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RESEARCH AND APPLICATION ON LONG CAMPAIGN LIFE TECHNOLOGIES OF BLAST FURNACE AT SHOUGANG[1]

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Abstract

At the beginning of 1990s, Shougang No.2, No.4, No.3 and No.1 blast furnace (BF) were rebuilt for new technological modernization in succession. The campaign life of No.1, No.3 and No.4 BF reach 16.4 years, 17.6 years and 15.6 years separately; the hot metal output of one campaign life reaches 3.38Mt, 3.548Mt and 2.637Mt separately; the hot metal output per m^3 BF effective volume of one campaign life reaches 13328t/m^3, 13991t/m^3 and 12560t/m^3 separately, which reaches the international advanced level of BF high efficiency and long campaign. In BF designing, several advanced BF long campaign technologies were adopted. BF proper inner profile is optimized, reasonable profile is adopted, soften water closed circulation cooling technology is applied in 4 BFs. Double row cooling pipe high efficiency cooling stave is developed which can prolong the service life of bosh, belly and stack. Hot pressed carbon brick and ceramic cup hearth lining structure are applied and optimized. During BF operation practice is improved continuously to ensure stable and smooth operation of BF. Hearth working condition control is strengthened, burden distribution control technology is applied to achieve reasonable distributed gas flow, heat load monitoring is strengthened to maintain BF reasonable operation profile. Proper maintenance during end of BF campaign is enhanced. Hearth and bottom service life is prolonged by adding titaniferous material and enhancing hearth cooling etc. Gunning of lining is carried out periodically for the area above tuyere zone.

Key words: Blast furnace; Long campaign life; Hearth lining; Cooling stave.

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1 INTRODUCTION

Shougang's No.2, No.4, No.3 and No.1 BFs were rebuilt, enlarged and modernized by new technologies respectively in 1990s. For a successful 2008 Olympic Games held in Beijing, Shougang shut down steel plants in Beijing region. No.2 and No.4 BFs blew down in the year of 2008, No.1 and No.3 BFs blew down respectively on December 18th and 19th in 2010. No.1 and No.3 BFs were in good operating conditions and performances when they shut down. The campaign life of No.1, No.3 and No.4 BFs lasted for 16.4 years, 17.6 years and 15.6 years respectively, and the hot metal output per unit BF volume during one campaign was 13328 t/m^3, 13991 t/m^3 and 12560 t/m^3 respectively. The international advanced level is achieved in the high efficiency and long campaign life BFs.

2 DESIGN FOR HIGH EFFICIENCE AND LONG CAMPAIGN OF BF

2.1 Design of BF Inner Profile

The Chinese ironmaking engineers have always focused on the design of BF inner profile and such basic philosophy as optimized design of BF inner profile has been formed as a result of investigation and summarization of the BF breakage mechanism and BF reaction principle.[1] It is an effective technical method to restrain the elephant foot shaped abnormal wear by way of increasing the welldeath depth properly. After increment of the welldeath depth, a direct settlement of deadman onto the bottom is avoided, the access of hot metal flow between the deadman and bottom is enlarged, the liquid and gas permeability in the hearth are improved, the peripheral flow of hot metal is lightened and the service life of hearth and bottom are effectively prolonged. It is confirmed by theoretical research and practice that the welldeth depth is approximate 20% of the hearth diameter normally. A proper increment of hearth height is not only good for combustion of pulverized coal in front of the tuyere, but also can increase the hearth volume in order to store slag and hot metal under the condition of high efficient production and reduce the potential “irregular blasting” under the condition of intensifying smelting. A trend to increase the hearth height is on the rise for large BFs in China and an appropriate hearth volume should be 16%-18% of the effective volume of BF. The study shows that it has a remarkable effect to restrain the wear on the hearth lining around the taphole area by way of properly deepening of taphole with the taphole depth is approximate 45% of the hearth radius normally. Thus, it can reduce the hot metal whirlpool formed nearby the taphole area during tapping and prevent the scour on the hearth lining by the whirlpool, and prolong the service life of the hearth lining in the taphole area. Reduction of BF bosh angle is not only good for bosh gas smooth ascension, but also for easing heat flux attack on the bosh and good for formation of stable protective slag skull in the bosh area to protect cooler for a long-term. The bosh angle of a modern large BF is within 80° normally. Table 1 shows the parameters of inner profile of some BFs of Shougang.

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Table 1. Proper inner profile of BFs at Shougang

Item	No.1 & No.3	No.2	No.4
Effective volume / m^3	2536	1726	2100
Diameter of hearth / m	11560	9700	10400
Diameter of belly / mm	13000	10850	11550
Diameter of throat / mm	8200	6800	8150
Height of well death / mm	2200	1800	1600
Height of hearth / mm	4200	4000	4350
Height of bosh / mm	3400	3100	3400
Height of belly / mm	2900	2000	2200
Height of stack / mm	13500	15600	13950
Height of throat / mm	1800	2000	2000
Effective height / mm	25800	26700	25900
Angle of bosh α	78°02′36″	79°41′42″	80°24′3″
Angle of stack β	79°55′9″	82°44′24″	83°3′07″
Numbers of tuyere	30	24	28
Numbers of taphole	3	2	2
Space between tuyeres	1211	1270	1167
Height to diameter ratio	1.985	2.461	2.242

2.2 Design of BF Hearth Bottom Lining Structure

It has been proved by practice that the service life of a BF hearth and bottom is the key to determine BF campaign life and the ironmaking engineers have paid a great attention to effectively prolonging the hearth and bottom lining service life. Since 1960s, Shougang has been using such an integrated bottom technology as carbon bricks-high alumina bricks for the BFs that have been always in good conditions. With the development of ironmaking technology and since the middle period of 1980s, the BF smelting has been intensified and the problem of the BF hearth and bottom has be in the highlight. As a result of investigation and analysis by means of 10 over actual results of measurements when the BF blew down that the wear on the linings of Shougang's BF hearth and bottom is attributable to the typical and abnormal elephant-foot-shaped wear and annular cracks on the side wall of the hearths.[2] The position that the most serious erosion occurred due to the abnormal elephant-foot-shaped erosion is located at the junction between the hearth and bottom, the position corresponding to the cooling stave on the 2nd part of the hearth and the most serious wear was less than 100mm only from the cooling stave by way of actual measurements. The coagula with high melting point as solidified slag, hot metal and Ti (C, N) were coagulated on the surfaces of the residual carbon bricks and high alumina bricks, and annular cracks appeared on all the annular carbon bricks around the hearth, the cracks were 80-200mm and solidified slag, hot metal existed in the cracks.

The wear mechanism of hearth and bottom lining of Shougang's BFs was investigated and analysed under consideration of the BF raw materials, fuel and operation. Mainly including: penetration and erosion of hot metal into and on the carbon brick, mechanical wear by peripheral flow of hot metal, corrosion and chemical erosion of such alkali metal as molten slag and hot metal, ZnO, Na_2O, K_2O, damage of carbon brick by thermal stress, oxidization and damage of carbon brick by oxide gas such as CO_2 and H_2O, etc. Application of high-quality carbon brick and rational cooling are the musts to prolong the service life of the BF hearth and bottom. The thermal conduction process

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(hot-pressed carbon brick process) hearth design system, as a representative of UCAR in USA, has been successfully adopted for the large BFs. The refractory process (ceramic cup process) hearth design system, as a representative of SAVOIE in France, has been popularly applied to the large BFs, too. Thermal conduction process and refractory process hearth design systems have a same essence of the technical principle, i.e., control of distribution of 1150°C isotherm in the hearth and bottom enables the carbon bricks to keep away from the 800-1100°C embrittling temperature zone as possible as they can. Small size hot-pressed carbon brick NMA with high thermal conductivity and excellent resistance to permeability of hot metal are used for the called thermal conductive process. Through a rational cooling, a layer protective skull of slag or hot metal can be formed on the hot surfaces of the carbon brick and 1150°C isotherm is restrained inside the protective skull. Therefore, the carbon bricks are effectively protected and prevented from the damages caused by penetration and wear of the hot metal. For the ceramic cup solution, the ceramic materials with low thermal conductivity are adopted on the hot surfaces of the carbon blocks so that a cup-shaped ceramic lining forms, i.e. so-called ceramic cup that has a purpose to control the 1150°C isotherm inside the ceramic cup. All of these two technical systems must adopt the carbon bricks with high thermal conductivity and excellent resistance to permeability of hot metal. [3]

Carbon brick - alumina brick comprehensive bottom lining structures are applied on No.2, No.3 and No.4 BFs and the hot pressed carbon brick - ceramic cup combined hearth and bottom lining structure is adopted for No.1 BF (as shown in figure 1). Small size hot-pressed carbon brick NMA are applied to the junctions between the hearth and bottom of the four BFs, i.e. elephant-foot-shaped abnormal erosion areas.[4] All of these two structures have been successfully applied and actual achievements of BF long campaign life have been obtained. The campaign of Shougang's BFs in Beijing district is indicated in table 2. Especially for No.1 and No.3 BFs with the same volume and profile, under the similar conditions of raw materials, fuel and production, the campaign of them exceeds the designed target that proves a long campaign life of the BFs can be realized by means of all of these two technical systems for hearth and bottom of the BFs.

Table 2 Shougang's BFs campaign life at Beijing district

BF	Effective volume (m^3)	Blow in (year-month)	Blow down (year-month)	Campaign life (year-month)	Output during a campaign (Mt)	Production per m^3 during a campaign (t/m^3)
No.1	2536	1994-8	2010-12	16-5	33.80	13328
No.2	1726	1991-5	2002-3	10-10	15.40	8926
No.3	2536	1993-6	2010-12	17-7	35.48	13991
No.4	2100	1992-5	2008-1	15-8	26.38	12560

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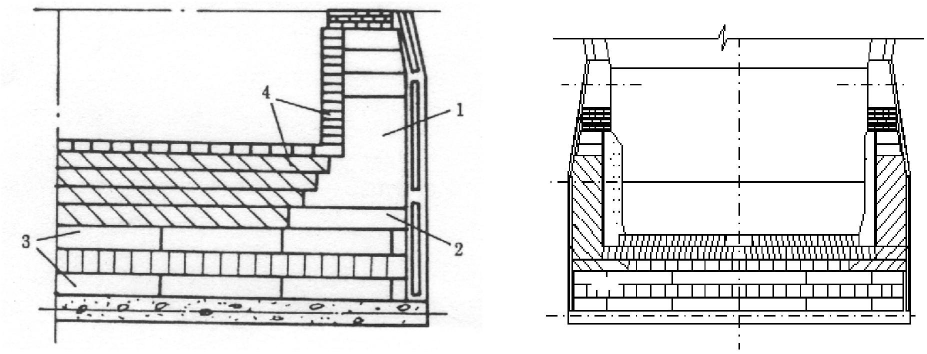

(a) (b)

Figure 1. Hearth and bottom lining structure. (a) carbon brick-comprehensive bottom structure; (b) carbon brick-ceramic cup combined structure. 1-NMA, 2- carbon block, 3- bottom carbon beam, 4- alumina brick.

2.3 Design of BF Cooling Technology

2.3.1 Design of cooling stave

In 1990s, there were 3 kinds of major cooling structure of BF: copper cooling plates were used for cooling from bosh to lower shaft; cooling staves were used for BF proper completely; cooling staves and copper cooling plates were used together for BF. To make the BF campaign life reach 10-15 years, the full cooling stave structure was adopted for Shougang's BFs. When the types of the cooling staves for all parts of the BFs were selected, the following factors were taken into consideration:[5]

The heat load at the position is higher, but it is lower than the area above the bosh and the temperature fluctuation is smaller. The hot surface of the cooling staves can maintain the carbon bricks with a certain thickness to prevent the cooling staves from erosion by high-temperature liquid slag and hot metal. Therefore, grey cast iron cooling staves with higher thermal conductivity are used in the hearth and bottom areas (including tuyere zone) and five sections of cast iron cooling staves are totally provided.

The BF bosh, belly and lower shaft are the points that the cooling staves are most seriously damaged. Since the brick lining (slag skull) can not be stably stored for a time, the surface of the cooling stave directly expose to the BF and are impacted by severe heat load, eroded by slag and hot metal, scoured by strong gas flow and due to the mechanical wear and tear of burden and so on, it is required that the cooling staves in the area should have a higher thermal mechanical property and a stronger cooling capability. In the design, the third generation of double-row-pipe cooling staves made of nodular graphite cast iron were applied. Six rows of brick-inlaid cooling staves were totally installed and beads were furnished for the cooling staves at the belly and lower shaft to support the brick lining. Three rows of home-made copper cooling staves were adopted when No.2 BF rebuilt in the year of 2002.

The middle part of shaft is mainly worn and torn by burden, scoured by gas flow, chemically eroded by alkali metal and bears a higher heat load. Therefore, the brick-inlaid cooling staves with beads and made of nodular graphite cast iron with inlaid clay bricks were used in design. Four rows of cooling stave were totally installed in middle part of shaft.

One row of C shaped stave cooler made of nodular cast iron was added between the upper part of shaft and lower edge of throat armour. The stave type cooler directly contact the burden and refractory lining was cancelled.

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2.3.2 Design of BF cooling system

It is proved by Shougang's BF production practice for many years that when the advanced hearth bottom lining structures are adopted, it shall specially take care of cooling of the hearth and bottom, detection and monitoring shall be reinforced. For the key positions, the high-quality carbon brick with high thermal conduction, resistance to penetration and anti-erosion shall be used and a rational cooling system shall be adopted for intensification of cooling. For design of the cooling water flowrate, a sufficient adjusting capacity shall be fully taken into account and control of cooling water flowrate shall be determined according to the actual conditions of the production practice in order for energy saving and consumption reduction. It is not good in the design to unilaterally pursue a lower cooling water flowrate. In the mid and later stages of BF campaign, thinning of the lining will make the heat load and temperature rise up considerably, an insufficient cooling water flowrate will cause an inadequate capability of the cooling system and an overheat or break-out will easily take place at the hearth in case the hearth and bottom temperature is exceed the normal range or the heat load is abnormal.

Industrial water circulating cooling system is used for of bottom cooling pipes, hearth cooling staves (1-5 rows), C shaped stave type coolers and tuyeres of Shougang's four BFs. The bottom cooling pipes, 1st, 4th and 5th rows of cooling staves and tuyere coolers are cooled by industrial water with normal pressure of 0.60MPa. An intensifying cooling system with medium pressure of 1.2MPa is carried out in the 2nd and 3rd rows of cooling staves are located at the junction (abnormal "elephant-foot-shaped" erosion zone) between the hearth and bottom. Circulating industrial water cooling system with high pressure of 1.7MPa is used for the middle and noses jackets of tuyere. The soften water closed circulating system is adopted in cooling staves above bosh.

2.4 Automatic Detection and Control

Automatic detection is an indispensable technical measure to prolong BF campaign life. An on-line monitoring of the hearth bottom temperature has become an important approach to control the status of erosion on the hearth bottom and also is a necessary condition to establish a mathematical model of erosion on the hearth bottom linings. Detection of the temperature and pressure in the parts of bosh, belly and lower shaft provides the BF operators with the reliable informations to know at any time the BF working conditions. By means of detection of the flowrate, temperature and pressure of the cooling water, such parameters as heat flux density and heat load can be calculated out and the working status of the cooling system can be monitored and controlled, too. Application of such technologies as stationary temperature probes of throat, top camera, automatic on-line analysis of gas, monitor of lining thickness and so on further ensures the long BF campaign life. To create favourable conditions for prolonging BF campaign life, an artificial intelligent expert system of BF iron-making was introduced in the year of 2002 when No.2 BF rebuilt.

3 PRODUCTION MANAGEMENT

3.1 Strengthening of BF Body Monitoring and Supervision

The hearth working status can be correctly judged only a real-time collection and

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monitoring of the hearth cooling water temperature difference and variation of the heat flow density are realized, and on the basis of these, the corresponding agent adjustment for the upper and lower parts of the BFs, measures for protection of the BFs and adjustment of the production capacity are conducted and taken to ensure a smooth and stable production, prolong the BF service life and reach the target of long life and high efficiency.

To realize a real-time acquisition and monitoring of the cooling water temperature difference and variation of the heat flow density of the cooling staves at the 2nd and 3rd rows of the hearth and in the taphole area, and to satisfy the need of real-time monitoring of the hearth working status, an on-line cooling stave water temperature collection module, a data processing module and a communication module are developed; an on-line collection and communication system of the hearth water temperature difference is established for real-time detection of the stave water temperature, calculation of the temperature difference and heat flow strength of the hearth cooling staves; a database of the cooling stave temperature difference and hearth heat load during the production is established; a variation curve of the hearth stave water temperature difference, a variation curve of the hearth heat load, a circumference distribution diagram of the hearth heat load and a data report of the hearth heat load are automatically generated; a real-time alarming and warning for overrun of the hearth heat load is realized in order to provide the reference and guidance about the BF internal status in the course of production.

A closed circulating soften water cooling system is used for cooling of No.1, No.2 and No.4 BF above bosh areas. The cooling system for No.3 BF bosh and above part is divided into 2 parts, i.e. industrial water is used for cooling stave of 1-12 rows and a closed circulating soften water system is used for cooling stave of 13-15 rows. Flowmeters, pressure gauges and temperature detectors are furnished in the soften water supply and return pipelines; pressure gauges are installed in each of the return water branch pipes and temperature detectors are arranged at certain intervals in the branch pipes of the cooling staves around the BF body to calculate the average heat load of the cooling staves. Alarming devices for pressure too low, water level too low and make-up water pressure too low are installed on the expansion tanks. All the above detected data are, besides the displays and logs in the water pump house, are transmitted to the computers in the main BF control room for realization of such functions as display, storage, record, alarming and printing, etc. Control and regulation of the soften water system, nitrogen pressure stabilizing system on the expansion tanks and make-up water system are all automatically controlled.

3.2 Strengthening of BF Body Maintenance

A stable and smooth BF production requires an active hearth working status, the dead man at the hearth centre has sufficient gas permeability and liquid permeability and the peripheral flow of hot metal in the hearth is weakened. If the gas permeability and liquid permeability of the deadman at the hearth centre are bad, then, hot metal will accumulate at the hearth edge and the peripheral flow of hot metal easily formed during tapping will make the hearth lining partly eroded, make the hearth overheat locally and such accident as hearth break-out and the like will occur. And a large amount of slag and hot metal staying in the deadman will enable the initial gas to hardly penetrate the hearth

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centre, damage the gas distribution of the BF so that the smooth operation and long campaign life of the BF will be influenced. Therefore, measures shall be taken to activate the dead man in the hearth centre, maintain the hearth sidewall and bottom in appropriate temperature and keep the active hearth working situation.

The temperature of the hearth side wall and the bottom reflects the variation of the temperature field in the hearth and bottom. With the production increment, the temperature of the hearth side wall and bottom goes up and with the increment of PCI, the temperature of the hearth side wall rises up while the bottom temperature drops down. The activity index of the hearth working is an important parameter to monitor the hearth working status and to provide a basis for adjustment of ironmaking parameters under the condition of a long-time high PCR of BF so as to ensure a stable and smooth BF production.

Such measures as improving the quality of raw materials and fuel, control of the charging system on the rational distribution of the gas flow in the centre and peripheral based on a stable and sufficient blast kinetic energy will make the BF operation stable and smooth be beneficial to the activity of the hearth working. By monitoring the activity index of the hearth working, all the BF ironmaking parameters are timely adjusted and the activity index is maintained within a normal range in order to make the BF operation stable and smooth under the high PCR and the temperature of the hearth side wall is kept lower for safety and long life of the hearth and bottom.

Rational gas flow distribution is in relation with BF stable and smooth operation, energy saving, consumption reduction and long life. The Shougang's evaluation standard for BF gas rational distribution are: the first is to ensure stable and smooth operating condition, the second is to increase gas utilization and reduce fuel ratio, typical gas distribution is “central gas is open and peripheral gas is stable”, the “open” of central gas means that central gas flow is narrow and strong, furnace condition is smooth, gas utilization is high, fuel ratio is low and hearth works actively. Over development of peripheral gas flow will not only result in increasing of furnace body heat load and affecting BF campaign, but also make the gas efficiency worse, fuel consumption increasing and consequently affect the long and stable smooth operation of BF. The stable peripheral gas flow will benefits the protection of stave and stabilization of protective skull, central gas flow has the influence on gas utilization, energy consumption, intensified smelting and has direct influence on the stabilization of peripheral gas flow. The target of BF rational gas distribution is to realize BF stable and smooth operation, based on which, to increase gas efficiency, realize energy saving and consumption reduction for BF ironmaking and obtain BF long campaign life.

Management of operating BF profile relates to design elements of profile design, configuration of cooler and usage of refractory and operating elements of raw material management, furnace body cooling, gas distribution, tapping management and BF operation, it is the comprehensive reflection of BF production management and the foundation for long, stable and rational operating profile and also for long campaign life. Management of operating BF profile shall be taken as the most important regular management system of BF production, the variation of BF profile has to be timely and accurately monitored, the profile change information has to be quantitatively analysed to judge and solve the problem that cause the profile change and to maintain normal BF operating profile.

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In order to reduce the damage to furnace body, the remote controlled gunning technology for lining is adopted, the similar operating profile complying with BF smelting regulation is formed through gunning lining technology, which benefits to prolong the service life of stave and furnace body above the tuyere, and also provide a reliable condition for rational distribution of gas flow.[6]

After BF intensified smelting, in-time tapping of hot metal and slag become the key factors to BF stable and smooth operation. Behind-time tapping of slag and hot metal will result in difficult seepage of slag and iron in deadman, disturb the initial gas distribution in hearth and affect the operating BF profile. Taphole maintenance will directly affect the maintenance of operating profile in taphole area, taphole depth will be continuous over shallow, carbon brick in taphole area will be severely corroded, affecting the long life of BF hearth. Quantitative analysis on BF tapping interval, tapping time, tapping quantity, taphole depth, clay quantity, enhance cast house operation level, ensure BF non-irregular blasting, reduce taphole excess clay, stable taphole depth, increase the stability of cast house operation. The quality of clay will influence the tapping, which has to be stabilized; the taphole clay which adapts to different operating condition and smelting intensity has to be developed; the features of anhydrous taphole clay such as high strength and better anti-corrosion performance shall be fully utilized; it is the trend for BF cast house operation to adopt tapping method with less tapping, long tapping time and short tapping interval.[7]

In addition, the grouting technology for the hearth sidewall has become an important technical approach to prolong the service life of the BF hearth and taphole area. The taphole area is always the BF key position to be maintained and is a weak link of the BF campaign life, too. The brick lining in the taphole area is repeatedly impacted by the clay gun and driller, cracks easily appear on it form the accesses to leak the high temperature gas. Therefore, a grouting operation is necessary for the taphole area. Otherwise, it is not only difficult to plug the taphole, but also affects the smooth BF operation and the whole BF campaign life. Care shall be taken when the grouting technology is adopted for the hearth that the cooling staves and brick lining cannot be damaged and the grouting holes should keep away from the staves that should be prevented from damage if the holes are drilled while the inlet pressure and grouting rhythm should be well controlled during grouting and the BF hearth lining should be prevented from impact due to over-high pressure, especially in the mid stage and later stage of the BF.

Modern BF with a higher intensity smelting, especially the BF at late stage of the campaign, the addition of titaniferous material should become regular measure for maintenance of hearth and bottom, long term and continuous addition of titaniferous material, keep proper addition of TiO_2, so that a protection layer with high viscosity shall be formed at the inside of hearth and bottom to slow down the corrosion on the hearth by flowing hot metal; on the other hand, accumulation of TiC, TiN and Ti (CN) will be formed in time at hearth corrosion area to avoid continuous corrosion inside hearth. TiC, TiN and Ti（CN）with high melting point is generated, grown and accumulated in hearth and form sticky material together with hot metal and graphite from hot metal, cemented on the surface of severely corroded hearth lining which is close to the stave, as a result it will repair and protect the hearth lining. When using titaniferous material for maintenance, the TiC, TiN in the slag shall not be smelted under hearth temperature, suspended in the slag

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in the form of solid particle, and worsen the flowability of slag, the slag become more sticky with more TiC and TiN, and will lost flowability at the worst. When titaniferous material is used for BF maintenance, the charged TiO_2 is rationally controlled, the hearth temperature gradients is rationally utilized to solve the contradiction between BF hearth maintenance and intensified smelting. Table 3 shows the main parameters of No.1 and No.3 BFs in 2010.

Table 3. Main technical - economic parameters of Shougang's No. 1 & No. 3 BFs in 2010

Issue	No. 1	No. 3
Output (t)	2093035	2026395
Productivity ($t \cdot m^{-3} \cdot d^{-1}$)	2.338	2.277
Coke rate (kg/tHM)	340.4	358.1
PCR (kg/tHM)	144.9	124.2
Fuel ratio (kg/tHM)	505.2	499.9
Oxygen enrichment ratio (%)	1.12	0.68
Blow down ratio (%)	2.11	1.86
Hot blast temperature (□)	1136	1076
TFe in burden (%)	58.79	58.85

5 CONCLUSIONS

BF long campaign life is the main technical developing trend of modern BF. BF design, operation and maintenance have important function on BF long campaign life. At early 1990's, a series of advanced long life technologies were adopted for Shougang's BF design. In BF production practice, the BF life is tremendously extended owing to adoption of these advanced long life technologies and better application effects are obtained. Optimization of the BF profiles, application of rational hearth bottom lining structure, adoption of the advanced staves and desalinated water closed loop circulating cooling system, deployment of perfect automatic monitoring system are the important foundations to prolong BF campaign life.

During the BF production process, to intensify the on line monitoring and maintenance is an important measure to prolong BF campaign. During the BF production process, the technical measures for Shougang's BF long campaign life are: on-line monitoring on hearth cooling water temperature difference and soften water closed loop circulating cooling system by using automation model; optimization of BF operation by the expert system for BF ironmaking; intensify the maintenance of BF body, to keep active hearth working status and rational gas flow distribution; to intensify the management of operating furnace profile and casthouse operation; adoption of gunning lining and titaniferous material to protect lining technologies etc.

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