Chapter 11
Low CO_2 Emission by Improving CO Utilization Ratio in China's Blast Furnaces

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Abstract In recent years, the CO_2 emission in China is the highest all around the world, accounting for about 30 %. China's 15 % CO_2 emission is produced from iron and steel companies, where blast furnace contributes more than 60 %. Therefore, blast furnace is the key to reduce CO_2 emission for iron and steel companies. Blast furnace is a countercurrent reactor between descending burdens and ascending gas. The higher the CO utilization ratio is, the lower the CO_2 emission. There are two main measures to improve CO utilization ratio—upper adjustment and lower adjustment. The upper adjustment is mainly about the burden distribution which includes adjusting batch weight, charging mode, stock line and so on. The lower adjustment is mainly about the gas distribution in the lower part of the blast furnace, which includes adjusting the gas volume, gas temperature, gas humidity and so on. The paper presents the upper and lower adjustments to improve CO utilization ratio in China's blast furnaces.

11.1 Introduction

In recent years, the CO_2 emission in China stays in the first place all around the world, accounting for about 30 % (Olivier et al. 2014). One of the largest CO_2 emission contributors is the iron and steel companies, whose CO_2 emission occupies

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about 15 % of the total CO_2 emission in China. As the largest subsystem, the ironmaking process has about 90 % CO_2 emission of the iron and steel companies. And the CO_2 emission of the blast furnace exceeds 70 % of the ironmaking process. It can be found that blast furnace encounters very huge stress. Therefore, it is imperative to study blast furnace in order to reduce its CO_2 emission (Zhang et al. 2013; Liu et al. 2015).

Blast furnace is a countercurrent reactor between descending burdens and ascending gas, consisting of complicated transfer processes of heat, energy and momentum. Therefore, the smooth descending of burdens and the reasonable distribution of gas are the key to maintain a steady and smooth operation of blast furnace. The higher the CO utilization ratio is, the lower the CO_2 emission. There are two main measures to improve CO utilization ratio—upper adjustment and lower adjustment (Wang 2013a).

The upper adjustment is mainly about the burden distribution, which determines the second or third distribution of gas ascending from the lower part of blast furnace. The aim of burden distribution is to obtain reasonable radial distribution of ore/coke at throat. When burden is uniformly distributed at the throat, gas will be also uniform. In this way, the heating and reduction of burden by gas will also be adequate, which leads to a higher CO utilization. The upper adjustment mainly contains batch weight, charging mode, stock line and so on (Wang 2013a; Xiang and Wang 2014).

The lower adjustment is mainly about the initial gas distribution in the lower part of the blast furnace. The initial gas distribution is the priority of the second or third one. When the initial gas distribution is reasonable, there will be only little work to be done, or it is much easier to obtain a better gas distribution in the upper part of shaft furnace. The lower adjustment mainly contains the gas volume, gas temperature, gas humidity and so on (Wang 2013b; Xiang and Wang 2014).

Generally speaking, the effects of the lower adjustment are relatively timely and remarkable, while those of the upper adjustment will take a longer time to show. In practice, the upper adjustment and the lower adjustment are usually matched together to acquire a better gas distribution and a higher CO utilization.

11.2 The Upper Adjustment

11.2.1 Batch Weight

Batch weight has a critical value. When the batch weight is larger than the critical value, burden in the centre part of the blast furnace throat will become thicker with the increase of batch weight of ore, and the burden distribution will become evener; when the batch weight is smaller than the critical value, ore cannot reach the centre part of the furnace, and burden thickness in the peripheral part will become thicker with the increase of batch weight.

There is a relationship between the batch weight and the ratio of the burden thicknesses in peripheral and central area, which is illustrated in Fig. 11.1 (Liu 2005).

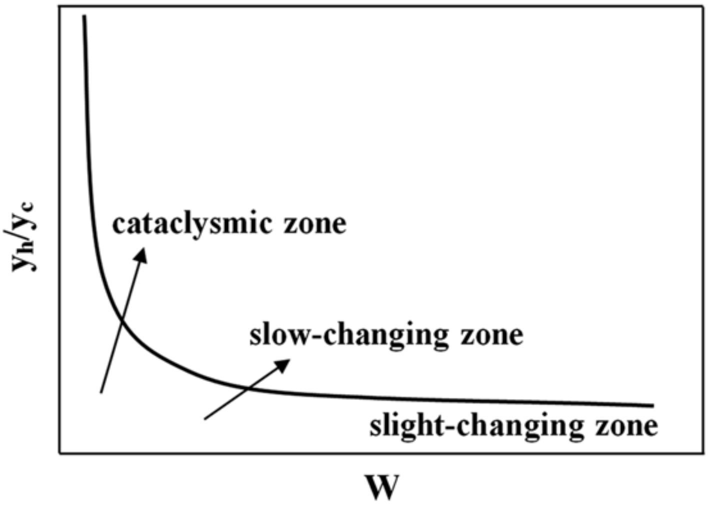

Fig. 11.1 Typical relationship between *W* and y_h/y_c

Where y_h is the burden thickness in peripheral part, y_c is the burden thickness in central part and *W* is the batch weight. The y_h/y_c line is usually divided into three zones, which are cataclysmic zone, slow-changing zone and slight-changing zone from left to right, respectively. When the batch weight belongs to the cataclysmic zone, the burden thickness in the central part will be thicker with the increase of batch weight; when it belongs to the slight-changing zone, the burden distribution can be hardly affected by the increase of batch weight; and when it belongs to the slow-changing zone, the effect of batch weight on the burden distribution will also be between the cataclysmic zone and slight-changing zone. In the slight-changing zone, the burden and gas distributions are stable, which are beneficial to obtain smooth operation and high CO utilization ratio. Therefore, the batch weight should be kept in the slight-changing zone. If there are too many powders in burdens, the batch weight should be kept in the slow-changing zone in order to prevent the burden blockages in central and peripheral areas (Liu 2005).

Channelling will be frequently occurred when the batch weight is too small. The gas will be blocked by overweighted burden when the batch weight is too large. The batch weight determines the thickness of the layered burdens. This means that when the batch weight increases, on one hand, the burden layers will be thicker, and the area of "coke window" will be also increased and the permeability will be also improved as a result. On the other hand, the number of burden layers will be reduced, then the "interface effect" between coke and ore will be also weakened, which also improves the burden permeability (Wang 2013b).

In the No. 3 Blast Furnace of Jiuquan Steel, the ore batch weight increased from 17.6 to 22.2 t, and the coke load increased from 4.0 to 4.2 (which means the coke batch weight increased from 4.40 to 4.78 t). The CO utilization ratio was increased, and the coke rate decreased from 438 to 428 kg/t (Bao 2008).

In No. 2 Blast Furnace of Shougang Jingtang United Iron & Steel Co. Ltd, the ore batch weight increased from 148 to 165 t, and the coke load increased from 5.00 to 5.44 at the same time in 2011. Smooth operation was enhanced, and the silicon content also kept about 0.3 % (Zhang et al. 2012a).

After three trials on large ore batch weight, the reasonable ore batch weight was found to be 100–115 t for 3200 m^3 blast furnace in Laiwu Steel. When the ore batch weight increased from 85 to 100–115 t, the fuel rate and the pressure drop decreased by 10 kg/t and 7 kPa, respectively (Mu et al. 2012).

In 2008, the ore batch weight went up from 10 to 21 t gradually in No. 4 blast furnace (inner volume: 400 m^3) of Nanjing Steel. Compared with the ore batch weight before adjustment, the CO_2 content in the top gas increased 0.2 %, and the blast furnace productivity increased by 0.49 $t/m^3\ d^{-1}$ (Lan and Wang 2009).

The ore batch weight was increased from 56 to 77 t in Benxi Steel. As a result, the gas distribution was stable, and CO utilization ratio was also increased by about 3 % (Zhu and Zhang 2009).

Huang et al. suggested that the coke layer thickness should between 500 and 700 mm, and the ore batch weight should be 0.95–1.20 % of daily production (Huang et al. 2015).

Hang and Wu thought the reasonable ore batch weight should be 0.012–0.015 of blast volume. The calculated ore batch weight was 55–68 t in No. 7 Blast Furnace of Jiugang Steel (Hang and Wu 2012).

11.2.2 Charging Mode

In the beginning, blast furnace is usually with bell top. The bell is used to store burdens and then goes down to discharge burdens into the blast furnace. However, the bell charging mode has some disadvantages, like bad sealing performance in the top, severe burden and gas segregations and so on. Therefore, the bell-less top blast furnace top is created. Blast furnaces are almost with bell-less top in China nowadays. The bell-less top will be only discussed in this paper.

The bell-less top blast furnace can be generally divided into three types based on the hoppers' location. The first type is parallel-type hoppers, which means that two hoppers are allocated on both sides of the centreline (see the left one in Fig. 11.2). The second type is serial-type hoppers, which means that two hoppers are allocated along the centreline of the blast furnace, and one is upper hopper, and the other is lower hopper (see the right one in Fig. 11.2). The third type is multi-hoppers, which means there are no less than three hoppers located around the centreline of blast furnace. There is no multi-hopper blast furnace yet in China, so it will not be discussed in this paper (Xiang and Wang 2014).

No matter parallel hopper or serial hopper, they both use rotating chute to discharge burdens from hopper into blast furnace. Therefore, charging mode of rotating chute is of significant importance to burden and gas distributions and further the CO utilization. The rotating chute usually has 8–12 rings corresponding to different angles. It can achieve many distributing modes due to its flexibility.

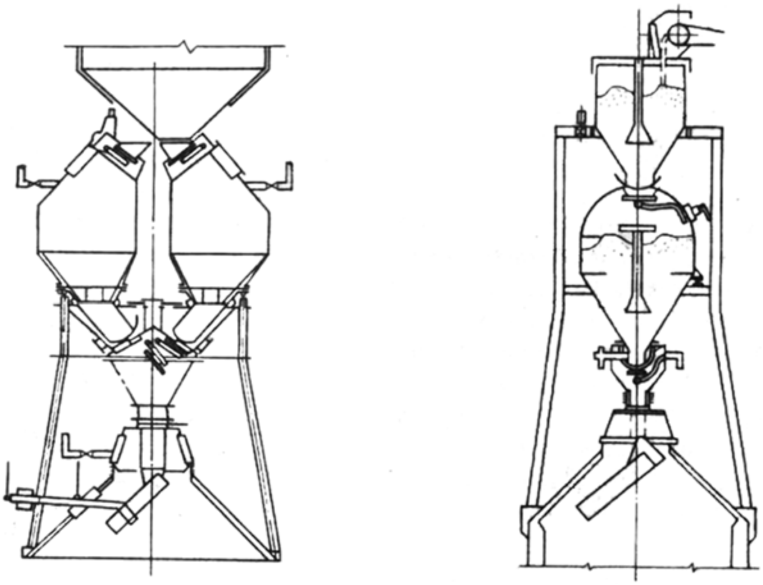

Fig. 11.2 Schematic diagram of bell-less blast furnace top

In general, there are four typical types of distributing modes: single-ring distributing, multiring distributing, fixed-point distributing and sector distributing. The former two modes are usually used in practical operation, while the latter two are only used when the gas distribution is not normal. The burden trajectory, burden stack shape and size distribution are directly determined by the rotating chute. The "terrace + funnel" burden stack shape is the most favourable one in China. Coke is easier to form a terrace, and the amounts of coke and ore can be adjusted based on the terrace. If the terrace is narrow and the funnel is deep, the burden stack will not be stable. On the contrary, if the terrace is wide and the funnel is shallow, the central gas flow will be suppressed. Once the terrace is developed, it should not be changed too much since the coke terrace controls the ore/coke ratio and size distribution in blast furnace.

Du and Guo proposed that the reasonable width of coke terrace should be 1.2–2 m for large-sized blast furnace and 0.8–1.2 m for middle-sized blast furnace. For example, the width of the coke terrace of the No. 2 blast furnace in Baosteel is 1.5 m (Du and Guo 1995). Li et al. suggested that the width of coke terrace should be 0.8 m and the depth of the funnel should be 1.5 m in the 1750 m^3 blast furnace of Ji'nan Steel (Li et al. 2006).

Wang et al. moved the main striking point of ore away from centre about 0.7 m and the main striking point of coke away from centre about 0.6 m by changing the charging modes in Shougang No. 2 blast furnace (inner volume: 1780 m^3) from March to April in 2008. As a result, the gas temperature in the top decreased from 200 to 180 °C, and the CO utilization ratio increased from 46 to 49 % (Wang et al. 2009).

Table 11.1 The CO utilization ratio corresponding to different charging modes in No. 5 blast furnace of TISCO

	Ore							Coke									
Rings	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	Fuel rate (kg t^{-1})	CO utilization ratio (%)
2008.02	0	3	3	3	3	3	1	2	2	2	2	2	2	2	2	508	49.9
2008.03	0	3	3	3	3	2	1	2	2	2	2	2	2	2	2	506	49.2
2008.11	2	3	3	3	1	1	2	1	2	3	3	3	1	1	1	503	50.1
2009.05	2	3	3	3	2	2	0	2	2	3	3	3	1	2	0	497	50.5
2010.04	3	3	3	3	2	1	1	3	2	3	3	3	1	1	0	503	50.05
2011.09	4	3	3	2	2	1	0	4	3	3	2	2	2	0	0	500	50.85
2012.03	4	3	3	2	2	2	0	4	4	3	2	2	2	0	0	507	50.5

Lu et al. used $C_3^{38^\circ}{}_2^{36^\circ}{}_2^{33.5^\circ}{}_2^{30.5^\circ}{}_2^{27.5^\circ}{}_4^{17^\circ}O_2^{38^\circ}{}_3^{36^\circ}{}_3^{33.5^\circ}{}_3^{31.5^\circ}{}_1^{28.5^\circ}$ to develop the gas flow in both peripheral and central gas at the beginning after the blow-in of No. 2 blast furnace (inner volume: 2500 m^3) of Chongqing Steel, then changed it to $C_2^{41^\circ}{}_2^{39^\circ}{}_2^{36.5^\circ}{}_2^{33.5^\circ}{}_2^{30.5^\circ}{}_3^{23^\circ}O_2^{41^\circ}{}_3^{39^\circ}{}_3^{36.5^\circ}{}_2^{33.5^\circ}{}_2^{30.5^\circ}$ to inhibit the peripheral gas flow. After the adjustment, the CO_2 concentration increased from 18 to 20.0–21.0 %, and the comprehensive coke rate also decreased from 525 to 500 kg/t (Lu et al. 2012).

Table 11.1 shows the changes of charging mode from February of 2008 to March of 2012 in TISCO No. 5 blast furnace (inner volume: 4350 m^3). It can be seen that the CO utilization increased from 49.9 to 50.5 % (Li et al. 2013).

Another technique is also adopted to the burden charging in China, which is central coke charging. This technique charges coke in the central area of the blast furnace in order to develop central gas flow. Jingtang No. 1 blast furnace of Shougang group employed the central coke charging in 2011 to conquer the deterioration of raw and fuel materials and obtain a long and stable operation condition (Wang et al. 2013). However, this mode is not good to increase the CO utilization ratio in the blast furnace. When the amount of coke in the centre increased 1 %, the CO utilization ratio decreased 0.317 % (Teng et al. 2014). When the raw and fuel materials deteriorated, the central coke charging mode was adopted to keep a stable operation in No. 2 blast furnace of Shougang Jingtang. A higher CO utilization ratio was achieved, but it was still 1.5 % lower than the period with no central coke charging (Zhang et al. 2012b). Therefore, many companies cancelled the central coke charging to increase the CO utilization ratio, such as the No. 9 blast furnace in Xinyu Iron and Steel Co., Ltd., No. 2 blast furnace in Ji'nan Steel and so on (Zhou et al. 2015; Meng et al. 2010).

The advantages of the "terrace + funnel" are high CO utilization ratio and low fuel rate, but this mode requires a stable quality of raw and fuel materials. However, the central coke charging mode can adapt to the quality fluctuations of raw and fuel materials, but the disadvantage of this mode is low CO utilization ratio, which usually ranges at 46.5–48.5 % (Zhu 2014).

Table 11.2 Angle compensations at different stock lines in Baosteel

Level	1	2	3	4	5	6	7	8	9	10	11
Stock line base	52°	50.5°	48.5°	46°	43°	40°	36.5°	33°	29.5°	24°	15°
Stock line 1	51°	49.5°	47.5°	45°	42°	39°	35.5°	32°	28.5°	23°	15°
Stock line 2	50°	48.5°	46.5°	44°	41°	38°	34.5°	31°	27.5°	22°	15°
Stock line 3	49°	47.5°	45.5°	43°	40°	37°	33.5°	30°	26.5°	21°	15°
Stock line 4	48°	46.5°	44.5°	42°	39°	36°	32.5°	29°	25.5°	20°	15°

11.2.3 Stock Line

As for the bell-less top blast furnace, the stock line is defined as the vertical distance between the 0 m stock line and the burden stack surface. And the 0 m stock line is defined as the level of chute tip when the chute is vertically still or the position of top edge of steel brick in the blast furnace throat (Wang 2013b).

Changing the stock line equals to change the height of burden free falling zone and then to change the burden striking point. Therefore, it is matched with the initial angles of rotating chute. When the stock line is heightened, which means that it is close to the 0 m stock line, the burden striking point will move towards the centre, then the peripheral area is loosened and beneficial to developing peripheral gas. When the stock line is lowered, the burden striking point will move towards the wall, then it helps to develop the central gas (Liu 2005).

The stock line is related to the blast furnace throat, inside profile of the blast furnace top, burden properties and so on. Since the burden striking point can be controlled by the angles of the rotating chute, the stock line does not usually change once it is found suitable for the blast furnace operation. Generally, the stock line is controlled at 1–2 m (Xiang and Wang 2014).

When the practical stock line is higher than the preset stock line, the angles of the rotating chute should be adjusted to prevent burden from hitting on the furnace wall. Table 11.2 illustrates the angle compensations at different stock lines (Xiang and Wang 2014).

11.3 The Lower Adjustment

11.3.1 Gas Volume

Generally speaking, the more the gas volume is, the more the pig iron blast furnace produces, but the gas volume should not be too high. In order to have a high CO utilization and low fuel rate, the gas volume should be appropriate. The gas volume increases with the increase of blast furnace volume, but the ratio of gas volume to furnace volume almost stays at 1.6–1.7 Nm^3/m^3 (Li 2011). If the ratio of gas volume to furnace volume is too small, the blast furnace hearth will not be active enough, and permeability will be worsened, and the operation will not be smooth. Therefore,

Table 11.3 Main parameters corresponding to the change of tuyere area

Time	Tuyere area (m^2)	Gas volume (m^3 min^{-1})	Production (t d^{-1})	Coke rate (kg t^{-1})
2010.9.26	0.3476	4000	5200	438
2010.10.6	0.3599	4020	5155	447
2010.10.23	0.3732	4050	4180	533
2010.11.11	0.3486	4050	3900	544
2010.11.25	0.3609	4200	4350	510
2010.12.12	0.3742	4600	4890	487
2011.01.16	0.3619	4600	4620	495
2011.01.28	0.3558	4560	5760	423
2011.02.15	0.3520	4600	5380	425
2011.03.12	0.3398	4730	5440	417
2011.03.28	0.3340	4730	5740	404
2011.04.11	0.3463	4770	5810	403

a relative high ratio slows down the erosion of gas on the furnace wall and prevents the furnace accretion, then helps to keep smooth operation (Lin and Xiang 2012).

When the appropriate gas volume is reached, it will not be changed much anymore. Then a common way to adjust the gas is to change the tuyere area. Generally, reducing the tuyere area increases the gas velocity, and it is beneficial to the development of central gas; increasing the tuyere area decreases the gas velocity and helps to develop peripheral gas. When the amount of PCI (pulverized coal injection) increases or the quality of the raw and fuel materials deteriorates, the tuyere area should be reduced to develop central gas. For example, Qiu et al. decreased the tuyere area from 0.4248 m^2 in 2011 to 0.4076 m^2 in 2012 in order to perform the injection of bituminous coal for No. 3 blast furnace of Laiwu Steel (Qiu et al. 2014).

There were 24 tuyeres with 130 mm diameter and 8 tuyeres with 140 mm diameter in No. 5 blast furnace of WISCO, so the total tuyere area was 0.4417 m^2. However, the number of tuyere with 140 mm diameter was reduced to 2, and the total tuyere area was 0.4331 m^2, in order to cope with the deterioration of the raw and fuel materials (Hu 2012).

In 2011, the tuyere area was changed from 0.4278 to 0.3957 m^2 in the 3200 m^3 blast furnace of Laiwu Steel, and it turned out that the CO utilization ratio was improved, and the fuel rate decreased from 522 to 512 kg/t (Lin and Wang 2013).

The tuyere area was also changed to increase production and reduce fuel rate for No. 2 2500 m^3 blast furnace of Xuanhua Steel from 2010 to 2011, as shown in Table 11.3 (Hao 2011).

It can be seen that coke rate almost decreases with the decrease of tuyere area. And the gas volume should increase gradually after the reduction of tuyere area.

11.3.2 Gas Temperature

The main sources of the heat needed for blast furnace are the combustion heat of fuel and the physical heat of blast gas. The more heat the gas brings into blast furnace, the less heat the fuel needs to combust. Therefore, high gas temperature can

Table 11.4 The amount of saving coke corresponding to high blast gas temperature

Blast gas temperature (°C)	Around 950	950–1050	1050–1150	>1150
Saving coke (kg t^{-1})	About 20	About 15	About 10	About 8

Table 11.5 Typical technical index in some steel companies with high gas temperature in 2014

Company name	Gas temperature (°C)	Fuel rate (kg t^{-1})	Coke rate (kg t^{-1})	Coal rate (kg t^{-1})	Productivity (t m^{-3} d^{-1})
No. 6 blast furnace in Taiyuan Steel	1245	524	330	194	2.20
No. 5 blast furnace in Taiyuan Steel	1238	529	333	195	2.11
No. 3 blast furnace in Baosteel	1241	486	303	183	2.11
San'an Steel	1240	523	344	158	2.52
No. 9 blast furnace in Jingye Steel	1232	548	396	152	2.55
No. 10 blast furnace in Jingye Steel	1231	541	392	149	2.49

decrease the fuel rate and the cost of pig iron. At the same time, more coal can be injected to the blast furnace to replace some coke due to high gas temperature. Table 11.4 shows the amount of saving coke corresponding to the high gas temperature (Wen et al. 1996).

Many steel companies have high gas temperatures over 1200 °C, and typical technical indexes of some companies in 2014 are given in Table 11.5 (Wang 2015).

Table 11.6 shows some main technical and economical parameters of some advanced blast furnaces from January to June of 2011 in China (Zhang 2013).

Chen et al. reported that when the blast gas temperature increased from 1240.7 °C in 2008 to 1258.7 °C in 2009 in Qian'an Steel's No. 2 blast furnace, the coke rate decreased from 295 to 287 kg/t, while the coal rate increased from 164 to 172 kg/t (Chen 2010).

Guo et al. also tried to increase the gas temperature in No. 1 blast furnace of Chongqing Iron and Steel Company from 2010 to 2012. The main technical and economical parameters are given in Table 11.7. It can be found that the coke rate decreases greatly when the blast gas temperature increases (Guo et al. 2013).

Wang and Li reported the change of blast gas temperature in 2200 m^3 blast furnace in Angang Iron and Steel Company in 2006. Table 11.8 illustrates some typical parameters (Wang and Li 2007).

From 2004 to 2007, the blast gas temperature of No. 2 blast furnace in Meishan Steel increased from 1131 to 1223 °C, and the coal rate increased from 109 to 158 kg/t, while the coke rate decreased from 393 to 227 kg/t (Wang 2008).

Table 11.9 shows some main economic indicators of No. 7 blast furnace in Benxi Steel from 2005 to 2010 (Huang 2011).

Zhu reported that the blast gas temperature in 2500 m^3 blast furnace for Chengde Iron and Steel Company increased by 7.1 °C in 2012 from 1211.5 °C in 2011, the comprehensive coke rate decreased by 14.4 kg/t (Zhu 2013).

Table 11.6 Main technical and economical parameters of some advanced blast furnace from 2011.01 to 2011.06 in China

Company name	Effective volume (m^3)	Gas temperature (°C)	Fuel rate (kg t^{-1})	Coke rate (kg t^{-1})	Coal rate (kg t^{-1})	Productivity (t m^{-3} d^{-1})
No. 1 blast furnace in Shougang Jingtang	5500	1300	480	305	175	2.37
No. 3 blast furnace in Qian'an Steel	4000	1280	503	327	176	2.39
No. 3 blast furnace in Baosteel	4350	1236	–	306	185	2.50
No. 4 blast furnace in Baosteel	4747	1254	488	318	170	2.02
No. 8 blast furnace in WISCO	3800	1192	532	355	177	2.69
5800 m^3 blast furnace in Shazhou Steel	5800	1230	502	341	161	2.21
No. 5 blast furnace in Taiyuan Steel	4380	1243	502	315	187	2.50
No. 1 blast furnace in Ma'anshan Steel	4000	1225	514	338	140	2.22
No. 1 blast furnace in Bayuquan of Anshan Steel	4038	1225	523	372	151	2.11

Table 11.7 Main technical and economical parameters of No. 1 blast furnace in Chongqing Steel from 2010 to 2012

Time	Gas temperature (°C)	Coke rate (kg t^{-1})	Productivity (t m^{-3} d^{-1})
2010	1080	529	1.49
2011	1202	414	2.08
2012.01	1219	428	2.24
2012.02	1221	436	2.20
2012.03	1215	418	2.00
2012.04	1223	396	2.15
2012.05	1216	390	2.26
2012.06	1228	397	2.14
2012.07	1230	415	2.23
2012.08	1170	400	2.12
2012.09	1187	390	2.26
2012.10	1206	391	2.28
2012.11	1126	479	1.74
2012.12	1220	412	2.21

Table 11.8 Some typical parameters of 2200 m^3 blast furnace in Angang Steel in 2006

Time	Gas temperature (°C)	Coke rate ($kg\ t^{-1}$)	Coal rate ($kg\ t^{-1}$)	Productivity ($t\ m^{-3}\ d^{-1}$)
2006.01–2006.03	1015	573	30	1.49
2006.04	1218	520	79	2.08
2006.05	1236	457	111	2.24
2006.06	1199	404	137	2.20
2006.07	1218	388	150	2.00
2006.08	1189	383	150	2.15
2006.09	1192	383	143	2.26

Table 11.9 Some typical parameters of No. 7 blast furnace in Benxi Steel from 2005 to 2010

Time	Gas temperature (°C)	Coke rate ($kg\ t^{-1}$)	Coal rate ($kg\ t^{-1}$)
2005	986	466	39.9
2006	1070	388	93.8
2007	1109	386	106.5
2008	1091	374	90.3
2009	1140	347	119.0
2010	1155	348	124.6

11.3.3 Gas Humility

At the beginning, the gas humility keeps at the value it originally has. However, the gas humility varies day by day, which results in unstable blast furnace operation. In order to solve the problem of the variation of gas humility, there are two ways: one is humidified blast and the other is dehumidified blast. Humidified blast is to fix the humility at a relatively high value to keep a stable furnace operation. But the water vapour brought by humidified gas needs to be decomposed, which consumes the heat in blast furnace. When the gas humility increases by 1 %, the coke rate will be increased by 4–5 kg/t, otherwise, the gas temperature needs to be increased by 25 °C. Dehumidified blast is to fix the humility at a low value. It reduces the heat consumed by the decomposition of water vapour and increases the theoretical combustion temperature, then decreases the coke rate. Therefore, the amount of CO generated at the lower part of blast furnace will decrease, then the CO utilization will increase as a result. Generally, when the gas humility decreases by 1 g/m^3, the coke rate can be decreased by 0.8–1.0 kg/t (Xiang and Wang 2014).

The dehumidified blast has been applied to No. 1 blast furnace in Liuzhou Steel since 2010. The gas humility decreased from 20 to 6~7 g/m^3, and the fuel rate decreased by 9.2 kg/t as a result (Huang et al. 2013).

Yao et al. also reported that the gas humility decreased from 18.3 to 10 g/m^3 for No. 3 blast furnace in Hangzhou Steel from 2011. As a result, the coke rate decreased from 373 to 357 kg/t, and the CO_2 content at the top of the furnace increased from 18.81 to 19.23 %, which indicated a better CO utilization ratio (Yao et al. 2012).

Table 11.10 Some parameters before and after the application of dehumidified blast technique in No. 8 blast furnace of Nanjing Steel in 2011

Time	Gas humility (g m^{-3})	Productivity (t m^{-3} d^{-1})	Fuel rate (kg t^{-1})	Coke rate (kg t^{-1})	Coal rate (kg t^{-1})	Gas temperature (°C)
Before dehumidified blast technique (2011.07–2011.08)	18	2.47	542	357	151	1209
After dehumidified blast technique (2012.07–2012.08)	8	2.63	509	325	166	1220

In 2011, the No. 8 blast furnace in Nanjing Steel adopted the dehumidified blast technique, and some main technical and economical parameters before and after the dehumidified blast technique are shown in Table 11.10 (Wang 2013b).

The coke rate also decreased by 17.3 kg/t when the gas humility decreased by 7.7 g/m^3 for No. 2 blast furnace in Meishan Steel (Tao 2010).

Zhang et al. reported that the fuel rate decreased by 18.40 kg/t, while the production increased by 27.51 t/d after the application of dehumidified blast in 2005 in 2500 m^3 blast furnace of Stainless Steel Branch of Baosteel (Zhang et al. 2006).

11.4 Conclusions

The principle of upper adjustment and lower adjustment is that they should be suitable for each other. When the peripheral gas in the lower part of blast furnace is developed, then the upper adjustment should not block the peripheral gas heavily. The upper adjustment should gradually open the central gas and control the peripheral gas at the same time in order to prevent the sudden block of peripheral gas, which may affect the smooth operation of blast furnace. Likewise, when the central gas in the lower part is overdeveloped, the upper adjustment should not block the central gas immediately, but should open the peripheral gas properly and then release the overdevelopment of central gas. Above all, the upper adjustment and lower adjustment should not form confrontation. The CO utilization ratio can be increased remarkably with the cooperation of the upper adjustment and lower adjustment.

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