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Factors Influencing Gas Generation Behaviours of Lump Coal Used in COREX Gasifier

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Abstract: The influences of coal rank, particle size, temperature and gasifier atmosphere on the gas generation of lump coals used in COREX gasifier were investigated. The results showed that an increase in gasifier temperature and a decrease in particle size hardly affected the final mass loss of lump coals but strongly enhanced the gas generation rate. When the temperature was greater than 1000 °C, a decrease in coal rank increased the gas yield but had little effect on the gas generation rate. Moreover, the promotion ability of the atmosphere for the gas generation rate of lump coal from low to high was as follows: N_2, CO_2, CO and H_2. Considering energy conservation, to improve the gas generation rate of the gasifier, the coal rank and particle size should be decreased first, and afterwards, an increase in reduction potential of the atmosphere in gasifier is also encouraged.

Keywords: COREX, lump coal, gas generation behaviours, influence factors

Introduction

COREX is a new ironmaking process that has successfully been realized during production by using lump coal instead of coke to extract hot metal from iron ore [1, 2]. Industrial applications have proved that the lump coal quality has a significant impact on stable operation and energy consumption. Kumar [3, 4] et al. revealed that the quality of lump coal could affect the fuel ratio and Si content in hot metal, and then proposed suitable quality requirements for lump coal used in the COREX process [5, 6]. Guo et al. found that the metallurgical properties of coal greatly influenced the temperature of hot metal [7, 8]. Xu et al. also demonstrated that the good properties of lump coal could be benefited to the melting performance, production target, hot metal quality and the tuyere damage [9]. Besides the lump coal properties, the particle sizes in raw fuels are also of concern. Wang et al. found that the sizes of the lump coal and powder ratio (<5 mm) were both important factors influencing gasifier operation [10, 11]. In view of the abovementioned industry facts, the effective utilization of lump coal can contribute to maintaining a stable COREX process; therefore, understanding the evaluation process of lump coal in the gasifier is an essential step.

It is well known that the COREX gasifier is a huge reactor that operates at high temperatures. Lump coal undergoes rapid pyrolysis at high temperatures upon being charged into the gasifier [12, 13]. The microstructure, morphology and metallurgical properties of the lump coal are always changing during the pyrolysis process [14]. Previous studies have shown that the pyrolysis behaviour of coal is determined by intrinsic characteristics (such as the coal rank, particle size, and ash composition) and working conditions (such as temperature, heating rate and atmosphere). However, most of the above studies were aimed at an investigation of pulverized coal pyrolysis using thermogravimetric analysis. Limiting information regarding the lumpy coal pyrolysis can be found, especially under the conditions of COREX gasifier. Wang et al. revealed that the pyrolysis and metallurgical properties of lump coal were related to the coal rank [15]. Wu et al. investigated the pyrolysis behaviour and tar generation process of lump coal and calculated the kinetics parameters based on a segmentation method [16, 17]. Kim et al. investigated the pyrolysis and cracking characteristics of six Australian lumpy coals, revealing that the cracking and swelling behaviour of the coals was infâluenced by both their physical and chemical properties [18]. For the Chinese COREX lump coal, Zhang et al. also investigated the pyrolysis behaviours and kinetics of lump coal at high temperatures; however,

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most of the studies were focused on the structure, strength and reactivity of the resulting chars [19, 20]. The gas generation of the gasifier not only determined the operation of the gas reforming system but also affected the reduction of the pellet in the shaft furnace. Therefore, it is necessary to understand the influencing factors of the fast pyrolysis of lump coal to control dome gas generation.

To date, there are limited reported systematic studies on the factors influencing the pyrolysis behaviour of lump coal under COREX gasifier conditions, particularly, a comparative analysis between the different factors. The aim of this study is to investigate the factors influencing the gas yield and gas yield rate of lump coal under simulated gasifier conditions, including the coal rank, particle size, temperature and gas type. The results of this research may be beneficial for an understanding of the gas generation and top gas control in COREX gasifier.

Experimental

Experimental material

Four lump coals were selected for this study. Lump coal A came from Shandong province in China; lump coal B originated from Heilongjiang province in China; and lump coal C and lump coal D came from Xinjiang province in China. After crushing and drying the coal samples at 25 °C for 10 h, the proximate analysis of coals was tested according to Chinese standard GB/T212-2008 and the ultimate analysis of coals were tested according to Chinese standard GB/T214-2007, GB/T476-2008 [21–23]. The results are shown in Table 1. The chemical compositions of coal ash were detected by X-ray fluorescence (XRF) using a Shimadzu sequential XRF spectrometer. The results are listed in Table 2.

The maceral analysis of lump coals was conducted with a DAS microscope (Leica DMRP RXP) at a magnification of 500. The maceral analysis method was based on the Chinese standard GB 8899–88. The tested results are shown in Table 3.

To ensure the same experimental conditions, a symmetrical cubic shape was used to maintain the identical physical dimensions, as shown in Figure 1. The coal was shaped into a coal cake by manual grinding.

Experimental apparatus and methods

To simulate the high-temperature conditions in the gasifier, a self-designed heating furnace was developed, as shown in Figure 2. This equipment consisted of a heating furnace, a temperature control system, an electronic balance, a computer acquisition system and a gas control system. The heating element used in the furnace was $MoSi_2$, which produced a maximum working temperature of 1600 °C. The heating rate of the furnace was controlled by PID-controllers, and the maximum heating rate of 20 °C/min was reached. The diameter of working tube was 60 mm. The constant temperature region of the furnace was 10 cm and was monitored by a B-type thermocouple. The mass loss data of the sample were recorded by an electronic balance (Longteng JD200-3 made by Shenyang Longteng electronic CO., LTD in China.) with a maximum mass of 200 g and a precision of 0.001 g. The gas flow was controlled using a gas flow meter whose flow range was 0–5 L/min and accuracy was 0.01 L/min. The gas was flowed into the furnace from the bottom of the heating furnace. The experimental data were acquired by a computer with an acquisition frequency of 0.1 s.

After the furnace was heated to a set temperature (900 °C, 1000 °C, 1100 °C and 1200 °C), the reaction gas was continuously flowed into the furnace at a rate of 2 L/min under standard conditions (25 °C, 1 atm). Subsequently, a lump coal was placed into a crucible that was connected to a stainless steel suspension, as shown in Figure 2(b). Then, the crucible with lump coal was quickly placed into the furnace and the stainless steel suspension was hung on the bottom of the electronic balance. At the same time, the data acquisition

Table 1: Proximate analysis and ultimate analysis of the coal samples, *mass* %.

Lump coal	Proximate analysis (ad)				Ultimate analysis (ad)				
	M	A	V	FC	C	H	N	St	O
A	0.95	2.62	43.89	52.54	74.95	4.41	1.01	0.15	10.31
B	1.45	11.79	38.81	47.95	69.78	5.07	0.73	0.19	8.52
C	2.06	2.77	33.74	61.43	72.20	4.82	0.97	0.23	12.27
D	1.89	2.64	23.26	72.21	77.28	3.86	1.00	0.25	9.61

Table 2: Chemical compositions of the coal ash, *mass* %.

Lump coal	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	Na_2O	MnO
A	57.37	15.55	3.31	9.82	0.87	0.90	0.16	0.37	0.04
B	67.53	21.97	1.57	3.02	0.60	1.47	1.76	0.75	0.02
C	15.16	9.58	21.76	39.99	2.22	0.27	0.05	0.31	0.79
D	13.67	5.70	27.42	32.23	4.46	0.49	0.08	0.95	0.36

Table 3: Results of the maceral content and maximum vitrinite reflectance.

Lump coal	Vitrinite, %	Liptinite, %	Inertinite, %	Minerals, %	R_{max}
A	88.86	3.48	5.72	2.74	0.47
B	85.68	2.22	1.98	10.12	0.55
C	62.93	0.62	33.20	4.05	0.60
D	48.30	0.00	43.65	8.85	0.71

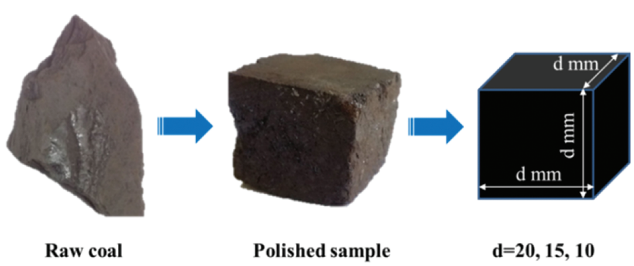

Figure 1: Coal cake size and shape for the experiments.

system was turned on by the computer. To investigate the effect of particle size on the gas generation behaviour, three different sizes (20 × 20 × 20mm, 15 × 15 × 15mm and 10 × 10 × 10mm) were used in the study. The weights of samples varied with coal size and coal rank.

The instantaneous weights were recorded under different experimental conditions. The mass loss, final mass loss, pyrolysis conversion and conversion rate were calculated according to eq. (1)–(4) [24–27]:

$$Mass\ loss = \frac{m_0 - m_t}{m_0} \times 100, \quad (1)$$

$$Final\ mass\ loss = \frac{m_0 - m_\infty}{m_0} \times 100, \quad (2)$$

$$\text{Conversion} = \frac{(m_0 - m_t)}{m_0 - m_\infty} \times 100, \quad (3)$$

$$Conversion\ rate = -\frac{100}{m_0 - m_\infty} \times \frac{d_m}{d_t}, \quad (4)$$

where m_0 is the initial weight of lumpy coal, g; m_t is the instantaneous weight of lumpy coal, g; m_∞ is the mass of residual material after a reaction, g; and $\frac{d_m}{d_t}$ is the first derivative of weight loss curve, g/s.

Results and discussion

Properties of lump coals

As shown in Table 1, Lump coal B has a higher ash content (11.79 %) than that of the other coals (approximately 2.7 %). The lowest moisture content of 0.95 % is found in lump coal A, whereas the largest moisture content of 2.06 % is in lump coal B. Lump coal D has the most fixed carbon content (72.21 %), whereas the lump coal A exhibits the least carbon content (47.95 %). The volatile content of the four coals from high to low is as follows: coal A, coal B, coal C and coal D, which indicates that the metamorphic degree of these coals may increase gradually in this order. The H/C and O/C ratios in the lump coals, as shown in Figure 3, have no clear relationship with coal rank.

The compositions of ash in lump coal A and lump coal B are mainly acidic oxides, whereas the compositions in lump coal C and lump coal D are mostly alkaline oxides, as shown in Table 2. The mineral compositions of ash not only determine the melting point of coal ash but also affect the pyrolysis process of coal [28–30]. The higher contents of Fe_2O_3 and CaO in lump coal C and D can promote their pyrolysis. The maceral compositions of

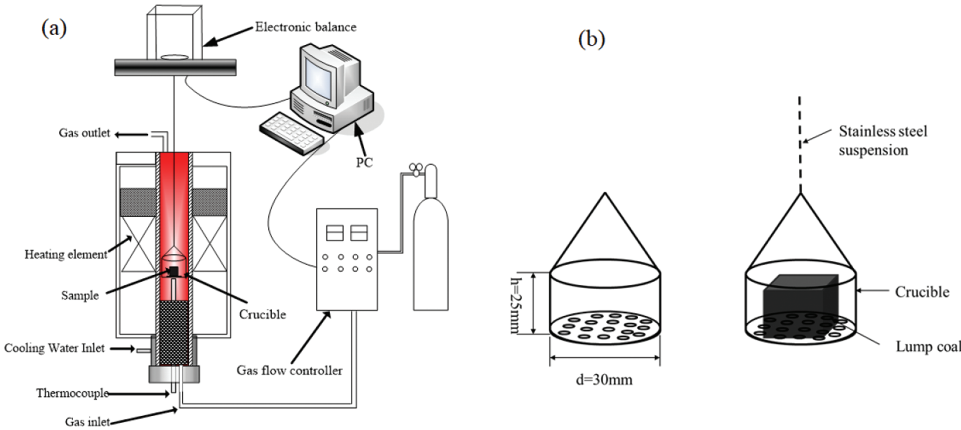

Figure 2: Schematic diagram of the self-designed experimental equipment (a) and alumina crucible (b).

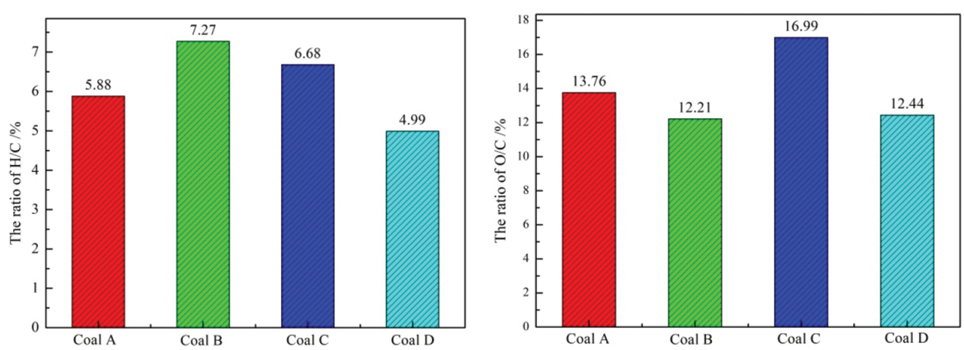

Figure 3: H/C ratio and O/C ratio of lump coals.

lump coal A and B are similar and mainly consist of vitrinite, as shown in Table 3. While the macerals of lump coal C and D both primarily consist of vitrinite and inertinite.

Effect of temperature on lump coal pyrolysis

The dome temperature of the gasifier often fluctuates due to different working conditions, which can affect the pyrolysis of lump coal. To investigate the influence of temperature on the pyrolysis of lump coal, coal pyrolysis was simulated by experiments at high temperatures (900 °C, 1000 °C, 1100 °C and 1200 °C). The size of the lump coal was 20 mm in these experiments. In general, the effects of temperature on coal pyrolysis are focused on the final mass loss and the reaction rate.

(1) Mass loss of lump coal at different temperatures

Figure 4 shows the mass loss curves of four lump coals pyrolysed at high temperatures. The mass loss curves of the lump coals at different temperatures almost overlapped at greater pyrolysis times. The final mass loss of lump coal A increases from 43.56 % to 44.84 %, when the temperature changes from 900 °C to 1200 °C, respectively. In this temperature range, the final mass loss of lump coal B changes from 39.01 % to 40.36 %, that of lump coal C changes from 36.32 % to 37.41 % and that of lump coal D changes from 24.66 % to 25.57 %. These results show that although the temperature of the gasifier increases by 300 °C, the change in the final mass loss of each lump coal is less than 1.5 %, indicating that the temperature fluctuation has little influence on the final mass loss of lump coal. This phenomenon is attributed to the pyrolysis procedure of coal. The reported non-isothermal experimental results [31] showed that the mass loss during coal pyrolysis was nearly completed before 750 °C, while the mass loss caused by the reactions at higher temperatures (above 750 °C) was minimal. When the lump coal was charged into the gasifier whose dome temperature ranged from 900 to 1200 °C, all the side chains and the oxygen-containing functional groups of coal quickly turned into

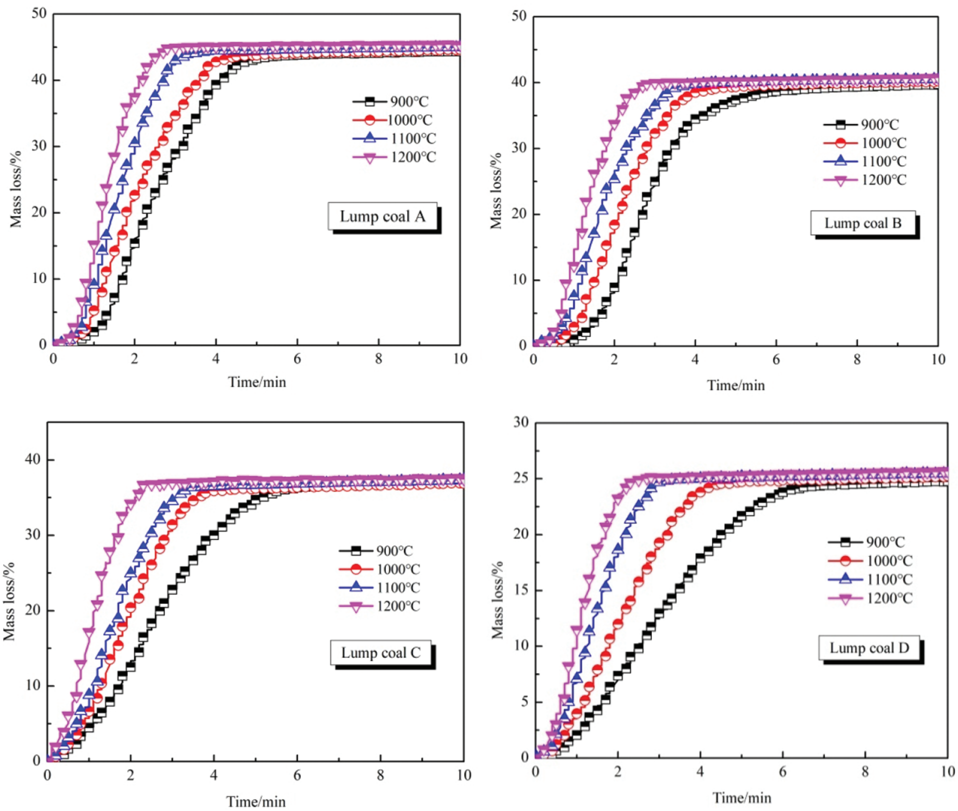

Figure 4: Mass loss of lump coals at different temperatures.

volatile matters. Thus, the change of the temperature in the practice hardly affects the gas output per ton of coal.
(2) Conversion rate of lump coal at different temperatures

Figure 5 exhibits the conversion rate of four lump coals at various high temperatures. The shapes of conversion rate curves of the four coals are similar, and all the curves appear as a single peak. With an increasing experimental temperature, the peak values gradually increase, and the peak positions gradually move to the low temperature region. As is known, the higher and narrower the peak is, the more intense the pyrolysis reaction is. The tendency of peak position to move to the low temperature region indicates that the occurrence of an intense pyrolysis reaction becomes earlier. Therefore, the pyrolysis conversion rate of lump coal strongly increases with increasing temperature from 900 to 1200 °C. Additionally, the intense pyrolysis reaction occurs earlier and the total reaction time is reduced with increasing temperature.

To quantitatively analyse the relationship between the pyrolysis rate of lump coal and the temperature, the pyrolysis parameter $S_{0.5}$ [32, 33], which could represent the conversion rate of lump coal under different conditions, was used in this study.

$$S_{0.5} = \frac{0.5}{t_{0.5}}, \tag{5}$$

where $t_{0.5}$ represents the time required to reach a 50 % conversion. As seen in

Figure 6, the pyrolysis parameter $S_{0.5}$ increases linearly with increasing temperature for all the lump coals. In addition, the curves of coal C and D are similar to each other, which indicate that the effect of temperature on the pyrolysis rate of lump coal is greater than that of coal rank. In conclusion, the temperature fluctuation (from 900 °C to 1200 °C) of the gasifier has little effect on the final mass loss of lump coal but has a great impact on the pyrolysis rate. Therefore, as the temperature increases, the pyrolysis rate of lump coal will be greatly improved, which results in an increase of the gas generation rate during the COREX melting process.

Effect of coal rank on lump coal pyrolysis

To further investigate the effect of coal rank on the pyrolysis behaviour, the conversion and conversion rate

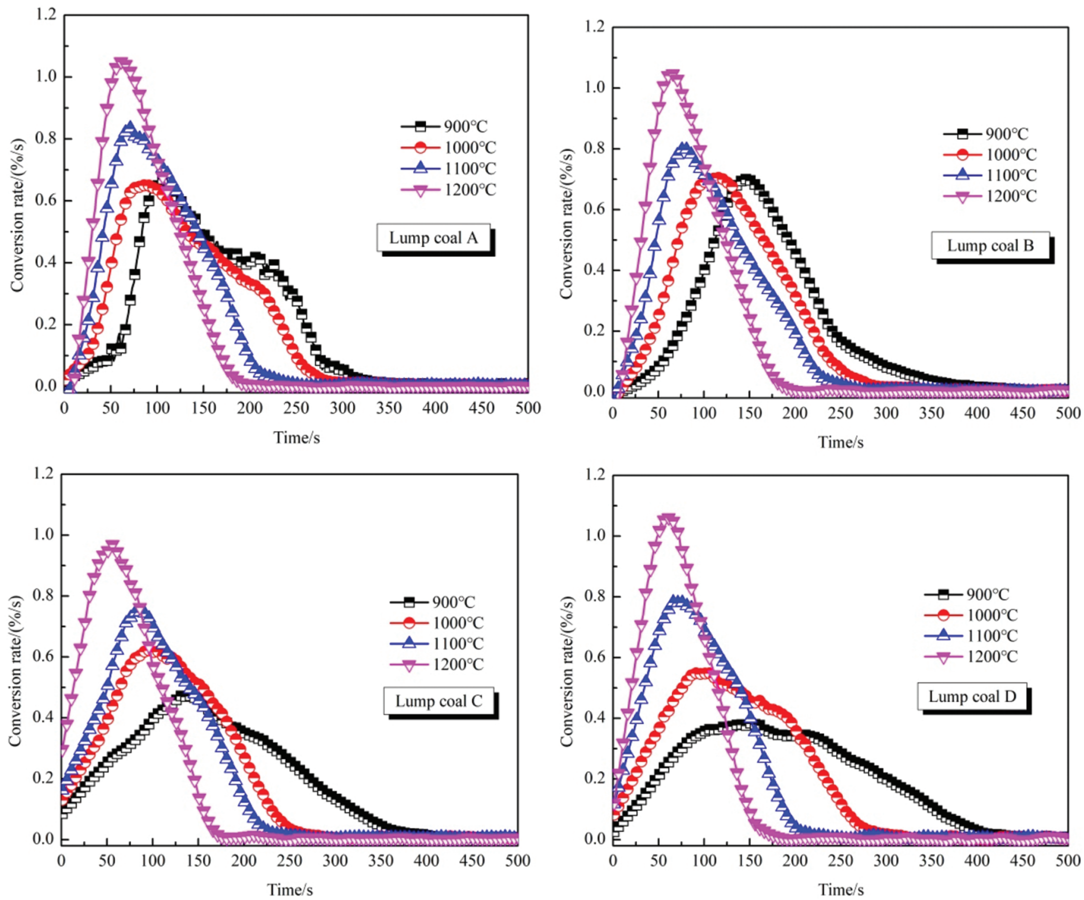

Figure 5: Conversion rate of lump coal at different temperatures.

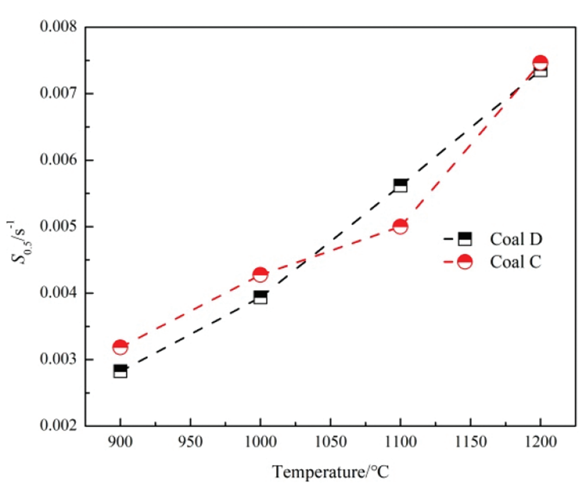

Figure 6: Relationship between the pyrolysis parameter $S_{0.5}$ and temperature.

curves of lump coals at the same temperature were compared, as shown in Figure 7.

The conversion curve and conversion rate curve gradually move closer together, and finally overlap with each together, when the temperature increases from 900 °C to 1200 °C. In terms of the conversion curve at 900 °C, the slope of four conversion curve decreases in the order of lump coal A, lump coal B, lump coal C and lump coal D, and the conversion curves of lump coal C and lump coal D are similar to each other. In terms of the conversion rate curves at 900 °C, the peak value of the conversion rate curve is at a maximum for lump coal A, followed by lump coal B and then lump coal C. The peak value is at a minimum for lump coal D. Therefore, it can be concluded that the coal rank has a certain influence on the gas generation rate, when the temperature is less than 900 °C. However, when the temperature is greater than 1000 °C, the conversion curve and the conversion rate curve almost overlap. This overlap indicates that the coal rank hardly influences the gas generation rate under normal dome temperatures (approximately 1050 °C), although there are significant differences in the properties of the four coals, Combined with Figure 4, Tables 1, 2 and 3, the final mass loss of coal is determined by the coal rank. The gas yield increases with the decreasing metamorphic degree of the lump coal. At

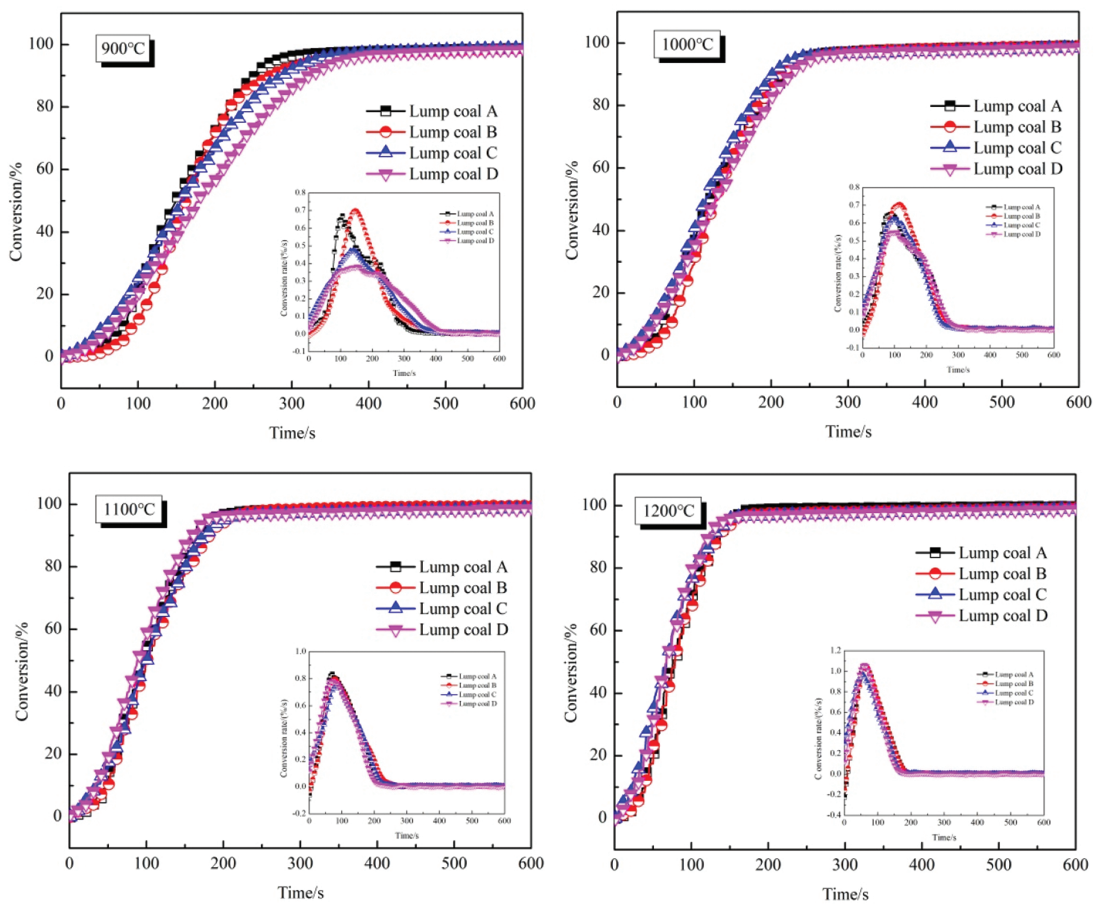

Figure 7: Compared analysis of the pyrolysis behaviours of lump coals.

higher temperatures (above 1000 °C), the coal rank has little effect on the gas generation rate. Furthermore, even though there is quite a difference in the ash compositions among the lump coals, the gas generation behaviours (conversion and conversion rate curves) are similar when the temperature is above 1000 °C. Therefore, the higher temperature has greater effect on the pyrolysis of coal than the coal rank and ash compositions.

Effect of atmosphere on lump coal pyrolysis

When the lump coal was charged into the gasifier, the pyrolysis of lump coal occurred rapidly, and the coal gases were dramatically generated due to the high temperature in the gasifier. Therefore, the main compositions of generator gases were CO, CO_2 and H_2 in the freeboard area [34]. To reveal the effects of different gases on the pyrolysis, the pyrolysis behaviours under various pure gases (CO, CO_2, H_2 and N_2) were first investigated. Researchers in China and India found that a stable and good performance of COREX process required that the mean particle size (MPS) of coal was in the range of 19–22 mm; therefore, the coal size was controlled in this range during production [5, 6, 11, 35]. To simulate a practical situation in industry, the size of lump coal in this study was set as 20 mm, and the experimental temperature was 1100 °C.

(1) Mass loss of lump coal under different atmospheres

The final mass loss values of the four lump coals under different pyrolysis atmospheres are shown in Figure 8. The change rule of the final mass loss for all lump coals under different gas conditions is the same. The final mass loss of coal in N_2 atmosphere is smallest, while that in CO_2 atmosphere is the largest.

CO_2 contributes to the cracking of the hydroxyl, methyl, and methylene groups and the benzene ring of coal during pyrolysis. In addition, CO_2 reacts with coal char to form CO at high temperatures, which increases the final mass loss. H_2 contributes to the increase in the final mass loss mainly due to the hydrogenation reaction. The main reason for the increase in the final mass loss of

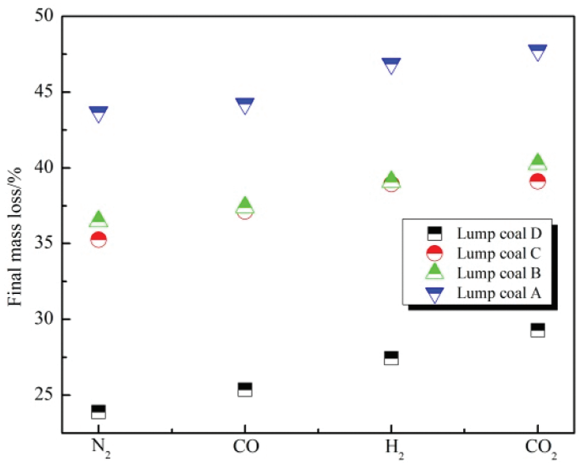

Figure 8: Final mass loss of lump coals under different atmospheres.

lumpy coal under CO compared with that under N_2 is because CO easily induces the cracking of aromatic rings in semi-coke structures. Additional small molecular fragments and free radicals generated by the cracking of side chain, ether bond and fatty chain under CO atmosphere results in a higher gas yield. Therefore, when the contents of $CO/CO_2/H_2$ increase in the gas of the gasifier, the gas yield of lump coal will increase.

(2) Conversion rate of lump coal under different atmospheres

The pyrolysis conversion and conversion rate curves of lump coal under H_2, CO_2, CO and N_2 atmospheres are shown in Figure 9. The conversion curve gradually moves to the low temperature region, when the atmosphere is changed in the sequence of N_2, CO, CO_2 and H_2. The same rule is obtained from the change in the conversion rate curve under different atmospheres. The narrowest and steepest curve exhibits in the H_2 atmosphere, and the pyrolysis peak time exhibits the smallest value, followed by that in the CO atmosphere. The conversion rate curve of coal is relatively broad under the N_2 atmosphere, and the pyrolysis time at the peak position is the maximum one.

To quantitatively analyse the relationship between the reaction rate and the gas atmosphere, the pyrolysis parameter $S_{0.5}$ of two lump coals was calculated, as shown in Figure 10. The change rule of the pyrolysis parameter $S_{0.5}$ under different atmospheres agrees with the results obtained from the pyrolysis conversion curve, namely, the value of $S_{0.5}$ decreases when the atmosphere is changed in the sequence of H_2, CO, CO_2 and N_2. This finding reveals that the promotion ability of the atmosphere for the pyrolysis of lump coal from low to high is CO_2, CO and H_2.

Based on the above studies, it can be concluded that the main compositions (CO, H_2) in the gasifier gas have a marked influence on the pyrolysis reaction of the lump coal. These atmospheres not only increase the gas yield of lump coal but also promote the gas generation rate. Therefore, improving the reduction potential of the atmosphere leads to an increase in the gas yield and gas generation rate.

Effect of particle size on lump coal pyrolysis

The lump coals were charged into the high-temperature gasifier (average size was approximately 20 mm), then the pyrolysis of the lump coals quickly occurred due to the high temperature of the furnace. To investigate the effects of particle size on the lump coal pyrolysis behaviours, three different sizes (10 × 10 × 10 mm, 15 × 15 × 15 mm, 20 × 20 × 20 mm) were selected for the pyrolysis experiments at 1100 °C.

Figure 11 shows the conversion and conversion rate curves for coal C and coal D with different particle sizes during the pyrolysis process. The comparative analysis of the conversion curves shows that the curve moves sharply to the low-temperature region, and the curve slope quickly increases with decreasing coal size. It is apparent that the smaller coal size can increase the peak value of the conversion rate curve and narrow the curve shape. These results suggest that the pyrolysis rate is acutely promoted by a decrease in the coal size. In addition, the pyrolysis parameter $S_{0.5}$ of the two types of lump coal was calculated, as shown in Figure 12. The results indicate that the value of $S_{0.5}$ decreases as the coal size increases. The $S_{0.5}$ value of 10 mm sized coal C increases 1.8 times compared with that of 20 mm sized coal, while the $S_{0.5}$ value increases 1.5 times when coal D is used. This increase suggests that the coal size has much more influence on the pyrolysis behaviour of low rank coal than high rank coal.

The above experimental results reveal that the coal size significantly influences coal pyrolysis. There are two reasons for this phenomenon: first, larger coal particles need more time to complete the heat transfer process, resulting in a longer pyrolysis time and a slower pyrolysis rate; and second, as the coal size increases, the volatile matters have a greater chance to react with the char during its overflow process (especially tar, which is more easily trapped by the larger particles) [36], then the gas production rate will decrease. Therefore, the size reduction of coal under stable furnace operation conditions can be used as the method to improve the gas generation rate.

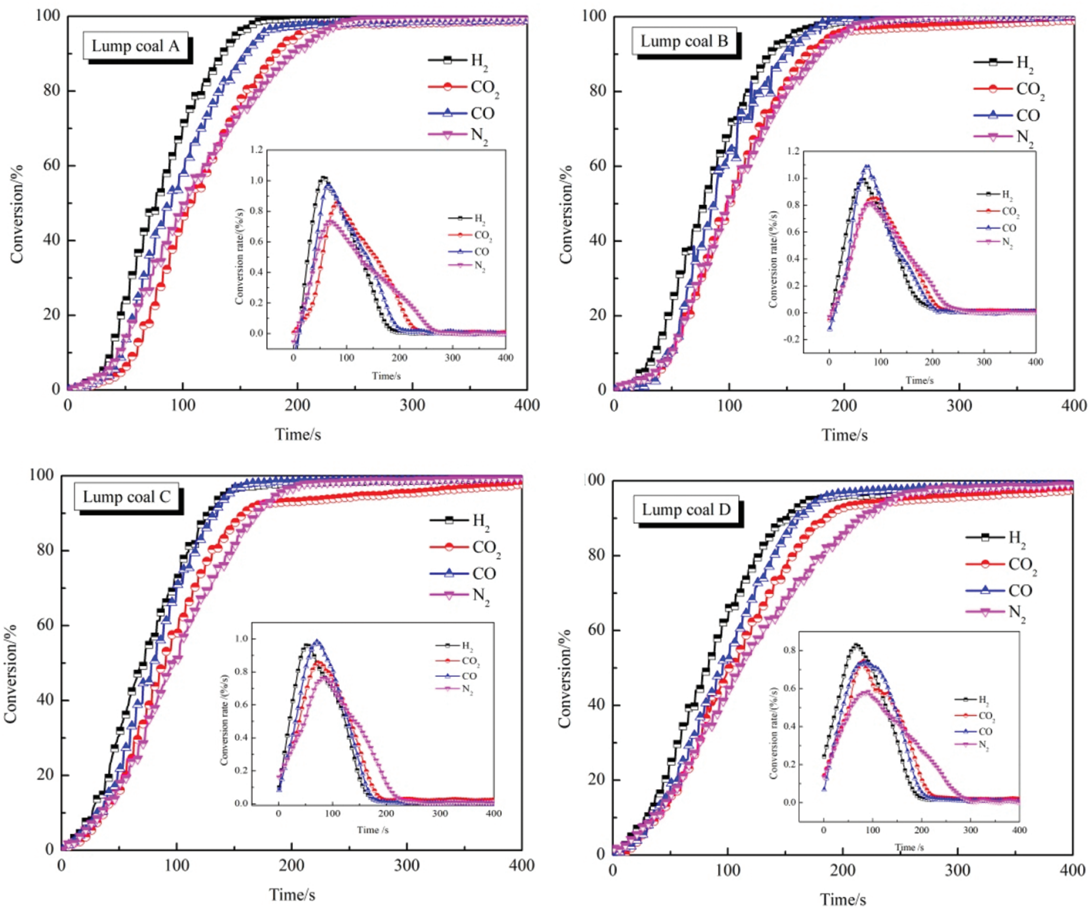

Figure 9: Pyrolysis conversion and conversion rate curve of lump coal under different atmospheres.

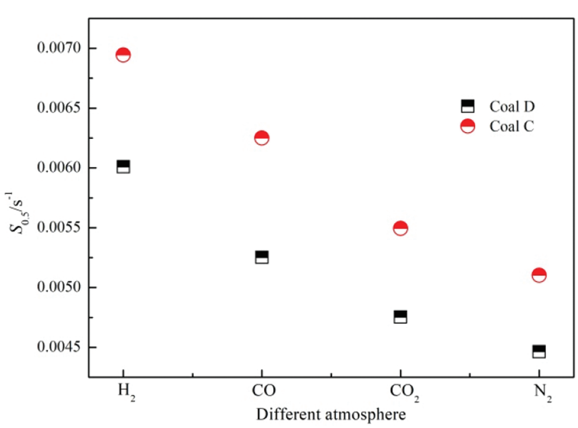

Figure 10: Relationship between pyrolysis atmosphere and pyrolysis parameter.

Analysis of the factors influencing gas generation of lump coal

The gas generation behaviour of the gasifier not only affects the reduction process of iron ore burden in upper shaft furnace but also affects the gas balance of the total system. From the above research, it can be noted that the self-properties of lump coal and the melting parameters of the gasifier both have great effects on the gas generation, as show in Table 4.

The maximum mass loss of coal pyrolysis can represent the gas yield per ton coal, while the conversion rate of coal pyrolysis can represent the gas generation rate ability for lump coal. From Table 4, the gas yield per ton coal is mainly affected by the coal rank, namely, a low rank coal that contains more volatile matters has a greater gas yield. In addition, a high reduction potential atmosphere can promote the gas yield. However, the coal size and temperature have a minimal effect on the gas yield per ton coal. However, the gas generation rate per ton coal is determined by the coal size and temperature. A reduction in the coal size and an increase in the temperature can significantly raise the gas yield rate. An increase in the reduction potential of the gasifier atmosphere also contributes to the improvement of the gas yield rate. However, the coal rank hardly affects the coal gas yield rate, when the dome

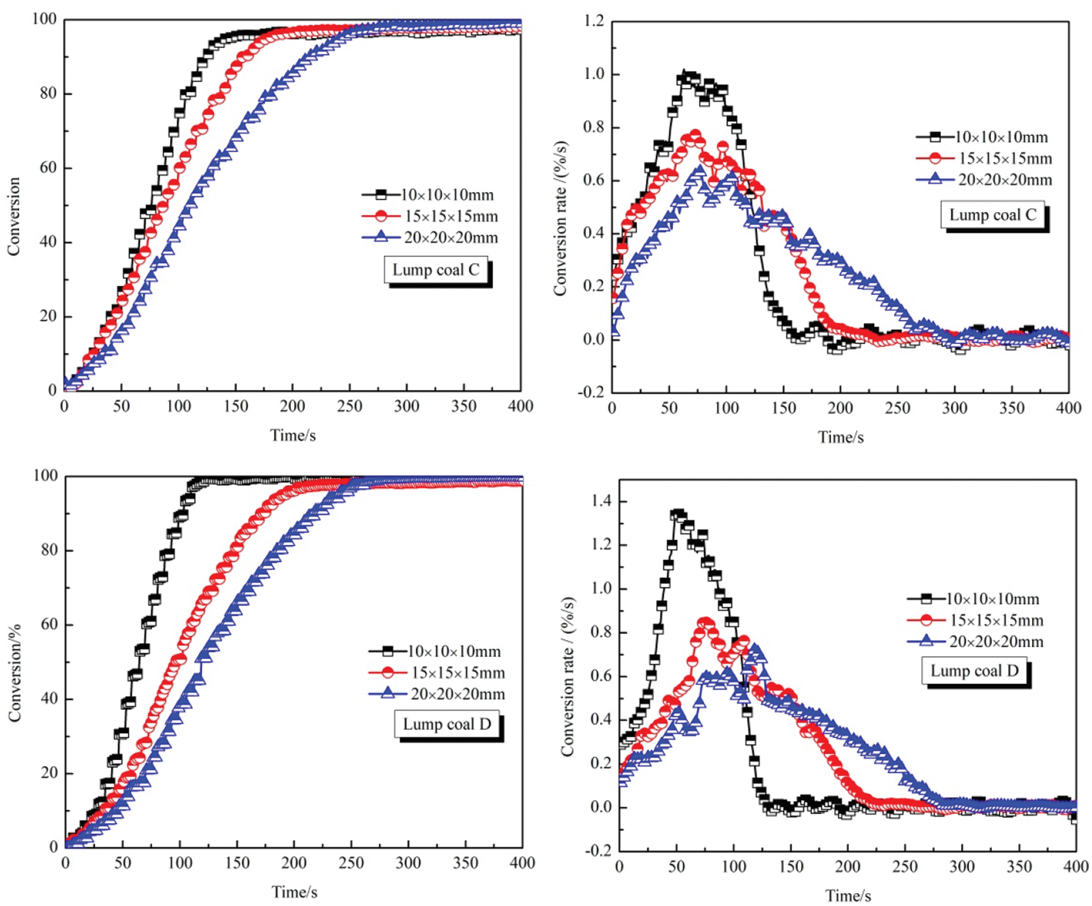

Figure 11: Conversion and conversion rate curve of coals with different particle sizes.

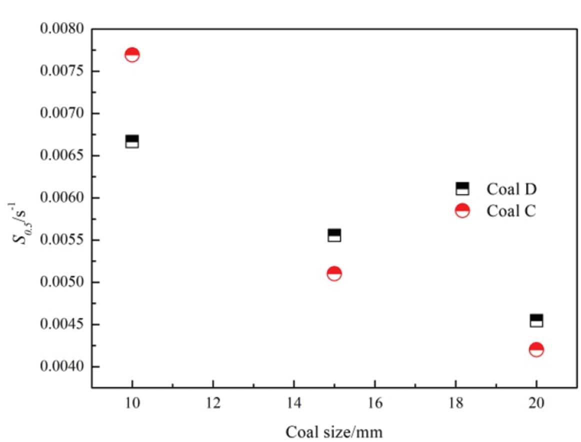

Figure 12: Relationship between $S_{0.5}$ and the coal size.

temperature is above 1000 °C. Although the increasing temperature of the gasifier can significantly improve the coal pyrolysis rate, it will lead to a temperature increase in the output gas. The high temperature of output gas not only may result in the coal ash sticks on the gas pipelines, but also may affect the control of the gas balance system. Moreover, because the temperature of output gas will be cooled to 850 °C to satisfy the upper shaft furnace needs, so the higher the temperature of the output gas is, the greater the energy waste is, which does not meet the requirement of energy saving and consumption reducing.

Therefore, for the regulation of gas generation in COREX gasifier, the method of coal rank and coal size optimization should be considered first. Additionally, an improvement of the reduction atmosphere of the gasifier is also encouraged to enhance the gas generation rate. The improvement of the reduction potential of the gas atmosphere not only contributes to an increase in the gas generation rate but also benefits to the burden reduction in the upper shaft of the furnace. Some measures such as coke oven gas injection and coal injection can be used in COREX to improve the reduction potential of the atmosphere.

Table 4: Influence factors on the gas generation behaviour of lump coal.

NO	Influence factors	Gas yield per ton coal	Gas generation rate per ton coal
1	Coal rank	★★★	Scarcely influence
2	Particle size	Scarcely influence	★★★
3	Temperature	Scarcely influence	★★★
4	Gasifier atmosphere	★	★

Note: ★★★ represents the strong influence factor; ★ represents the general influence factor.

Conclusions

1. The results of the coal properties show that the metamorphic degree of these coals increases gradually in the following order: coal A, coal B, coal C and coal D. Coal B has the highest H/C ratio, while coal C has the highest O/C ratio. The chemical compositions of the ash in lump coal A and lump coal B are mainly acidic oxides, whereas the compositions in lump coal C and lump coal D are mainly alkaline oxides. The content of active macerals in coal decreases in the order of lump coal A, lump coal B, lump coal C and lump coal D.
2. The temperature fluctuation (from 900 °C to 1200 °C) of the gasifier has little effect on the final mass loss of lump coal, but the pyrolysis rate of lump coal increases strongly with increasing dome temperature. Coal rank hardly affects the gas generation rate of lump coal when the dome temperature is above 1000 °C, but the gas yield of lump coal increases with decreasing coal rank.
3. The reduction atmospheres in the gasifier not only raise the gas yield of lump coal but also promote the pyrolysis reaction rate. The promotion ability of the atmosphere for the pyrolysis of lump coal from low to high is CO_2, CO and H_2. With decreasing particle size, the pyrolysis rate of lump coal increases, and the completion time of the reaction decreases, but the gas yield hardly changes.
4. Although an increase in the gasifier temperature significantly improves the coal gas rate, it is not beneficial for energy savings and the reduction of fuel consumption. Therefore, the methods of coal rank and coal size optimization should be considered first, and an improvement of the reduction potential of the gas atmosphere in the gasifier is also encouraged to enhance the gas generation rate.

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