EXPLORATION ON PRACTICES TO MAINTAIN STABLE AND SMOOTH OPERATION OF BF UNDER NEW NORMAL STATE*

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Abstract

Under the new normal state, blast furnace outputneeds to be adapted to the market demand, however the limitation in blast furnace output has significant impact on blast furnace operation and is prone to cause inactive furnace hearth and higher fuel ratio. To address such problems, some practices to maintain stable and smooth operation of blast furnace in case of output limitation are proposed based on data analysis philosophy, which allows the blast flow and hence the top pressure to be determined based on the hot metal output, and adequate kinetic energy of blast supply can be assured by adjusting the tuyeres. Matching between the oxygen enrichment and the pulverized coal injection is also proposed based on theoretical flametemperature, and burden distribution cycle calculation method is proposed, whichoffersnew approach for analyzing the change in burden distribution pattern.

Keywords: Blast Furnace; output limitation; stable and smooth operation.

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1. Introduction

In the context of supply-side reform aiming to cut the capacity of steel industry in China, the steel producers are under severe pressure to survive, and such state is expected to continue for a rather long time. Being the upstream procedure in iron and steel production process, blast furnace is a typical continuous production unit, whose operational cost taking up more than 70% of the total cost of entire process [1]. Under the new normal state, when the market demand shrinks, the way to modify the operation mode of blast furnace to ensure stable and smooth operation when the output is limited becomes extremely critical for the safe operation and cost reduction of blast furnaces. This paper explores the impact of blast furnace output limitation on blast furnace operation and the appropriate solutions.

2 Impact of output limitation on blast furnace performance

Blast furnaces running for normal outputareeasier to achieve high efficiency and low consumption and can accommodate the variation in blast furnace behavior in a better way than those running for a limited output, as the output limitation will affect the blast furnace performance in many aspects.

2.1 Impact on Hearth Activity

Output limitation involves reduction in blast flow and oxygen flow, which will reduce the kinetic energy of blast supply to blast furnace, and hence the permeability at hearth center will be lower, resulting in lower hearth activity [2], consequently the smooth operation of blast furnace becomes worse. Taking a ~5,000m^3 blast furnace as an example, the impact of the decrease in blast flow and oxygen flow upon the kinetic energy of blast supply to blast furnace is calculatedand the result is shown in the chart below.

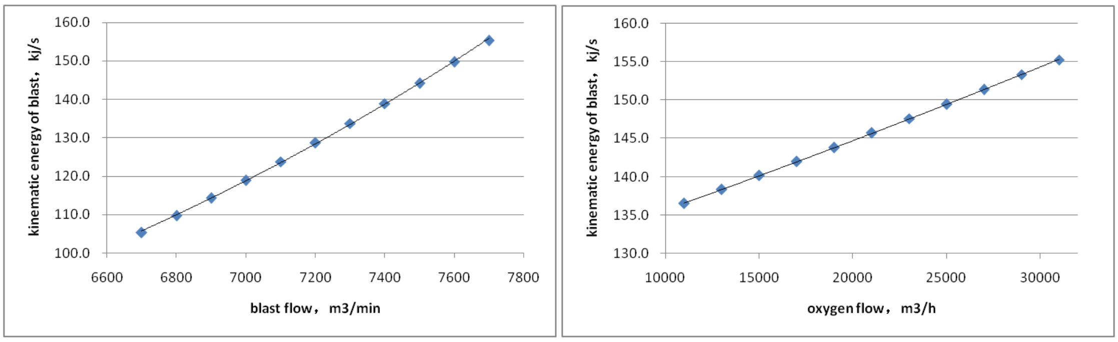

Fig. 1: Impact of blast flow and oxygen flow on kinematic energy of blast supply for a 5,000m^3 BF

Based on the calculation, the kinetic energy of blast supply will be reduced by about 50kJ/s when the blast flow is decreased by 1,000m^3/min, and reduced by about 20kJ/s when the oxygen flow is decreased by 20,000m^3/h.

Fig. 2 is the transition diagram showing the relation between the hearth temperature and the hot metal output for a ~4,000m^3 blast furnace. It can be seen that the furnace hearth temperature is reduced during the two outputs decreases, reflecting the deterioration of hearth activity. Although the second output is gradually recovered, the furnace hearth temperature remains low, reflectingthe hysteresis and complexity of hearth recovery, therefore special attentions are required for hearth activity in case of low output to avoid hearth accumulation.

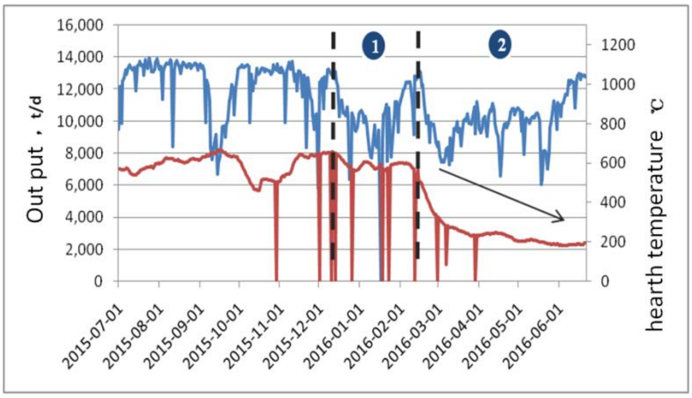

图 2 某 4000 级高炉产量与炉芯温度关系

Fig. 2 Relation between the output and hearth temperature for a 4,000m^3 BF

2.2 Impact on Fuel Consumption

Due to output limitation, the matching potential for blast furnace operation is reduced and adjustment becomes more difficult, consequently the fuel ratio is very likely to increase. In Fig. 3, the fuel ratio and output data of three blast furnaces sized 3,000m^3~ 5,000m^3 are presented, which shows the fuel ratio is inversely proportional to the output, which means low output is unfavorable for fuel ratio control.

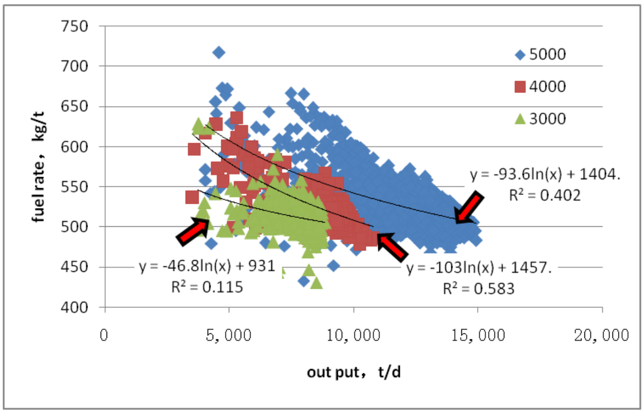

Fig. 3 Output vs. Fuel Ratio for BFs of Various Sizes

2.3 Impact upon Cooling Devices

When the output is reduced, furnace wall accretion is very likely to happen due to the distribution of furnace temperature field, and the tuyere equipment is susceptible to damage due to the decrease in hearth activity. For example, the tuyere noses of a

2,000m^3 blast furnace were damaged frequently during the output limitation period, but significantly improved when the normal output is resumed. [3].

Table 1 Record of Tuyere Damage

Time	Output (t/d)	No. of Damaged Tuyeres
Early Oct. 2008	4393	0
Mid Oct., 2008	3312	4
Late Oct. 2008	3992	2
Early Nov., 2008	3734	12
Mid. Nov, 2008	3443	
Late Nov. 2008	3332	
Early Dec. 2008	3894	4
Mid. Dec. 2008	4615	0
Late Dec. 2008	4695	0

3 Solutions

To address the blast furnace operation problems caused by output limitation, the causesshall be analyzed, andcombinewiththeoretical calculation and experiences, the pointed solutions shall be applied.

3.1 Determination of ReasonableBlastFlow

Blast flow shall be determined based on the output change. In normal conditions, the blast flow can be obtained from empirical blast ratio, however, such empirical figure becomes inappropriate in case of output limitation, therefore, blast flowsappropriatefor different outputscanbe inferred from the relation between historical output and oxygen consumption per ton of hot metal.

Taking the 4,000m^3 blast furnace in Fig. 3 as an example, the required blast volume is calculated. For standardization reason, firstly the oxygen enrichment rate is converted into blast flow, and then the blast consumption per ton of hot metal at different output is calculated as follows:

$$V_{\text{conversion}} = \frac{(V + \frac{O}{0.21}) \times 1440}{P} \qquad （1）$$

Where: $V_{\text{conversion}}$ - converted blast consumption per ton of hot metal (m^3/t);

V- blast flow (m^3/min.)
O- oxygen enrichment rate (m^3/min.)
P- output (t/d)

The relationbetween the converted oxygen consumption per ton of hot metal and the output is shown in Fig. 4, which indicates strong relevance.

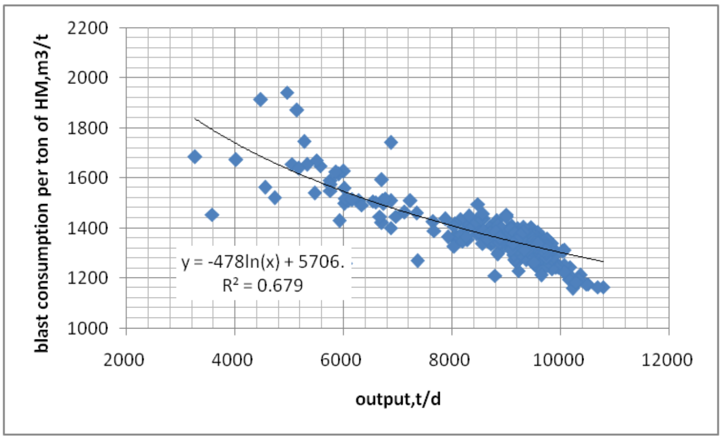

Fig. 4. Relation between the blast consumption per ton of HM and the output for a 4,000m^3 BF

Based on the relevance indicated in the figure above, the blast consumption (without oxygen enrichment) per ton of hot metal at different output of the same blast furnace can be obtained. To calculate the reasonable blast flow for limited output, the output can be used in the regression formula to calculate the corresponding blast consumption per ton of hot metal, and the reasonable blast flow for that output can be obtained by multiplying the output with the blast consumption per ton of hot metal (results are shown in the table below).

Table 2 Output vs. Tuyeres

Output (t/d)	Blast consumption per ton of HM (m^3/t)	ReasonableBlastFlow (m^3/min.)
4,000	1,741	4,837
5,000	1,634	5,676
6,000	1,547	6,448
7,000	1,473	7,165
8,000	1,410	7,834
9,000	1,353	8,461
10,000	1,303	9,051

It should be noted thatfollowingconversion is required in case of oxygen enrichment:

$$V = V_{\text{formula}} - \frac{O}{0.21} \qquad （2）$$

Where V_{formula}representsthe blast flow obtained from the regression formula in Fig. 4, and the other symbols represent the same meaning as those in Formula (1). Selection of appropriate blast flow in accordance with the output will contribute to stable and smooth furnace operation and lower fuel ratio.

3.2 Determination of ReasonableTopPressure

To ensure a reasonable relation between top pressure and blast flow, top pressure must be controlled with respect to the blast flow, especially when the output is limited, to ensure adequate permeability, top pressure shall be selected based on blast flow. The blast flow vs. top pressure chart varies with blast furnaces, but typically it represents a linear relationship. The correlation can be obtained from long-term historical data, and used as a reference for selecting top pressure for various blast flow. Fig. 5 shows the therelation between blast flow and top pressure for a 4,000m^3 BF in Baosteel, and Fig. 6 shows the relation between blast flow and top pressure for the ~4,000m^3 BF mentioned above.

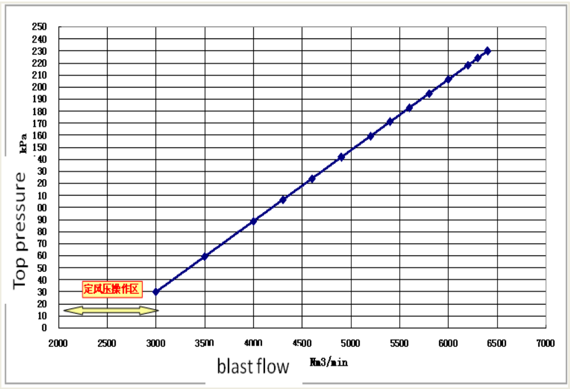

Fig. 5 Top pressure vs. blast flow for a ~4,000m^3 BF in Baosteel

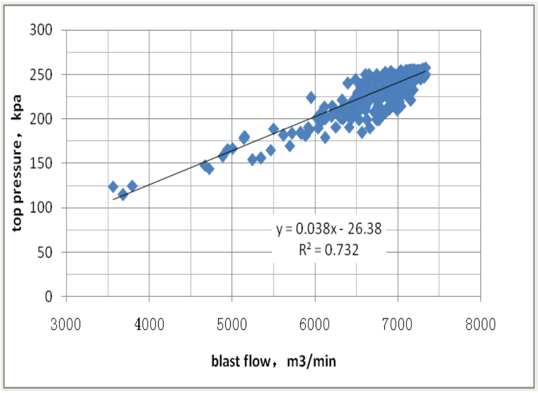

Fig. 6 Top pressure vs. blast flow for a ~4,000m^3 BF mentioned above

3.3 Tuyere Adjustment

Maintainingan adequate kinetic energy of blast supply is an important measure to prevent hearth accumulation, but when the blast furnace output is reduced, the blast flow is limited. As can be seen from Fig. 1, blast flow has significant impact on the kinetic energy of blast supply, therefore, providing that reasonable blast flow is selected, tuyere area shall be properly adjusted and reasonable blast speed shall be maintained to achieve adequate kinetic energy of blast supply.

Still taking the operation data of the ~5,000m^3 BF mentioned in 2.1 as an example, calculations are made to show the relevance betweentuyere area and blast flow in order to achieve the adequate kinetic energy of blast supply. As shown in Table 3, by adjusting the diameter of tuyeres to increase the blast speed, the kinetic energy of blast supply shall almost remain unchanged when the blast flow is reduced. When the blast flow is reduced by 1,000m^3/min, the tuyere diameter is reduced from 130mm to 120mm.

Table 3 Diameter of Tuyeres and Kinetic Energy of Blast Supply

Blast flow (m3/min.)	Tuyere diameter (mm)	Blast speed， (m/s)	blast kinetic energy (kj/s)
7700	130.0	262.5	155.3
7500	127.6	265.7	155.3
7300	125.2	269.2	155.4
7100	122.8	272.5	155.2
6900	120.3	276.3	155.4
6700	117.9	280.2	155.5

3.4 Theoretical Flame Temperature

The theoretical combustion temperature depends on blast temperature, humidity, oxygen enrichment and coal rate, etc. As for the blast temperature, the use of low-quality blast furnace gas instead of high-quality coke is the most effective means to reduce energy consumption of blast furnaces. The energy conversion efficiency of hot stoves is higher 80%, which is the most efficient energy conversion process and also the effective measure to improve the overall energy efficiency of iron and steel system. Therefore, in whatever cases, blast temperature shall be fully used to achieve efficient energy utilization and lower operational cost of blast furnaces.

For blast furnaces with higher oxygen enrichment rate, the oxygen enrichment rate shall also be somewhat reduced in addition to the blast flow reduction as a result of output limitation, which will affect the theoretical flame temperature before tuyeres.While the blast temperature and humidity remain the same, the adjustment to theoretical flame temperature will be achieved by adjusting oxygen enrichment rate and pulverized coal injection rate, therefore, oxygen enrichment rate and pulverized coal injection rate shall be adjusted in combination to avoid possible inadequate hearth heat due to reduction in theoretical flame temperature. Typically, high pulverized coal injection rate requires high oxygen enrichment rate, which will result in further increase in output, so in case of limited output, pulverized coal injection rate and oxygen enrichment rate should be properly controlled.

Fig.7 shows the relation between oxygen enrichment rate and pulverized coal injection rate at different blast flow for a ~5,000m^3 BF in order to keep theoretical flame temperature constant when the blast temperature and humidity remain unchanged. Based on this chart, the reasonable range for oxygen enrichment rate and pulverized coal injection rate control can be developed to maintain a reasonable theoretical flame temperature.

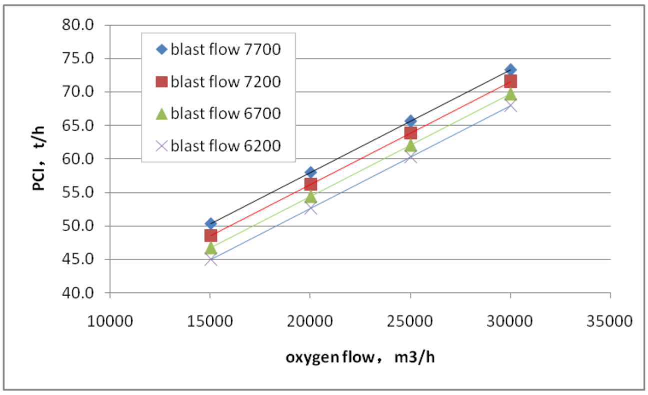

Fig. 7 Oxygen rate vs. PCI rate at different blast flow for a ~5,000m^3 BF

3.5 Tracking of Burden Distribution Pattern Variation

In case of reduced output, as the hearth activity becomes poorer, central gas flow will become impeded. Moreover, adequate gas flow shall be maintainat edge in order to prevent wall accretion. Therefore, the blast furnace distribution pattern shall also be adjusted in case of output limitation to allow adjustment to two gas flows.

However, conventional blast furnace burden distribution pattern recording features discrete statistics of level, angle, number of laps, batch weight and stock line, which makes it difficult to understand the impact of change in burden distribution pattern on BF in an intuitive and accurate way, therefore, new calculation method is required to make allowance for changes in burden distribution factors, serving as a references for quantitative description of the impact caused by change in burden distribution cycle.

A calculation method for quantitative representation of burden distribution pattern information is proposed herein. Firstly, furnace throat is divided into three portions (i.e. edge, platform and center) along the radius, and based on calculation result of burden path [5], the ores and cokes at different gear shall be calculated for different portion, and then coke ratio and ore ratio for each portion shall be calculated as shown below:

$$q=\frac{\dfrac{r'_{\mathrm{ore}}}{\sum r_{\mathrm{ore}}}\times O}{\dfrac{r'_{\mathrm{coke}}}{\sum r_{\mathrm{coke}}}\times C} \qquad （3）$$

Where: q - ore ratio and coke ratio for the portion;

r'_{ore}、r'_{coke}——number of rings for ore and coke distribution in each portion

$\sum r_{ore}$、$\sum r_{coke}$——total number of rings for ore and coke distribution

O——batch weight of ore，t；
C——Batch weight of coke，t。

By optimizing the representation of burden distribution pattern information as described above, discrete information is converted into continuous data, which is good for analyzing the impact of burden distribution pattern on furnace behavior fluctuations. Fig. 8 shows the correlation between burden distribution cycle adjustment and furnace behaviors for a 5,000m^3 blast furnace during output limitation. With formula 3, ore ratio and coke ratio for different portions are calculated, which allows continuous recording of burden distribution cycle information and real-time relevance to furnace behavior parameters. It can be seen that heat load at edge and gastemperatureat center change significantly while the edge gas flow and central gas flow is adjusted.

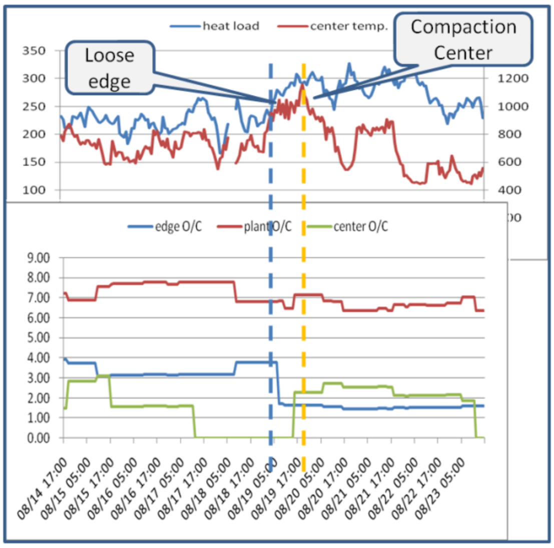

Fig. 8 Analysis of the impact of burden distribution pattern variation on BF behaviors

3.6 Stability of Raw Material Properties

At limited output, the blast furnace's adaptability to furnace behavior fluctuations will decline, which requires good stability of blast furnace burden and significant changes in burden properties[6] must be avoided.Consequently, more efforts shall be made on raw material data monitoring to timely detect the raw material change, and countermeasures shall be taken in advance by tracking the raw material change in blast furnace process to avoid significant variation in blast furnace behavior while the output is reduced.

4 Conclusions

By analyzing the impact of blast furnace output limitation on blast furnace operation under new normal state, solutions for stable and smooth operation of blast furnace through data analysis are discussed ,andfollowing conclusions are reached:

(1) Blast furnace output limitation will cause a series of impacts on blast furnace operation, notably the decrease in hearth activity, increase in fuel ratio and easy damage to cooling equipment.

(2) To address the problems caused by output reduction, calculation method is proposed to determine the appropriate blast flow based on hot metal output, which is good for lowering the fuel consumption. Moreover, by selecting appropriate top pressure based on blast flow, adequate permeability can be guaranteed, contributing to the stable and smooth operation of blast furnace.

(3) To address the problem of furnace hearth inactivity, solutions are proposed from aspect of increasing the kinetic energy of blast supply and stabilizing the theoretical flame temperature, and calculations are made for tuyerearea appropriate for different blast flow, as well as for correlation between oxygen enrichment rate and pulverized coal injection rate at different blast flow.

(4) To allow accurate monitoring of the impact of burden distribution pattern on BF behaviors, method to convertdiscreteburden distribution cycle into continuous parameters is proposed, which is good for studying the law between burden distribution pattern and furnace behaviors, and for finding out the impact of burden distribution cycle change on furnace behaviors.

References

[1] *Theory and Practice of Blast Furnace Ironmaking Process Design* by Xiang Zhongyong and Wang xiaoliu, published by Metallurgical Industry Press, 2007
[2] *Practices for Reducing Smelting Intensity for 2,500m3 BF* by Xiao Guocai, published in Nanjing Steel Technology and Management Journal, 2009, 3: 24-26
[3] *Treatment and Analysis of Output Limitation for 2,000m3 BF* in Nanjing Steel by Yang Mingsheng and Huang Mingfang, published inIronmaking Technology Journal, 2009, 5: 9-12
[4] *Priorities in Huge-BF Operation and Management* by Li Weiguo, published in Ironmaking Journal, 2011,30(3):7.

[5] *Rule of Blast Furnace Burden Distribution* (Version 4) by Liu Yuncai, published by Metallurgical Industry Press, 2012
[6] *Practices in Limiting the output of 2,500m3 BF in Chongqing Steel* by Pu Jun, published in Heibei Metallurgical Journal, 2016, 8: 52-56
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