \(D_E\) is the energy density of biochar (kJ/cm\(^3\)), \(C\) is the calorific value of biochar (KJ/g), \(D_0\) is the apparent density of biochar at this time (g/cm\(^3\)).

The porosity, specific surface area, microstructure and combustibility of biochar were selected to evaluate the influences of preformation process on properties of biochar. Equation (3) was used to calculate the value of porosity, and the specific surface area of biochar was examined by BET method. A calorimeter, model SDACM3100 (Sundy, China), an optical microscope, model DMRXP (Leica, Germany) and a simultaneous TG-DSC analyzer, model STA449C (Netzsch, Germany), were used to analyze the microstructure and combustibility of fuel samples.

During the TG-DTG analysis, 10±0.1 mg samples with a size range of 0.125–0.25 mm were heated from room

### Table 1. Chemical composition and percentage of raw materials in mixture (mass%).

<table>
<thead>
<tr>
<th>Sorts of raw materials</th>
<th>Chemical composition</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TFe</td>
<td>SiO\textsubscript{2}</td>
</tr>
<tr>
<td>Mixed iron ores</td>
<td>60.74</td>
<td>4.65</td>
</tr>
<tr>
<td>Dolomite</td>
<td>0.21</td>
<td>0.87</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.14</td>
<td>1.31</td>
</tr>
<tr>
<td>Quicklime</td>
<td>0.40</td>
<td>2.85</td>
</tr>
<tr>
<td>Return fines</td>
<td>56.38</td>
<td>4.92</td>
</tr>
<tr>
<td>Fuel</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\textsuperscript{a}LOI = loss on ignition in air atmosphere at 950°C; \textsuperscript{b}Proportion of return fines will be changed when do the experiments of return fines balance.

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

<table>
<thead>
<tr>
<th>Fuel types</th>
<th>Ultimate analyses (mass%)</th>
<th>Proximate analyses (mass%)</th>
<th>Calorific value (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>H</td>
<td>O</td>
</tr>
<tr>
<td>Raw biomass</td>
<td>44.69</td>
<td>5.10</td>
<td>45.49</td>
</tr>
<tr>
<td>Coke breeze</td>
<td>76.33</td>
<td>2.29</td>
<td>0.96</td>
</tr>
</tbody>
</table>

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temperature to 1 000°C to achieve complete combustion. Throughout the process, the heating and airflow rates were kept at 10°C min⁻¹ and 0.1 L min⁻¹. After that, differential scanning calorimetry (DSC), derivative thermogravimetry (DTG) and thermogravimetry (TG) curves were obtained. Combustion parameters, including the peak values \( V_{\text{max}} \) and \( Q_{\text{max}} \) on the DTG and DSC curves and the initial burning temperature \( T_i \) and the ending temperature \( T_e \) on DTG curves, were determined.\(^{14,15} \) Here, \( V_{\text{max}} \) and \( Q_{\text{max}} \) are respectively the maximum weight loss rate of the fuel and the maximum value of the heat release value, which are related in a positive manner to the reactivity of the fuel.

\[
P = \frac{100(D_i - D_t)}{D_i} \quad \text{.......................... (3)}
\]

Where \( P \) is the porosity of biochar (%), \( D_i \) is the true density of biochar (g/cm³), \( D_t \) is the apparent density of biochar calculated in Eq. (1) (g/cm³).

### 2.2.2. Sinter Pot Test

Sintering trials were conducted in a sinter pot of depth 700 mm and diameter 180 mm, the schematic of which can be found elsewhere.\(^8,9\) The raw materials were blended according to their proportions in Table 1, with water added to meet the prescribed moisture content. The mixture was then charged into an electrically powered drum of length 1 400 mm and diameter 600 mm for granulation, which was conducted at 15 rev min⁻¹ for 4 min. 1 kg sinter with size range of 10–16 mm was charged into the sinter pot as a hearth layer, and the granulated mixture was then fed in. After feeding, the fuel in the surface layer was initially ignited by an ignition hood, and the combustion front then moved downwards with the support of a downdraught system. The ignition period was 1 min at 1 050 ± 50°C, with a pressure drop of 5 kPa. However, the pressure drop was changed to 10 kPa for sintering and then to 5 kPa for cooling. The total sintering time and total flue gas flow were measured from the start of ignition to the point at which the sinter waste gas had reached its maximum temperature. During the whole sintering process, two types of infrared flue gas analyser, a DELTA 65-3 and a Vario Plus (MRU Corporation, Germany), were used to analyze the concentration of SOx, NOx in the flue gas.

Equation (4) was employed to calculate reduced emission of SOx, NOx, where \( R_{\text{SOX/NOx}} \) is the reduction ratio of SOx or NOx, \( Q_{\text{flue}} \) is sampled flue gas flow rate in base run where only coke breeze was used as fuel, \( t_i \) is the total sintering time in base run, \( c_i \) is the concentration of SOx or NOx at time \( t \) in base run, \( Q_t \) is sampled flue gas flow rate, \( t_1 \) is the total sintering time, and \( c_t \) is the concentration of SOx or NOx at time \( t \) when coke breeze was replaced.

\[
R_{\text{SOX/NOx}} = \frac{\int_0^t Q_{\text{flue}} c_i dt - \int_0^t Q_{\text{flue}} c_t dt}{\int_0^t Q_{\text{flue}} c_i dt} \times 100 \quad \text{............ (4)}
\]

The return fine balance (RFB), which is the ratio of the mass of produced return fines to the mass of afforded return fines, was taken as an important index to validate the tests of sintering speed, sinter yield, tumble index, productivity, etc., and these tests were conducted only when the RFB was in the range of 1 ± 0.05. The sintering speed is the ratio of layer height and sintering time. The sinter yield is the percentage of sinter above 5 mm after screening, with the mass of the hearth layer subtracted. The productivity is a measure of the quantity of sinter produced per unit area and unit time. The tumble index is a measure of sinter strength, based on the methodology outlined in ISO3271 (2007).

### 3. Results and Discussion

#### 3.1. Influence of Preformation on Physical Properties of Biochar

**3.1.1. Density and Energy Density of Raw Biomass and Biochar**

Influence of TCP and NTP processes on the apparent density of raw biomass (DRB), apparent density of biochar (DB) and energy density of biochar (EDB) are shown in Fig. 1, where can be seen that a significant improvement in DRB, DB and EDB compared with non-preformed biomass was achieved after both TCP and NTP process. As shown in Fig. 1(a), DRB, DB and EDB could obtain bigger increase when improving preformation temperature from 150°C to 200°C. After increasing the temperature further to 250–300°C, the increase of DRB, DB and EDB became marginal. 200°C was therefore selected as the proper preformation temperature. Extending preformation time from 0.5 min to 3 min contributed to gradually increasing DRB, DB and EDB (Fig. 1(b)). Specifically, relatively larger enhancement for DRB, DB and EDB was achieved when extending the time from 0.5 min to 1 min. However, the enhancement became slight when the preformation time exceeded 1 min, in accordance of which, 1 min was selected as proper preformation time. Increasing preformation pressure from 40–180 MPa was able to improve DRB, DB and EDB continually (Fig. 1(c)). However, DRB, DB and EDB merely increased slightly when changing preformation pressure from 40 MPa to 60 MPa, while a larger rise was achieved after improving the pressure to 120 MPa. Increasing the pressure further to 180 MPa, DRB, DB and EDB changed marginally. 120 MPa was thus selected as the proper preformation pressure.

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**Table 3. Factors and their levels for biochar preparation.**

<table>
<thead>
<tr>
<th>Preformation process</th>
<th>Changing factors</th>
<th>Constant factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP</td>
<td>Time (0.5 min, 1 min, 2 min, 3 min)</td>
<td>Temperature 100°C, Pressure 40 Mpa</td>
</tr>
<tr>
<td>TCP</td>
<td>Pressure (40 MPa, 60 MPa, 120 MPa, 180 MPa)</td>
<td>Temperature 200°C, Time 1 min</td>
</tr>
<tr>
<td>NTP</td>
<td>Pressure (60 MPa, 120 MPa, 180 MPa, 240 MPa)</td>
<td>Time 1 min</td>
</tr>
</tbody>
</table>
Like the TCP process, increasing the preformation pressure of NTP process from 60 MPa to 240 MPa also enabled to gradually increase DRB, DB and EDB (Fig. 1(d)). However, only slight rise was achieved before increasing the pressure to 180 MPa. Increasing the pressure further to 240 MPa hardly changed DRB, DB and EDB obviously. The proper preformation pressure for NTP process was 180 MPa.

Mechanical interlocking and inter-diffusion between fibers and particles are the typical mechanism during forming process, which existed in both TCP and NTP processes with the help of mechanical pressure. However, it comprised the major mechanism for NTP process since no heating was afforded. Indeed, lignin and hemicelluloses in raw biomass are essentially thermoplastic polymers, which can build the bonding between particles from forming solid bridge by natural binders such as lignin and celluloses after their softening. Increasing temperatures benefited the increase of interfacial area between adjacent particles resulting in larger adhesive strength, which can serve as the better explanation for the influences of temperature (Fig. 1(a)). Extending preformation time increased the soften and adhesive degree between particles, while improving the pressure helped to increase the mechanical interlocking and inter-diffusion effects to binder the particles tighter, which potentially explained the changing resulting from preformation time (Fig. 1(b)) and preformation pressure (Figs. 1(c) and 1(d)). When moving the preformed briquettes into carbonization stage, the DB and EDB of biochar consequently achieved a significant rise as well.

3.1.2. Porosity, Specific Surface Area and Microstructure of Biochar

The influence of TCP and NTP process on the porosity and specific surface area of biochar are outlined in Fig. 2. As can be seen from Figs. 2(a)–2(c), increasing preformation temperature from 150°C to 300°C, extending preformation time from 0.5 min to 3 min, and improving preformation pressure from 40 MPa to 180 MPa benefited the continual reduce of porosity and specific surface area. Specifically, a relatively larger decrease appeared when increasing the temperature from 150°C to 200°C, extending the time from 0.5 min to 1 min, and improving the pressure from 60 MPa to 120 MPa. Similarly, during NTP process, with increasing preformation pressure, the porosity and specific surface area of biochar also achieved continual rise (Fig. 2(d)). When increasing the pressure to 180 MPa, the porosity and specific surface area achieved a larger increase. Those phenomenons showed good relationship to the changing tendency of DRB, DB and EDB (Fig. 1). Therefore, after TCP and NTP process, the porosity and specific surface area could be reduced significantly, especially when optimizing the preformation parameters.

The change of porosity ad specific surface area was closely related to the microstructure of biochar, which is shown in Fig. 3. After carbonization, the char formed from the preformed raw biomass exhibited a considerably tighter distribution as compared to non-preformed case. More linkage had appeared between the separated small char particles, which linked the particles together with less pores and voids distributed inside the biochar. This phenomenon well explained the decrease in terms of porosity and specific surface area between non-preformed biochar and preformed biochar (Fig. 2). As a consequence, preformation process has the advantage to densify the structure of biochar, which showed more similarity to that of coke breeze (Fig. 3(f)).
Fig. 2. Influence of TCP and NTP parameters on porosity and specific surface area of biochar. (a), (b) and (c) are influences of preformation temperature, time and pressure for TCP process; (d) is the influence of preformation pressure for NTP process.

Fig. 3. Influence of preformation on microstructure of biochar. (a) Non-preformed biochar; (b) Biochar from TCP (Preformation temperature 200°C, time 1 min and pressure 120 MPa); (c) Biochar from NTP (Preformation pressure 180 MPa); (d) Coke breeze.
3.2. Influences of Preformation on Combustibility of Biochar

Figure 4 summarizes the influences of preformation on the combustion characteristics of biochar using TG-DSC analysis. The Ti of non-preformed biochar was only 335°C (Fig. 4(a)), while that of the coke breeze reached about 523°C (Fig. 4(d)). Besides, the Te of non-preformed biochar and coke breeze were 558°C, 917°C respectively. Obviously, the Ti of coke breeze showed a close value to the Te of biochar, which indicated that the combustion process showed less overlapping degree to that of biochar. More direct information could be obtained from Fig. 5, and only a small overlapping section existed between biochar and coke breeze during the combustion process. From the sharp shape of the DTG curve, it was found that biochar could intensively release a large amount of heat during its combustion process, and the Qmax and Vmax of biochar reached 20.25 mW/mg and −6.14%/min which nearly doubled and tripled that of coke breeze. However, the unmatched heat-release interval was adverse to create higher combustion temperature in practical sintering process when replacing non-preformed biochar to coke breeze.

As shown in Fig. 4(b), after the TCP process, the Ti and Te in the DTG curve increased from 335°C, 558°C to 453°C and 672°C respectively compared with that of non-preformed case. Consequently, the combustion interval of which became relatively closer to that of coke, which was able to be more clearly observed from Fig. 5. Therefore, the combustion of biochar showed greater overlapping degree to coke breeze, which stood for the overlap of the released heat to form higher temperature in sintering process. The values of Vmax and Qmax for biochar after TCP process reached −4.31%/min and 10.82 mW/mg, respectively, which showed smaller difference to that of coke breeze. The change of non-isothermal combustion characteristics of biochar was closely related to the change of its basic physical properties as shown in Figs. 2 and 3. Preformation process helped to improve the compactness of biochar, and thus reduced the porosity of specific surface area, which finally slowed down the combustion speed of biochar. After NTP process, biochar also showed closer combustion properties to that of coke breeze, as described in Fig. 4(c), and its combustion interval even showed larger overlapping degree compared with the TCP case.

3.3. Application of Preformed Biochar in Sintering Process

For examining the application effect of biochar from...
preformation-carbonization process, biochar from non-preformed process, TCP process and NTP process was selected to replace coke breeze. Tables 4 and 5 give the basic physicochemical properties of biochar from different processes. Biochar from non-preformed process, NTP process and TCP process showed similar elemental composition, fixed carbon content, volatile content and ash content. Since biochar is prepared from carbonization process, its water content is only 0.55–0.82%. Biochar is crushed and screened to achieve the proximate size distribution to that of coke breeze before its use. 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 calorific value of the fuels to that of the coke breeze. The specific blending ratio of biochar with replacement ratio of 20%, 40% and 60% and its influences on sinter operation and sintering indexes are shown in Tables 6, 7 respectively.

As shown in Table 6 the proper moisture content was reduced when applying preformed biochar compared with applying equal ratio of non-preformed biochar. The increase in moisture content after replacing coke breeze with biochar resulted from the higher porosity of biochar, which was able to absorb more moisture during the granulation, and the same results were obtained by R. Lovel,3) Lu20) and T. Kawaguchi.21) After preformation process, the density of biochar achieves an increase, while its porosity achieves an obvious decrease, which therefore needed less water to get saturated. Additionally, in combination with the results found by T. Kawaguchi,21) the change of biomass char is firstly related to the change of bulk density of sintering mixtures. Before preformation process, the apparent density of biochar is much smaller than that of coke breeze, which would reduce the bulk density of sintering mixtures and improve the permeability of sinter bed (Table 6). After NTP or TCP process, the apparent density of biochar achieves a significant increase, which not only contributes to bridging the differences in terms of the bulk density and permeability of sintering mixture between using coke alone and using a part of preformed biochar (Table 6).

According to the results shown in Table 7, it is found that when the replacement percentage was 20%, applying biochar from NTP and TCP process achieved more comparable sintering indexes to the base run compared with using non-preformed biochar. After increasing the replacement per-

### Table 4. Basic physicochemical properties of biochar used for sinter pot tests.

<table>
<thead>
<tr>
<th>Preformation process</th>
<th>Ultimate analyses (mass%)</th>
<th>Proximate analyses (mass%)</th>
<th>Calorific value (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>H</td>
<td>O</td>
</tr>
<tr>
<td>—</td>
<td>78.80</td>
<td>0.90</td>
<td>1.25</td>
</tr>
<tr>
<td>NTP</td>
<td>79.65</td>
<td>0.86</td>
<td>1.18</td>
</tr>
<tr>
<td>TCP</td>
<td>79.07</td>
<td>0.86</td>
<td>1.22</td>
</tr>
</tbody>
</table>

### Table 5. Water content and size distribution of coke breeze and biochar.

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>Preformation process</th>
<th>Water content (mass%)</th>
<th>Size distribution (mass%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>+3 mm</td>
</tr>
<tr>
<td>Coke breeze</td>
<td>—</td>
<td>7.50</td>
<td>8.10</td>
</tr>
<tr>
<td>Biochar</td>
<td>NTP</td>
<td>0.55</td>
<td>7.80</td>
</tr>
<tr>
<td></td>
<td>TCP</td>
<td>0.70</td>
<td>8.01</td>
</tr>
</tbody>
</table>

### Table 6. Influence of biochar with different densities on the sinter operation.

<table>
<thead>
<tr>
<th>Fuel types</th>
<th>Preformation process</th>
<th>Replacement ratio (mass%)</th>
<th>Blending ratio (mass%)</th>
<th>Moisture (mass%)</th>
<th>Bulk density (g/cm³)</th>
<th>Permeability (<em>J.P.U.</em>))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke breeze</td>
<td>—</td>
<td>0</td>
<td>3.85</td>
<td>7.25</td>
<td>1.72</td>
<td>33.50</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>20</td>
<td>0.79</td>
<td>7.50</td>
<td>1.68</td>
<td>35.15</td>
</tr>
<tr>
<td>NTP</td>
<td>20</td>
<td>0.78</td>
<td>7.25</td>
<td>1.70</td>
<td>34.33</td>
<td></td>
</tr>
<tr>
<td>TCP</td>
<td>20</td>
<td>0.79</td>
<td>7.25</td>
<td>1.70</td>
<td>34.45</td>
<td></td>
</tr>
<tr>
<td>Biochar</td>
<td>—</td>
<td>40</td>
<td>1.58</td>
<td>7.75</td>
<td>1.64</td>
<td>37.80</td>
</tr>
<tr>
<td>NTP</td>
<td>40</td>
<td>1.57</td>
<td>7.50</td>
<td>1.68</td>
<td>35.10</td>
<td></td>
</tr>
<tr>
<td>TCP</td>
<td>40</td>
<td>1.57</td>
<td>7.50</td>
<td>1.67</td>
<td>35.25</td>
<td></td>
</tr>
</tbody>
</table>

*J.P.U. = Japanese Permeability Unit
percentage to 40%, using non-preformed biochar significantly deteriorated the sintering yield, tumble index and productivity, while using preformed biochar could still obtain better sintering indexes. However, increasing the replacement ratio to 60% would decrease sintering indexes remarkably. Due to the proper replacement ratio of biochar was increased to 40% after preformation process, the emission reduction of SOx and NOx was improved from 18.37%, 15.88% to about 38%, 27% respectively.

4. Conclusions

In this investigation, the influence of thermo-compression preformation (TCP) and normal temperature preformation (NTP) on the basic physical properties, combustibility and the application of biochar were carried out, and the results can be drawn as:

1) Preformation benefits the improvement of the density for both raw biomass and biochar. Recommended preformation temperature, preformation time and preformation pressure for TCP were 200°C, 1 min and 120 MPa respectively, while the recommended preformation pressure for NTP was 180 MPa.

2) Compared with non-preformed biochar, the specific surface area and porosity of preformed biochar are increased significantly. The inner structure of biochar was therefore compacted to close to that of coke breeze. These changes bridged the differences in terms of combustion properties between biochar and coke breeze.

3) Laboratory-scale sintering tests showed that the proper replacement percentage of biochar to coke breeze was increased from 20% to 40% after preformation process, and the emission reduction of SOx and NOx were correspondingly increased from 18.37%, 15.88% to about 38%, 27% respectively.

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