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ACHIEVEMENTS OF COKEMAKING INDUSTRY AND THEIR SUPPORTS TO IRON AND STEEL INDUSTRY IN CHINA[1]

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Abstract
This paper reviews the achievements of Chinese cokemaking industry and their supporting to iron and steel industry during the Chinese 11th five-year plan. The large-scale coke-oven, coke dry quenching process and stamp charging process have benefited coke quality and their capacities exceed 100mt/a in China respectively. The behavior of coke in Blast Furnace and the coke quality required for Blast Furnace operation is discussed and summarized. The influence of stamp charging process on coke properties has been investigated. The investigation concludes that the stamp charging process can significantly improve the coke quality. So the stamp charging process will contribute a lot to rational utilization of coking coal resources and sustainable development of cokemaking industry and iron and steel industry.
Key words: Cokemaking industry in China; Large-scale coke-oven; Coke dry quenching; Stamp charging.

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1 PREFACE

Sustained increase of steel-making industry promoted the development of coke-making in China. In the year 2010, the crude steel and iron production were reached to 683.27 million ton and 629.69 million ton respectively and it is 8.9% and 8.4% higher than 2009. The coke production was 387.57 million ton and it is 9.13% higher than 2009. 94.69% of the production is metallurgical coke and it is 367.00 million ton. [5] Therefore, enough amount and stable quality metallurgical coke is provided to iron-making industry.

2 THE RECENT SITUATION AND TECHNICAL PROGRESS OF COKEMAKING INDUSTRY IN CHINA

2.1. The recent situation of cokemaking industry in China

The cokemaking industry was developed very fast during "Eleventh five-year plan", and the yearly coke production was increased from 297.68 million ton in 2006 to 387.57 million ton in 2010, the annual average increase is 6.82% (Fig.1). [1-5] At the same period, the percentage of coking and fat coal in coal blends for cokemaking was increased from 51.0% in 2006 to 58.7% in 2009 and dropped back to 54.9% in 2010. The annual average increase during 4 years is 5.0 percent (Fig.2). [1-5] During corresponding period the coke quality was stable and improved (Fig.3-Fig.4). [1-5] To maintain the effective operation of ironmaking, the demand for coking and fat coal in coal blends was increased and the proportion of other coals were decreased at the same time in cokemaking industry.

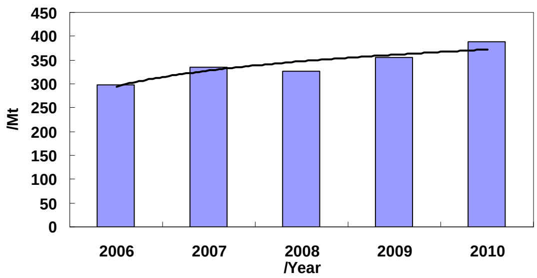

Figure 1. Coke production during "Eleventh five-year plan" [1-5]

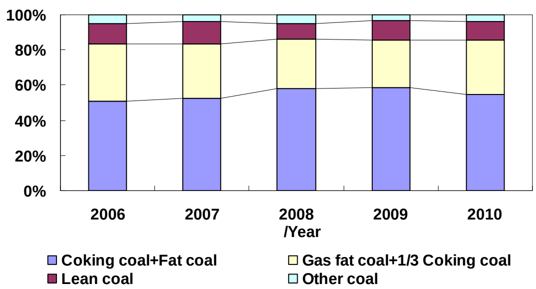

Figure 2. Coal composition in coal blends during "Eleventh five-year plan" [1-5]

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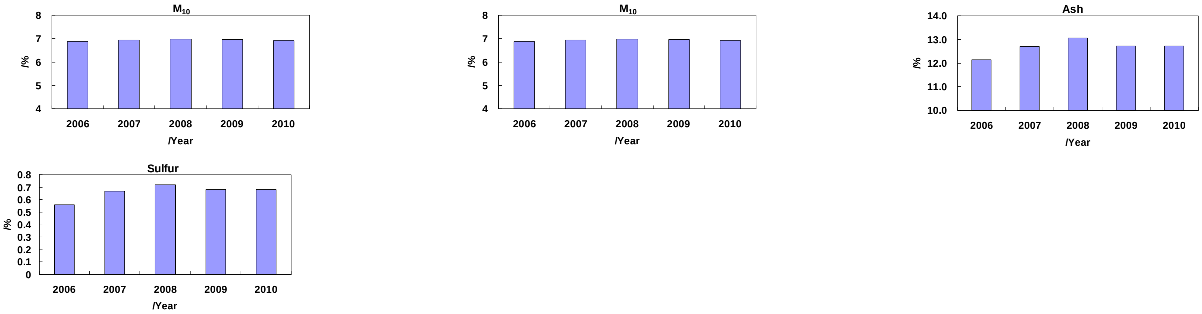

Figure 3. The trend and variation of coke quality of cokemaking industry in China during "Eleventh five-year plan" [1-5]

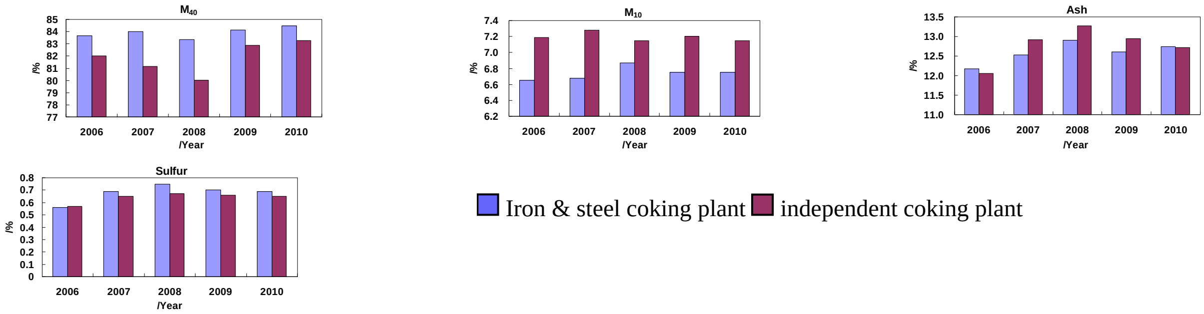

Figure 4. The trend and variation of coke quality of coking plants of iron & steel complex with independent coking plants in China during "Eleventh five-year plan" [1-5]

Obviously, the composition of coal blends varies with different coking plants. For example, the percentage of coking and fat coal in coal blend for coking plants of iron & steel complex is much higher than that of independent coking plants (Fig.5). For coking plants of iron & steel complex the percentage of coking and fat coal in coal blend was increased from 56.8% in 2006 to 61.3% in 2009 and dropped back to 57.7% in 2010. The annual average increase during 4 years is 2.6 percent. But for independent coking plants the percentage of coking and fat coal in coal blend was increased from 40.9% in 2006 to 51.2% in 2009 and dropped back to 44.7% in 2010. The annual average increase during 4 years is 7.0 percent. The difference of percentage of coking and fat coal in coal blend for different kind of coking plants is changed from 15.9% to about 10%. [1-5] It is clear from above that for coking plants of iron & steel complex, the first factor for coke is its quality and it must satisfy the ironmaking demand but the cost of coal blend comes second. While the independent coking plants pay more attention to cost of coal blends, to satisfy the daily increase requirement of coke quality the percentage of coking and fat coal in coal blends is also increased gradually and the speed of increase even faster than that of coking plants of iron & steel complex.

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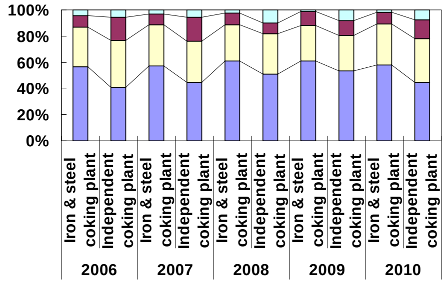

Figure 5. Comparison of coal blends for coking plants of iron & steel complex with independent coking plants in China during "Eleventh five-year plan" [1-5]

The coke quality of coking plants of iron & steel complex is much better in comparison with independent coking plants. The M40 and M10 are 2.06 and 0.45 percent better respectively. The ash content is 0.19 % lower but the sulfur content is 0.04% higher (Fig.4). These coincide with the high percentage of coking and fat coal in coal blend for coking plants of iron & steel complex.

2.2. Technical progress of cokemaking industry in China

During "Eleventh five-year plan" period, technical means have been made for optimization and effective utilization of natural resources of coking coals and for stabilization and improvement of coke quality, such as:

(1) The enlargement of coke oven: during "Eleventh five-year plan" period, the coke production in China was increased rapidly and equipment level was also improved at the same time. Up to the end of 2010, coke capacity of large coke ovens (stamp charging coke ovens with chamber height ⩾5.5m and top charging coke ovens with chamber height ⩾6m) reached more than 140 million t/a. [5] The enlargement of coke oven contributed to effective utilization of good coking coal resources and improvement of coke quality.

(2) Development of stamping charged technology: Up to the end of 2010, coke production capacity of stamp charging coke ovens reached more than 100 million t/a. [5] Adopting stamping charged technology is beneficial for effective utilization of coking and fat coals which are shortage in coal resources. According to committee of coke and coal resources under China Coking Industry Association, the composition of coking and fat coals in coal blends may be decreased by 14 percentages by using stamp charging technology. [6]

(3) Development of coke dry quenching technology: This technology was spread and widely used in coking plants under steel mills. Coke capacity by dry quenching reached about 100 million t/a by the end of 2010. [5] By adopting dry quenching technology the coke quality is improved remarkably and it contributed to improvement of coke quality of coking plants under steel mills and it save good coking and fat coals indirectly.

(4) Optimization coal blending technique: promotion and popularization of optimization blending technique based on petrography brought Chinese Coking industry to a new stage. Classification of received coal by application purpose, rational pile up, optimizing administration of coal yard, development and application of expert system for coal blending and prediction of coke quality parameters, development and application of different kind of test coke oven and so on, all above mentioned promote coal blending technique to the direction of fineness and

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optimization. During "Eleventh five-year plan" period, gradual and stable improvement of coke quality is caused not only by increase amount of coking and fat coals in coal blends but also by spreading and application of optimization coal blending technique.

(5) Research work of coke quality: New requirement for coke quality has been put forward based on progress of ironmaking technology. The progress of coke quality research showed the direction for optimization of coal blending, rational utilization of coking coal resources and realization of optimization of coking coal resources in coke production. For example, independent coking plants especially for independent coking plants with stamp charging coke ovens, paid more attention to not only the mechanical strength of coke at room temperature but also the parameters of coke at high temperature. The composition of coal blend is from using as less as possible amount of coking and fat coals for decreasing cost to suitable amount of coking and fat coals in coal blend for production metallurgical coke with satisfied quality.

Therefore, as can be seen from above, during "Eleventh five-year plan" followed by increasing amount of coking and fat coals in coal blend, application of large scale coke ovens, application of CDQ, adopting stamp charging technique and other techniques, coke quality of Chinese coking industry was improved and stabilized and it promoted and supported rapid development of metallurgical industry.

3 THE STUDY OF IRONMAKING REQUIREMENTS FOR COKE QUALITY

3.1. The behavior of coke in blast furnace

The main functions of coke in blast furnace are as follow: as fuel; as reductant; as structure support and as source of carbon. Less than 1% of coke leaves with blast furnace gas and all the rests are consumed in blast furnace. The approximate consumption ratio is as follow: burning at race way 55%～65%, reaction of carbon solution at the part between race way and top of furnace 25%～35%，permeation of carbon to iron 7%～10%，other elements reduction and loss2%～3%. The coke rate was decreased following by high PCI or other fuel injection, the rate of coke burned at race way will be decreased. The proportion consumed in carbon solution reaction will be increased. [7]

Based on investigation of a lot of literatures, Dr. Sushi Kumar Gupta et al. came to conclusions that main degradation factors of coke in BF such as, mechanical breakage and wear and tear; reaction of carbon solution; attack of alkali metals; high temperature action and damage caused by high speed blast at race way. The main consumption of coke fine in blast furnace is carbon solution loss reaction, carburizing reaction and the reaction of coke with slag. When coke fine production is balanced with coke fine consumption in blast furnace and there is no coke fine piled up then the process of iron-making will be successful. [8]

Therefore, coke should have good mechanical strength to resist the mechanical breakage and abrasion within lump zone, and should have proper strength at high temperature to guarantee the strength and size upon the part of race way after consumption of 25%～35% of carbon by carbon solution loss reaction. Finally coke should keep enough strength and size when it reached the dead line and race way where the temperature will be even higher.

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3.2. The study of coke quality requirements for Blast furnace

It is generally agreed by Chinese and foreign researchers that metallurgical coke should have high mechanical strength and strength after reaction to make effective blast furnace operation. M.A. Diez et al. summarized the quality parameters of coke which is used in European metallurgical process as following: M40＞78～＞88, M10 ＜5～＜8; CSR＞60, CRI 20～30.[9] In China, according to “Code for design of blast furnace ironmaking technology”, the requirement of metallurgical coke is shown as below (See table 1.) The actual coke quality parameters which are approved by iron-makers are shown in table 2.[10] It can be seen the coke quality are similar to quality requirements of coke adopted in Europe.

Table 1. The requirement of metallurgical coke for blast furnace

Volume of BF, m^3	1000	2000	3000	4000	5000
M40	≥78%	≥82%	≥84%	≥85%	≥86%
M10	≤8.0%	≤7.5%	≤7.0%	≤6.5%	≤6.0%
CSR	≥58%	≥60%	≥62%	≥64%	≥65%
CRI	≤28%	≤26%	≤25%	≤25%	≤25%
Ash content of coke	≤13%	≤13%	≤12.5%	≤12%	≤12%
Sulfur content of coke	≤0.7%	≤0.7%	≤0.7%	≤0.6%	≤0.6%
Coke size, mm	75~25	75~25	75~25	75~25	75~30
More than high limit size	≤10%	≤10%	≤10%	≤10%	≤10%
Less than low limit size	≤8%	≤8%	≤8%	≤8%	≤8%

Table 2. The real coke quality parameters used in ironmaking /%

Item	Ash	Sulfur	M40	M10	CRI	CSR
For large scale BF	11.5±0.5	0.6±0.1	82~90	5~6	<25	>65
For usual BF	12.5±0.5	0.7±0.1	78~82	6~7	<28	>62

Chinese iron-makers believe that on its way from top to bottom of BF the size of coke is decreased about 20%～40%. The coke size at the upper and middle part of BF is changed not much than that in softening and melting region due to carbon solution reaction. The coke quality will be an important factor which indicates the deterioration of coke. And the ash content, coke size and mechanical strength are most distinguished parameters.

Although above coke quality parameters are recognized widely by iron-makers but there are no such agreement on CSR and CRI among a lot of iron-makers. The CSR and CRI tested in laboratory under NSC standard condition and experimental BF condition have been carried out by Maria Lundgren et al. The test results show there is no any correlation between them. The CSR tested in EBF is much better than that tested in laboratory. As in test BF the reaction is mainly happened on surface of coke but in the NSC standard condition the reaction is happened much deeply. It

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means that in different conditions the controlling factor of reaction is different. In NSC standard condition the controlling factor of reaction is chemical dynamics but in EBF the controlling factor of reaction is diffusion. [11]

Author think in BF, coke is suffered from increasing temperature, reaction of carbon solution loss by upward gas and aggressive action by alkali metals and slag. The reaction condition is quite different in comparison with that NSC standard condition. In BF the carbon solution loss not only depends on coke quality but also depends on iron-making conditions such as thermo-balance, ratio between direct and indirect reduction. The carbon solution loss is about 25%～35%. When the carbon solution loss (weight loss) is fixed to 25%, CSR test will strongly influence on correct evaluation of coke quality (Table 3). As can be seen from the table, there is obvious difference of CSR values among these 5 coke samples but their difference of $CSR_{25\%\text{-off}}$ become smaller and all these coke can be used properly in BF with volume of 2500～4400 m^3.

Table 3. Test results of CSR and CRI under different test condition /%

Coke sample	A	B	C	D	E
CRI	26.4	21.5	29.7	38.6	19.2
CSR	60.1	66.0	61.9	38.9	74.1
CSR25%-off	65.7	65.1	69.8	50.1	63.3
CSR25%-off - CSR	4.6	-0.9	7.9	11.2	-10.8

Mechanical strength of coke is one of the important parameters of coke quality and it is the base of CSR of coke. Generally, there is a contrary relationship between CSR and CRI. If the CSR of coke is high its CRI will be low. For production of this kind of “high quality coke” in condition of definite coking technology it can be realized by increasing proportion of good coking coal in coal blends. It will be costly and resource consuming if pursuing too high mechanical strength and CSR of coke.

The requirements for coke quality vary with the volume of BF. For large scale BF with high PCI rate, as the coke stays longer in BF and undergoes serious deterioration so the mechanical strength and CSR of coke should be better. The requirements for medium and small scale BF the coke quality can be less restricted. In China Steel industry, there are different kinds of BF. For effective utilization of coal resources, maintain high efficiency and low cost iron making it is necessary to use different quality of coke i.e. different M40, M10 and CSR/CRI of coke for different volume of BF with different PCI ratio. [10]

4 THE COORDINATED DEVELOPMENT OF IRONMAKING AND COKING INDUSTRY IN THE FUTURE

4.1. The existing production capacity of coking industry will be the strong basic for the further development of ironmaking

After long period of rapid development, the production capacity of coking industry in China reached more than 500 million t/a, it can support 1000 million t/a of iron production. In 2010 the metallurgical coke production was 367Mt and it was 73% of total production capacity. It means the coke capacity in China is surplus seriously.

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Among the total production about 33.6% was produced by coking plants of iron & steel complex and other 66.4% was performed by independent coking plants. Therefore the production capacity of coke and coke production cannot be increased very fast and it should keep stable or develop with slow step. For sustainable development purpose, cooperation of coke maker and iron maker should focus on the relationship between coke quality and ironmaking process. Make full use of existing production capacity to produce suitable quality and reasonable price coke. This will be a win-win strategy for both cokemaking and ironmaking industry.

4.2. Stamp charging coking technology and equipments should contribute to the sustainable development of ironmaking in the future

As a wide spread technology, stamp charging not only reduce the proportion of coking coal in blends but also improve the coke quality. However, it may not acceptable for ironmaking plants as there are some differences in aspect of coke quality between cokes produced by top charged coke oven and by stamp charging coke oven.

Recently by attention and promotion of coking and ironmaking industry, the proportion of coking and fat coals in blends are visibly increased for independent coking plants with stamp charging coke ovens, therefore the coke quality both mechanical strength and property at high temperature is improved. The percentage of coke produced by stamping charged coke oven which applied in ironmaking is increased gradually. Besides, some coking plants under steel mill construct coke ovens by stamping change. [11] It is of great meaning to fully utilize 100 million ton coking capacity by stamp charging coke oven for effective utilization of coking coal resources and supporting sustainable development of ironmaking in the future.

For better guiding and promoting coke production by stamp charging method, the author has carried out research work on coke by stamping charge.

4.2.1 Effect of stamp charging on pore structure of coke

It can be seen from figure 6 that the apparent and total porosity of coke produced by stamp charging oven are much lower than that of coke produced by top charged coke oven, and there is almost no difference of closed porosity between them. It can be seen from table 4 that the mean pore diameter of coke produced by stamping charged coke oven is smaller than that of coke produced by top charged coke oven, the mean thickness of pore wall however is opposite.

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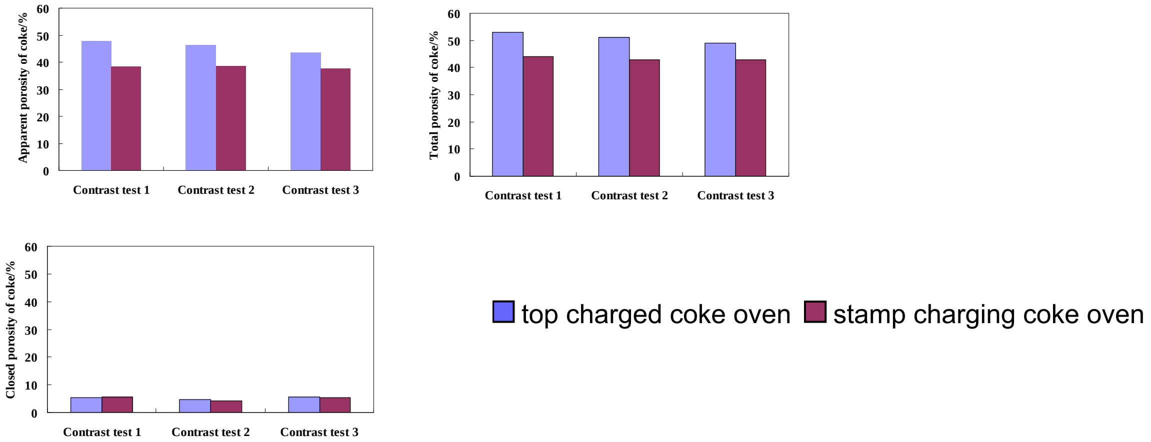

Figure 6. Comparison of apparent; total and closed porosity of coke produced by stamp charging coke oven and top charged coke oven

Table 4. Inspection data of pore structure of coke by microscopy

item		porosity/%	Mean diameter of pore/μm	Mean thickness of pore wall /μm
Comparative test No3	top charged	69	88.33	35.03
	stamp charged	65	85.50	44.17

4.2.2 Effect of stamp charging on mechanical strength of coke

It is clear, as showed in table 5, that there is no obvious difference of micro-strength between both cokes produced by different coking regime. If the caking ability of coal blends is comparatively weak (test No3), then the micro-strength of coke by stamping charge coking will be a little bit better than that by top charge coking, but the absolute value of them is comparatively low.

As the size of sample for micro-strength determination is quite fine (0. 6～1. 25mm) and it can be seen that the micro-strength of coke shows the strength of basic mass of coke i.e. the strength of coke pore wall.

Besides, there is also obvious difference of structure strength between two kinds of coke ovens. The structure strength of coke by stamping charge coking is much better than that by top charge coking. By stamp charging, the difference of structure strength of coke among three different tests became closer (as showed in table 5). The main reason is the coke porosity is decreased and the mean thickness of pore wall is increased due to the close contact and intensification of contact between coal particles by stamp charging. The structure strength of coke is deeply influenced by pore structure and strength of pore wall.

It can be seen from table 5 that influence of stamp changing on M40 (resistance to fragmentation) is different. For example, for coal blend with high proportion of highly caking coals (test No2) the M40 of coke obtained by “stamp charging” is worse than that of coke obtained by “top charge”, but in other cases (test No1 and test No 3) the M40 of coke obtained by “stamp charging” is better than that of coke obtained by “ top charge”. In terms of M10, all cokes obtained by “stamping charge” are improved notably.

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The parameters of mechanical strength of coke represent the complex character of coke such as macro-fissure and strength of basic mass of coke (micro-fissure, pore structure and strength of pore wall). By stamping the blends, the contact between coal particles is tight. During carbonization the gaps between coal particles can be filled fully with plastic mass, the resistance for gas release becomes much higher. Therefore the coke structure will be compact and it is beneficial for improvement of coke mechanical strength (M40 and M10) particularly for M10.

Table 5. Analysis of mechanical strength of coke at room temperature (%)

item	Scheme of coal blending	Mechanical strength of coke at room temperature (%)		structure strength (SSI) (%)	Micro-strength (MSI) (%)
		M_{40}	M_{10}		
Comparative test No1	top charged	73.7	10.3	80.3	54.6
	Stamp charged	76.3	7.2	87.2	55.9
Comparative test No2	top charged	74.3	10.4	84.2	58.3
	stamp charged	71.6	6.9	87.7	58.9
Comparative test No3	top charged	84.0	9.6	77.4	48.7
	stamp charged	88.0	6.8	83.4	52.6

4.2.3. Effect of stamp charging on property of coke at high temperature

(1) Effect of stamp charging on reactivity of granule coke with CO_2

The curves of reactivity of both “stamp charging” or “top charged” coke (sized 3~6mm) show similar trend (Figure 7). It means the reactivity of granule coke with CO_2 mainly depends on property of raw coals, the influence of stamp charging on properties of coke micro-pore and pore wall is not that distinct.

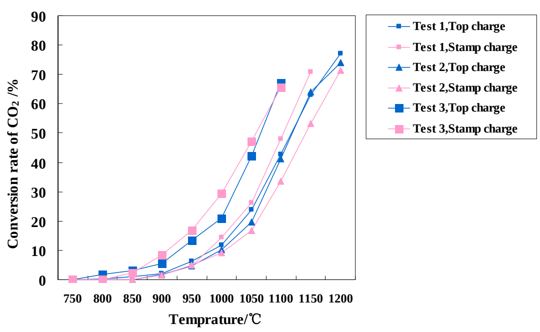

Figure 7. Curves of test coke reactivity with CO_2 for 3 groups of test coke

(2) Effect of stamp charging on reactivity of lump coke with CO_2

It can be seen from fig. 8 the reactivity (CRI) of coke obtained by stamping charged coking is lower than that of coke obtained by top charged coking, but the strength after reaction (CSR) is opposite, CSR of “stamping charged” coke is much

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better than that of “top charged” coke, particularly for coal blend with low caking ability.

Due to its compact structure, low total and open porosity, small diameter of pore and evenly distributed of pores, the area of reaction with CO_2 at high temperature is decreased therefore the CRI is low. In addition, stamp charging is benefit for improvement of pore structure of coke and increase the thickness of coke pore wall. As a result the CSR is getting much better, particularly for blends with low caking coals.

By testing mechanical strength at room temperature and property at high temperature of different sized coke, it is proved that the coke quality is improved by improvement of porous structure of coke under stamp charging technology but its chemical property is not changed that much. Improvement of parameters of M10 and CSR is beneficial for ironmaking. The reason of improvement of coke quality is decreasing of coke porosity, increasing thickness of pore wall and particular obviously decreasing amount of irregular and large pore. Therefore, it is important to intensify research work on relationship between coke quality and ironmaking and to promote high quality coke supply by using stamp charging technology and equipments for ironmaking.

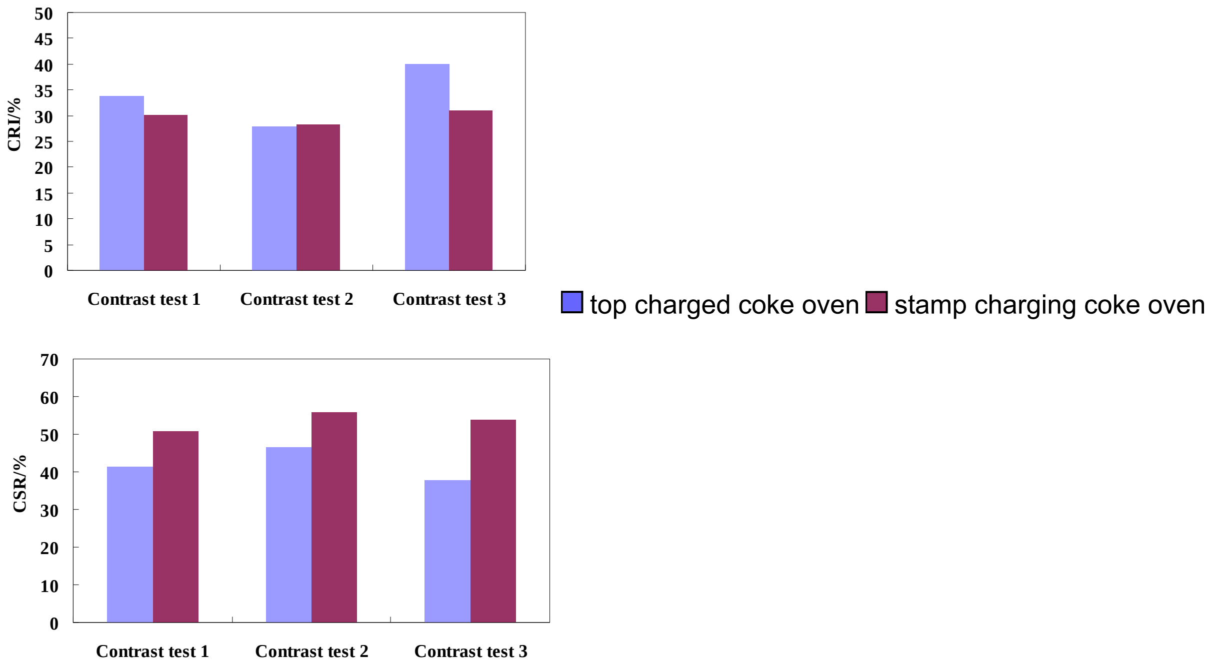

Figure 8. Comparison of CRI and CSR of coke produced by stamp charging coke oven and top charged coke oven

5 SUMMURY

(1) During “Eleventh five-year plan” period, the coking industry in China has made much progress, from increasing of coke production capacity and coke production to application of large scale coke oven and new techniques. It promoted rapid development of metallurgical industry and will continue to be a reliable support in China.

(2) Stamp charging coking method being an important technical technology, not only for improvement of coke quality but also for effective utilization of coal

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resources, the coordination of coking coal resources and cokemaking & ironmaking industry and for sustainable development.

(3) The relationship between ironmaking and cokemaking is relying on each other, therefore it is suggested that coke-maker and iron-maker altogether should carry out research work on the relationship between coke quality and ironmaking intensively. For realization of healthy and cooperative development of coking industry and coking coal resources, it is necessary to propose reasonable parameters based on real requirement of ironmaking and make further promotion to the sustainable development of metallurgical industry.

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