Technology and development of nickel pig iron blast furnace

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Abstract: The paper analyzes the difference between lateritic nickel ore BF smelting technology and conventional iron ore BF smelting technology from the point of sintering process, slagging system, operation system, furnace profile and product application, etc. Besides, it shows the development mode of co-existence between lateritic nickel ore BF process and other nickel ore smelting processes, and the development trend of smelting technologies, such as sinter quality improvement, BF enlargement, high coal injection technology, long campaign of BF hearth, high Ni and low Fe lateritic ore smelting technology, as well as energy saving and environmental protection technologies.

Key words: lateritic nickel ore, BF, operation system, furnace profile design

1 Lateritic nickel ore and origin of BF smelting process

Lateritic nickel ore has attracted more and more attention along with increasing depletion of nickel sulfide ore resources. Lateritic nickel ore deposit can be divided into three layers: 1) the upper layer of deposit is called limonite type lateritic ore with high Fe content, in which nickel and limonite co-exist; 2) the lower layer of deposit is called garnierite type lateritic ore, in which silicate is enriched, and nickel and silicate co-exist to form garnierite; 3) the deposit between limonite and garnierite is called transition type lateritic nickel ore. Classification and composition of the three types of lateritic nickel ore are shown in Table 1[1].

<table>
<thead>
<tr>
<th>Type</th>
<th>Ni</th>
<th>Co</th>
<th>Fe</th>
<th>MgO</th>
<th>SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limonite type</td>
<td>0.8~1.5</td>
<td>0.1~0.2</td>
<td>40~50</td>
<td>0.5~5.0</td>
<td>10~30</td>
</tr>
<tr>
<td>Transition type</td>
<td>1.5~2.0</td>
<td>0.02~0.1</td>
<td>25~40</td>
<td>5~15</td>
<td>10~30</td>
</tr>
<tr>
<td>Garnierite type</td>
<td>1.5~3.0</td>
<td>0.02~0.1</td>
<td>10~25</td>
<td>15~35</td>
<td>30~50</td>
</tr>
</tbody>
</table>

In the severe situation of increasingly scarce nickel sulfide ore resources, private enterprise in China has developed lateritic nickel ore BF smelting process through innovation, opening a new road for our nickel
industry. It proves that lateritic nickel ore can be smelted through BF, and provides the technical solution [2].

In recent years, lateritic nickel ore BF process technology has developed rapidly, and BF volume has been expanded from dozens of cubic meters to 580m³. Besides, raw material adopted by more and more iron & steel plants has been changed from pure nickel into nickel pig iron (NPI). Nickel industry has entered a new stage of development in China.

### 2 Process technologies different from conventional iron ore BF

Lateritic nickel ore, a composite type of low grade iron ore, is different from iron-enriched ore. Thus, lateritic nickel ore BF smelting process has the following technical characteristics different from that of conventional iron ore BF smelting process.

#### 2.1 Sintering process of lateritic nickel ore

Water in the surface of lateritic nickel ore is as high as 20%, and crystal water content is usually about 15%. This type of ore with high water content cannot be directly used for sintering. Thus, most enterprises have adopted burned lime mixing method to remove water, because moisture absorption and heat emission of lime can be used for the purpose of dewatering. Generally, 5~10 days shall be taken for dewatering through burned lime. Dewatering time shall not be too short, because short dewatering time will terribly influence sinter quality. Some NPI manufacturers have used drying kiln for drying before adding burned lime for mixing, so that surface of lateritic nickel ore can be dewatered to 8%~10%.

In my study, burned lime for dewatering is directly used in one 180m³ BF. Lateritic nickel ore shall enter the site ahead of 15 days, purity of burned lime shall be more than 90%, and dewatering time through burned lime mixing shall not lower than 10 days so that surface of lateritic nickel ore can be dewatered to about 5%. This is the dewatering solution recommended by me. Burned lime added earlier can also be used as slagging raw material of BF process.

Generally, powder less than 8mm is sintered by sintering machine. Ore of big particle size can be broken before being sintered, or be sent to BF directly for NPI smelting. During sintering, powder less than 8mm can be bound, and water and crystal water in raw material surface can be removed. Besides, sinter basicity can be adjusted as required during sintering so as to meet BF slagging requirements [4].

#### 2.2 Rational slagging system
The purpose of BF slagging is to obtain slag with proper melting point and viscosity. Generally, slag from conventional iron ore BF mainly consists of CaO-SiO₂ phase, and flux is added to control MgO and Al₂O₃ content in the slag. The four main components (CaO, SiO₂, MgO and Al₂O₃) in the slag accounts for more than 95% of the total slag, including 5 ~10% of MgO, and Al₂O₃<15%. Binary basicity CaO/SiO₂ of BF slag is 1.0 ~1.2[5].

Zhang Bo and other people have studied influence of different CaO content on low-melting-point area in CaO-Al₂O₃-SiO₂-MgO system phase diagram. Fig. 1 shows the relation between percentage of low-melting-point area in phase diagram and CaO content. It can be seen from the diagram that percentage of low-melting-point area in CaO-SiO₂-Al₂O₃-MgO system phase diagram is increased remarkably (like linear increase) along with increase of CaO content from 0 to 45%.

Zhang Bo and other people have also studied influence of different MgO content on low-melting-point area in CaO-Al₂O₃-SiO₂-MgO system phase diagram. Fig. 2 shows projections of CaO-Al₂O₃-SiO₂-MgO system liquidus in case of 5% and 10% MgO. Fig.3 shows the relation between percentage of low-melting-point area in phase diagram and MgO content.
Fig. 2 Projections of CaO-Al₂O₃-SiO₂-MgO system liquidus in case of different MgO content

(a) MgO=5%; (b) MgO=10%

Fig. 3 Relation between percentage of low-melting-point area in phase diagram and MgO content

It can be seen from Fig. 2 and Fig. 3 that low-melting-point area is increased remarkably along with increase of MgO content within 15%. In case of 15% MgO, low-melting-point area maximizes. Then, along with continuous increase of MgO content, low-melting-point area is reduced slightly. After MgO content exceeds 25%, low-melting-point area is decreased rapidly\(^6\).

Due to particularity of lateritic nickel ore, slagging system of conventional iron ore BF cannot be used for it. For example, if slagging system of conventional iron ore BF is used for garnierite lateritic ore with high MgO content, a large amount of slagging raw materials has to be added, causing a large amount of slag and increase of energy consumption. Thus, slagging system of lateritic nickel ore BF shall be rationally
established based on ore components.

The study in reference [7] shows that slag has good flowability in case that slag basicity is 0.85～1.15. Slagging system specified in reference [8] is that slag basicity is 0.6～0.8, and MgO content is 15 ~ 35%.

For the 180m³ lateritic nickel ore BF in my study, the slag basicity CaO/SiO₂ is controlled to be more than 0.55, and good application effect is achieved. Thus, rational slagging system can effectively reduce lateritic nickel ore smelting cost. Study of lateritic nickel ore BF slagging system shall be improved through continuous theoretical and practical trial.

2.3 Rational operation system

Slag height of conventional iron ore BF approximates to hot metal height, but lateritic nickel ore BF slag is much more than conventional iron ore BF slag. Height of slag in hearth is 5~6 times of liquid ferronickel height[8]. Wide adhesive zone of lateritic nickel ore and large amount of slag will cause poor permeability of BF, and influence smooth BF operation.

In order to ensure smooth operation of lateritic nickel ore BF, operation shall be featured with dominant central flow, proper edge flow and appropriate hot air flow. Proper increase of coke ratio and center coke charging measure are taken in case of poor BF permeability.

Over-thick slag layer will cause poor permeability. Thus, the upper liquid hot metal is difficult to permeate slag layer to reach lower part of the hearth, which will influence slag and hot metal separation. Due to thick slag layer, temperature of hot metal at the lower part is low. Finally, liquid ferronickel is hard to flow out. For small BF, poor flowability problem of hot metal is relatively not obvious due to small hearth. However, poor flowability problem of hot metal from large BF is obvious, which will affect tapping.

In order to solve this problem, hot air flow and theoretical combustion temperature at tuyere can be increased so that burden at upper part of BF can get more physical heat when passing through the tuyere. For BF designed with slag taphole, slag tapping frequency can be increased to keep slag layer in hearth at a proper thickness. Thus, hearth permeability can be improved effectively for the purpose of hot metal temperature rise at the lower part. In the 180m³ lateritic nickel ore BF in my study, slag tapping takes about 6 hours in a shift (8h), and the BF is operated smoothly.

In order to ensure long-term effective smooth operation of lateritic nickel ore BF, sinter quality shall also
be improved.

2.4 BF profile design

At present, outdated small iron ore BFs have been reused for most lateritic nickel ore BFs in China, and their functions can basically meet lateritic nickel ore smelting requirements. However, due to poor permeability of lateritic nickel ore, rational inner profile is key to ensure effective smooth operation of BF.

For new lateritic nickel ore BF, the inner profile shall be designed based on the following features:

(1) Volume of lateritic nickel ore BF shall not be too big. For nickel ore containing much Ni and less Fe, more attention is paid to BF of small volume. The lateritic nickel ore BF (80m³) in my study can produce NPI with Ni content more than 9.5%.

(2) Due to raw material of low grade and a large amount of slag, hearth enlargement of lateritic nickel ore BF shall be considered during design of inner profile. The detail shall be determined based on components of raw material.

(3) Due to adhesive zone located slightly at the top, wide adhesive zone and poor permeability of lateritic nickel ore, BF profile shall be dumpy, i.e. BF effective height shall not be too big.

(4) Whether lateritic nickel ore BF is designed with slag taphole shall be determined based on ore grade. For limonite type lateritic ore with high Fe content, slag taphole is not necessary for BF. For garnierite type lateritic ore with low Fe content, BF shall be designed with slag taphole.

2.5 Application of NPI products from BF

Although Ni, Cr and Fe in NPI are important components for smelting of stainless steel, instability of lateritic nickel ore component leads to instability of NPI product component. Especially, fluctuation of Ni content will get composition adjustment of stainless steel into trouble, and objectively hinder BF NPI product application. Thus, most BF NPI products are used as raw materials for production of low-end stainless steel at present.

3 Development trend of lateritic nickel ore BF process

3.1 Development mode of co-existence between BF process and other nickel ore smelting processes

In earlier years, metallurgists predicted that NPI smelting through BF process was a technology about to
be eliminated. But in recent years, China has overcome the technical problem of NPI production through small lateritic nickel ore BF, and enlarged the BF volume to increase BF heat utilization and production efficiency. Thus, it has promoted technical innovation and brought change to stainless steel industry in the world. However, NPI smelting technology through BF is on the early rise stage, and there is still a long way to go. In the long time following, it will be the development mode of co-existence between BF process and other nickel ore smelting processes.

3.2 Improvement of sinter quality

Sinter quality has enormous influence on operation of lateritic nickel ore BF. Due to particularity and treatment technical problem of lateritic nickel ore, the sinter strength is often lower than ordinary sinter strength. Low rate of finished products, easy powdering and softening are the fundamental reasons for poor permeability of lateritic nickel ore BF. If sinter quality of lateritic nickel ore can be improved fundamentally to meet BF smelting requirements, lateritic nickel ore BF process will make great progress.

In one Chinese 530m³ lateritic nickel ore BF in my study, sinter finished product rate is 70% under the condition that drying and dewatering technology is used for lateritic nickel ore. But in similar BFs, almost the same lateritic nickel ore is used as raw material, and sinter finished product rate is just 50% without drying technology.

In one 180m³ lateritic nickel ore BF in my study, BF productivity is 2 times of the original productivity after such measures as obvious improvement of lateritic ore sintering quality and adjustment of operation system are taken.

3.3 BF enlargement

Along with BF enlargement, heat utilization and production efficiency are increased. Thus, enlargement of lateritic nickel ore BF will be the direction for development. Of course, this has close relation with components of lateritic nickel ore. For lateritic nickel ore with high Fe content, BF enlargement is much easier. At present, through joint efforts made by private enterprise and ironmaking workers, max. volume of lateritic nickel ore BF has reached 580m³, which is designed by WISDRI. It is justified to believe that volume of lateritic nickel ore BF will be further enlarged along with technological updating.

3.4 High coal injection technology
At present, lateritic nickel ore BF process is featured with high coke ratio and small coal injection, and all-coke smelting is used for some BFs. If high coal injection technology is used to reduce coke consumption through technical innovation, smelting cost of lateritic nickel ore BF can be reduced effectively. But in order to reduce coke ratio and increase coal ratio, the following problems must be solved. Due to adhesive zone of lateritic nickel ore located slightly at the top, wide adhesive zone and poor permeability, reduction of coke ratio will make permeability of burden worse at upper part of BF. In case of increasing coal injection to BF, hot air flow passing through adhesive zone from tuyere shall also be increased. Besides, this has higher requirements on BF permeability. Thus, high coal injection and coke ratio reduction technology breakthrough of lateritic nickel ore BF are to be made by joint efforts of metallurgists\(^8\).

3.5 Long campaign of BF hearth

After hearth water cooling technology appears, BF life mainly depends on hearth. During lateritic nickel ore BF smelting, furnace cleaning materials are added sometimes to improve slag and hot metal flowability due to high temperature of tuyere area. This will accelerate damage of hearth refractories so as to shorten hearth life. Thus, the key of long campaign of lateritic nickel ore BF is to develop appropriate refractories and strength hearth cooling.

3.6 High-Ni low-Fe lateritic ore smelting technology

Ni and Fe co-existing in lateritic nickel ore are featured with low Fe content in case of high Ni content. In the current smelting technology, Fe content of lateritic nickel ore is usually controlled within 19%～49%, and Ni content in NPI product is low. Ni is much more valuable than Fe. If high Ni and low Fe lateritic ore can be effectively used in BF to produce NPI containing more Ni through technical innovation, economic value of Ni will be much higher. This is the direction worthy of studying by metallurgists.

3.7 Energy saving and environmental protection technology

Calorific value of gas and gas consumption per ton of hot metal in lateritic nickel ore BF is much higher than those in conventional iron ore BF\(^8\). Thus, comprehensive utilization of BF gas is the key to energy saving and environmental protection technology of lateritic nickel ore BF. Waste pressure of BF gas can be used to drive BPRT to operate. Heat from gas combustion can be used for heating of hot stove and lateritic nickel ore sintering, and excess gas can be used for power generation. Fume from heating of hot stove can be used for pulverized coal drying.
In case of comprehensive utilization of BF gas, specific net energy consumption by lateritic nickel ore BF will be lower than 900kg standard coal/10,000 yuan, far lower than 1,680kg standard coal/10,000 yuan\[^8\]. From this point of view, lateritic nickel ore BF process itself is an effective energy conservation technology, and its development should be encouraged.

Sensible heat recovery of BF slag, a hot topic, has been studying by many universities and scientific research institutions. This is also a research direction of energy saving and environmental protection technology of lateritic nickel ore BF.

Metal smelting industry is featured with high energy consumption and heavy pollution. It is the key field governed by environmental policy in China. Along with the steady progress of energy saving and environmental protection work in China, the economic value is also promoted continuously. Energy saving and environmental protection technology of lateritic nickel ore BF is also enjoying the opportunity for development. After advanced technologies, such as BF enlargement, are implemented, smelting ecosphere of lateritic nickel ore BF will be built step by step.

4 Conclusion

Lateritic nickel ore BF smelting process developed through innovation has opened a new road for our nickel industry. It has proved that lateritic nickel ore can be smelted through BF process. From the view of energy consumption per 10,000 yuan, lateritic nickel ore BF smelting process itself is an effective energy saving technology, and its development should be encouraged. During a long time in the future, it will be the development mode of co-existence between BF process and other nickel ore smelting processes. Lateritic nickel ore BF process will be developed from sinter quality improvement, BF enlargement, high coal injection technology, long campaign technology of BF hearth, high Ni and low Fe lateritic ore smelting technology, energy saving and environmental protection, etc.

5 References


