# Study on the permeability index of COREX melter-gisifer and its influencing factors

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**Abstract:** COREX is the main process of the current smelting reduction method. C-3000 introduced by Baosteel is the biggest production equipment of non-blast-furnace iron making in the world heretofore. However, some problems could often be met in operating practice, such as high coal and coke consumptions, low pre-reduction rate, and poor gas permeability *etc*. In this work, tuyere coke samples were firstly obtained after the screen and magnetic separation of tuyere samples taken out from COREX melter-gasifier. Then, the voidage and pressure difference experiments were undertaken, and the permeability index of tuyere coke in different position was calculated by the modified Ergun equation. Results show that the permeability index is positively correlated with particle size and negatively correlated with pressure difference. Moreover, the mean particle size in active region before tuyere and close to the deadman area is in the range of 10~12 mm and 4~6 mm, respectively. The gas permeability of the former is better than the latter. These findings could provide theoretical basis for improving the stable smooth operation of melter-gasifier, and be helpful for determining the reasonable fuel structures and finally raising production efficiency.

**Keywords:** COREX melter-gasifier, tuyere coke, permeability index, voidage, pressure difference

## 1 Introduction

COREX ironmaking technique is a new process to produce hot metal by directly using lump coals and pellets, which is also the main process of the current smelting reduction method. C-3000 introduced by Baosteel is the biggest production equipment of non-blast-furnace iron making in the world heretofore [1, 2]. However, some problems could be found in operating practice, such as poor coke forming of lump coals in melter-gasifier, high pulverization rates lead to the poor gas permeability and thus influence the heat exchange and thermal stability of hearth and decrease the production efficiency [3-6].

Similar to blast furnace, the gas permeability is one of the most important indexes to measure the stable smooth production of COREX. During the smelting process in melter-gasifier, it could reflect the difficult degree, the fluctuation and change law of gas flowing through furnace burden. The shaft furnace and melter-gasifier are the key devices of COREX [7-8].

Determination of the permeability index is mostly based on the Ergun equation at present. However, the pulverization rate of furnace burden is very high in COREX melter-gasifier [9]. The coke powder would be blown away by high pressure air flow pumped into the measuring device of pressure difference. Moreover, there is still no unified measurement of shape coefficient of burden particle. Therefore, how to determine the permeability index of furnace burden containing powder is worth studying further.

Through the study of tuyere samples in melter-gasifier, the pressure difference and voidage is determined. The mathematical formulation for calculating the permeability index of furnace burden containing powder has been established by the adopted measurement method. Besides, the size composition of tuyere cokes has been analyzed and the influencing factors of gas permeability has also been discussed, which helps to provide theoretical basis for improving the stable smooth operation of melter-gasifier, determining the reasonable fuel structures and finally raising production efficiency.

## 2 Calculation method

Sampling from the radial direction before tuyere in COREX melter-gasifier, coke, semi-coke, formed by lump coals cracking, slag iron, *etc*, could be taken out, which are called tuyere samples. Tuyere samples in 6 different positions from distal to proximal before tuyere are orderly numbered as1#~6#. Firstly, iron, coke and melting slag were separated after natural cooling. Then, the screening of obtained coke (semi-coke) samples were carried out with the different screening size fractions of 16mm, 10mm, 6mm, 2.5mm, 1mm and 0.5mm respectively.

The voidage and pressure difference experiments of coke (semi-coke) samples in different position were undertaken. The voidage, shape coefficient and surface diameter were orderly determined. Then, the permeability index of tuyere samples containing powder in different position could be calculated according to the modified Ergun equation as follows:

$$K = \frac{\rho\omega^2}{\Delta p_{all} / H_{all}} = 9.5(\frac{\varepsilon^3 \varphi d_e}{1-\varepsilon}) \quad (1)$$

Where $\rho$ is the gas density, kg/(m$^3$); $\omega$ is the gas flow velocity, m/s; $\triangle p_{all}$ is the pressure difference of furnace burden, Pa; $H_{all}$ is the total height of determined sample, m; $\varepsilon$ is the voidage; $\varphi$ is the shape coefficient and $d_e$ is the surface diameter, m.

## 3 Results

### 3.1 The voidage of tuyere coke (semi-coke)

The voidage of tuyere coke (semi-coke) could be determined after the separation of tuyere samples taken out from melter-gasifier. Here the determination of tuyere coke voidage in range of grearer than 2.5 mm is taken as an example. Firstly, the tuyere coke with size fraction of d≥2.5 mm was soaked in water for 2 days. Then, drain and compact in a container, $m_1$ was recorded as the weight. Secondly, adding water to the container until tuyere coke was exactly submerged, and $m_2$ was recorded as the weight. Then, the volume of coke particle gaps could be calculated as follows:

$$V_{\mathrm{V}} = \frac{m_2 - m_1}{\rho_{\mathrm{W}}}$$

Where $\rho_{\mathrm{W}}$ is the water density, g/(cm$^3$).

Keep adding water until the container was full of water and $m_3$ was recorded as the weight. Then, the total volume of coke samples could be calculated as follows:

$$V_{\mathrm{T}} = V_{\mathrm{C}} - \frac{m_3 - m_1}{\rho_{\mathrm{W}}}$$

where $V_{\mathrm{T}}$ is the total volume, cm$^3$; and $V_{\mathrm{C}}$ is the container volume, cm$^3$.

Thus, the voidage of tuyere coke could be calculated as follows:

$$\varepsilon = \frac{\mathrm{V_V}}{\mathrm{V_V} + \mathrm{V_T}} \times 100\%$$

Table 1 shows the calculated voidage of tuyere coke in different positions.

Table 1 Voidage of tuyere coke in different position

| Sample No. | 1# | 2# | 3# | 4# | 5# | 6# |
|---|---|---|---|---|---|---|
| Voidage | 0.396 | 0.367 | 0.388 | 0.401 | 0.423 | 0.452 |

**3.2 The shape coefficient and surface diameter of tuyere coke (semi-coke)**

As mentioned before, tuyere samples were separated in 7 different size fractions. The shape coefficient of the ith size fraction is defined as follows:

$$\phi_i = \phi_0 + (7 - i)h$$

Where $\phi_0$ is the shape coefficient of the 1st size fraction and h is the gradient of shape coefficient between two sizes.

The surface diameter of tuyere coke could be calculated as follows:

$$d_e = 1 \Big/ \sum_{i=1}^{n} \left(\frac{x_i \varphi_i}{d_i}\right)$$

Where $x_i$ is the weight percent covered by the $i$th coke sample in all the coke samples.

The shape coefficient and surface diameter of coke samples is shown in Table 2.

**Table 2** Shape coefficient and surface diameter of coke samples in different positions

| Sample No. | 1# | 2# | 3# | 4# | 5# | 6# |
|---|---|---|---|---|---|---|
| Shape coefficient | 0.860 | 0.862 | 0.859 | 0.840 | 0.800 | 0.799 |
| Surface diameter mm | 8.41 | 8.06 | 8.29 | 10.98 | 14.60 | 15.04 |

**3.3 The permeability index of tuyere coke (semi-coke)**

Figure 1 shows the permeability index of tuyere coke (semi-coke) in different position calculated by formula 1.

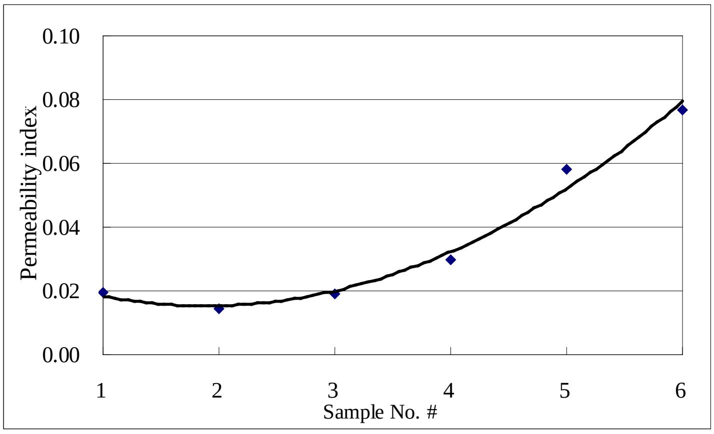


**Fig. 1** Permeability index of different tuyere coke samples

It can be seen that the permeability index is gradually downtrend with the distance increased from tuyere. The mean value of 5# and 6# permeability index is about 0.07, which is 2 times higher than that of 1#~4# as 0.02. It shows that 5# and 6# is located in tuyere raceway, while the other 4 samples are near the central area of furnace, of which gas permeability is relatively poor.

**4 Discussion**

**4.1 The influence of particle size on permeability index**

The permeability index data of different particle sizes in different positions are shown in Figure 2. It can be seen that the permeability index values of tuyere cokes in melter-gasifier are less than blast furnace in general. As non-coking coals are used in COREX melter-gasifier instead of cokes, semi-coke cracked by lump coals supports the packed bed, which is similar with that of cokes in blast furnace. Although the semi-coke has a certain mechanical strength, its thermal resistance, chemical and mechanical functions are considerably less than those of cokes. Therefore, the semi-coke strength decreases rapidly with the processing of coke solution loss reaction and temperature increasing. Most or even all of the semi-coke would be crushed to powder when it drops to the hearth. Thus, the gas permeability would be worse and worse, which is inferior to that of material bed supported by high quality coke in blast furnace. It is very difficult to insure the gas permeability and slag iron separation only by semi-coke. So a certain proportion of cokes must be used in COREX melter-gasifier.



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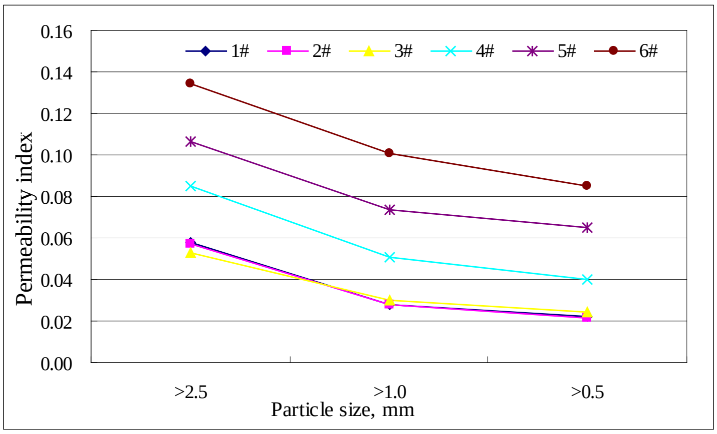


**Fig. 2** Permeability index of different particle sizes

Figure 3 shows the ratio of different granularity coke (semi-coke) in different position of tuyere samples in melter-gasifier.

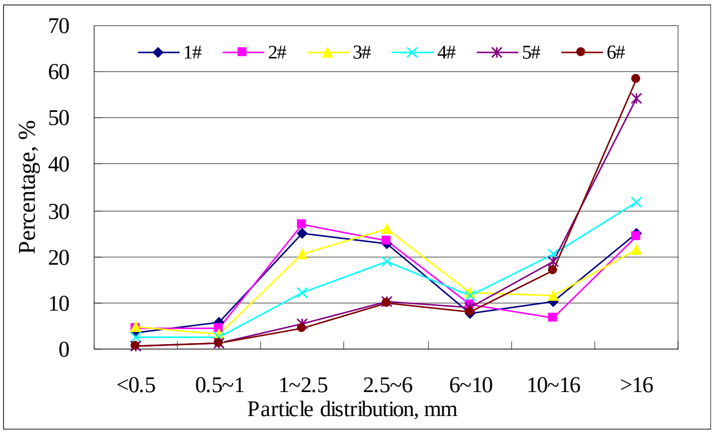


**Fig. 3** Coke (semi-coke) particle size distribution of tuyere samples

It can be seen that the mean particle size of coke (semi-coke) is gradually downtrend with the distance increased from tuyere. The mean particle size in tuyere raceway and near deadman area is 10~12 mm and 4~6 mm respectively. The pulverization rates in range of <6mm even reach 55 %. It shows that the charging cokes and semi-cokes cracked by lump coals have been squeezed and crushed, which leads to the severe pulverization. Moreover, pure oxygen blast has been adopted in melter-gasifier and a tuyere raceway similar with blast furnace would be formed in a certain depth. Therefore, a great amount of small coke (semi-coke) particles would accumulate in edge region of deadman, which would doubtlessly leads to the poor gas permeability and heat exchange ability.

On the other hand, Figure 2 indicates that between the same samples, the larger the meat particle size, the better the gas permeability. Between the same particle size, the closer the sample position near the tuyere raceway, 5# and 6# for example, the bigger the permeability index. Compared with Figure 1 and Figure 3, it can be seen that the gas permeability of 5# and 6# is better than that of 1#~4#, and the mean particle size of the


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former is also larger than the latter. Thus, the permeability index is positively correlated with particle size. The gas permeability of tuyere raceway is better than that of deadman area.

**4.2 The influence of pressure difference on permeability index**

Pressure difference could characterize the burden column resistance, namely the head loss when the gas flows through burden, which reflects the gas permeability changing in melter-gasifier. COREX C-3000 in Baosteel operates occasionally with kinds of blocks. Thus, determining the range of pressure difference under different blowing oxygen quantity is one of the means to search for the proper oxygen quantity in the case of recovering the charge hanging and other furnace condition disorder.

A device for the measurement of the coke (semi-coke) pressure difference has been developed as shown in Figure 4. The empty tube is 80mm in diameter and 700mm high. The pore size of sieve plate is 0.5mm. Gas pressure in experiments is 0.2MPa and flow rate is 0.1$m^3$/min. The experiments are performed under room temperature and with gas velocity of empty tower is 0.34m/s[10].

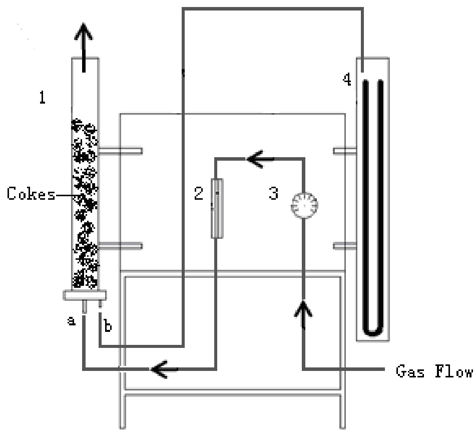


**Fig. 4** The schematic diagrm of measuring device for the coke pressure device

Table 3 shows the pressure difference and permeability index data of tuyere samples in different positions.

**Table 3** The pressure difference and permeability index of tuyere samples in different positions

| Sample No. | 1# | 2# | 3# | 4# | 5# | 6# |
|---|---|---|---|---|---|---|
| $\Delta P$ $mmH_2O$ | 13.663 | 17.424 | 15.845 | 10.472 | 3.219 | 1.067 |
| Permeability index | 0.019 | 0.014 | 0.019 | 0.030 | 0.058 | 0.077 |

It can be seen that the permeability index would decrease with increasing of pressure difference. Along with the distance increased from tuyere, the pressure difference firstly decreases, then increases and finally decreases again, which could reflect the gas distribution along the radial direction in a certain degree. Combined with the frontal particle size analysis, it can be concluded that 1#~4# samples have a small mean particle size, a large pulverization rate and weak central gas flow. Therefore, the gas permeability is poor and the permeability index is negatively correlated with pressure difference



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## 5 Conclusions

(1) Composition of tuyere samples in melter-gasifier is complicated and the pulverization rate is high. The mathematical formulation of calculating the permeability index of furnace burden containing powder has been established on the basis of Ergun equation.

(2) The thermal resistance, chemical and mechanical functions of semi-cokes cracked by lump coals in melter-gasifier are considerably less than that of cokes in BF. Moreover, pulverization of semi-coke is severe in lower part of hearth, and the fraction of cokes less than 6mm could increase to 55% in front of the tuyere, which leads to a poor gas permeability and heat exchange ability. Therefore, a certain proportion of cokes must be used in COREX melter-gasifier to maintain the reasonable fuel structures.

(3) The experimental results show that the mean particle size in active region in front of tuyere and close to the central area is 10~12 mm and 4~6 mm, respectively. The permeability index is positively correlated with particle size, and the gas permeability of tuyere raceway is better than that of central area.

(4) Through the study on the pressure difference distribution of gas flow in melter gasifer, it is found that the permeability index is negatively correlated with pressure difference. The particle size and pressure difference fluctuation provide theoretical basis for improving the stable smooth operation of melter-gasifier, as well as for determining the reasonable fuel structures and finally raising production efficiency

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## References

[1] H M W. Delport. The COREX process [C]. Second European Ironmaking Congress, Glasgow, 1991: 289-302.

[2] A. Eberle, D. Siuka, C. Bohm, W. Schiffer. Developments in Corex technology [J]. Steel World, 2002, 7: 28-32.

[3] P. Parchethan Kumar, S. C. Barman, B. M. Reddy and V. R. Sekhar. Raw materials for Corex and their influence on furnace performance [J]. Ironmaking and Steelmaking, 2009, 36(2): 87-90.

[4] L. Weiguo. Operation status quo and technical problems of COREX-3000 [J]. Baosteel Technology, 2008, 6:11-18.

[5] G. Yanling, X. Wanren, L. Zhanyi. Research on characteristics of the coal and coke mixed stock column in the Corex melter-gasifier [J]. Baosteel Technology, 2010, 5: 24-27.



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[6] P. Prachethan Kumar, P K. Gupta, M. Ranjan. Operating experiences with Corex and blast furnace at JSW steel Ltd [J]. Ironmaking and Steelmaking, 2008, 35(4): 260.

[7] S C Barman, K P Mrunmaya, M Ranjan. Mathematical model development of raceway parameters and their effects on Corex process [J]. Journal of Iron and Steel Research International, 2011, 18(5):20-24.

[8] S Pal, A K Lahiri. Mathematical model of Corex melter-gasifier: Part II Dynamic Model [J]. Metallurgical and Materials Transactions, 2003, 34B (1):115.

[9] Z. Zongshu. A brief consideration about PCI of COREX melger-gasifier [J]. Baosteel Technical Research, 2010, S1: 15.

[10] Z. Weichun, Z. Xuesong. Using the results of tuyere coke sampling to guide blast furnace operation, Research on Iron and Steel, 2009, 37(2): 13-16.