HIGH-TECHNOLOGY PROCESS OF REDUCTION MELTING FOR STEEL PRODUCTION

Yernar KIYEKBAYEV a, Suleiman TLEUGABULOV b

a Karagandy state industrial university, 30 Republic st., 101400 Temirtau, Kazakhstan, yernar-kiyek@mail.ru

b Kazak National Technical University named after K.I. Satbayev, 22 Satbayev st., 050013 Almaty, Kazakhstan, suleiman_70@mail.ru

Abstract

In the work presented analysis of existing two-stage processes of steelmaking and new processes of metals’ carbothermic reduction. The first stage of traditional metallurgical complex includes reduction or reduction-melting process (blast-furnace process), the second stage is realized by oxidative melting (basic oxygen, open-hearth and arc furnaces) of metalized or carbonized semi-products. Continuous reduction-melting in the traditional metallurgy is presented by blast-furnace process. But despite of high efficiency of heat and mass exchange in the blast furnace the finished product of the process is hot-metal (cast iron, pig metal).

Realization one-stage reduction-melting process for steelmaking is possible by working out of new theoretical statements which flow out from dissociation-adsorption mechanism of metals’ reduction presented by Tleugabulov S.M. (co-author of present article). Presented new mechanism of metal’s solid-phase reduction by carbon and authors’ theoretical statements are based for working out of steel’s reduction melting technology. Technology and control conditions of steel’s reduction melting are worked out that conducts to high and continuous technology from ore up to steel.

Alternative technology differs from blast-furnace process by excluding of coke filling in the charge column. Charge composition previously is prepared for steel production. The heat and mass exchange efficiency remains like in the blast furnace. The method realization is reach by special feeder design and modified shape of furnace, especially in the melting area where the main source of heat is energy of fuel combustion.

1. REVIEW, BOTTLENECKS, SOLUTION OPTIONS

Coke deficiency in the world caused of necessity of working out and creation of new direction in metallurgy – non-coke metallurgy. Only two processes – Midrex [1] and Hyl [2] are industrially wide spread from the large quantity of new methods of non-coke metallurgy. The creation of new processes didn’t eliminate of two-stage metallurgical process from ore up to steel.

The theoretical statements of organization of continuous process are already schematically described in [3]. The solutions of problems can be found on the base of new dissociation-adsorption theory [4] and can be based for organization of high technology [5].

The heat- and mass-exchange perfection between the gas flow and charge mixture at vertical stack, the continuity of charge smelting till metal and slag melts in the blast-furnace are the prototype of high technology. But the disadvantage of blast-furnace process is limited only by cast iron (hot metal) production that is result of organization of blast furnace process.

Loaded to the furnace charge mixture is oriented for hot metal production and consists of ore part (agglomerate, pellets) and coke which spread by horizontal layers at furnace section and is irregular. At furnace radius forms 3 vertical areas of charge mixture stack – periphery, intermediate and central parts with ore ratio 2.0-2.2; 4.5-6.0; 1.5-4.8 respectively [6].
In the practice happens that central part had much more ore content and this brings to process breakage and furnace cooling. Exactly in this case the central part is called “Totermann” as negative event in the blast furnace process.

Intermediate part with high ore content doesn’t form “Totermann” because hot reduction gas (HRG) is going through it and this part descends with high speed because it is arranged above tuyere area. Hence “Totermann” effect transforms to active “Lebendermann” effect under the reasons of 2 factors – 1) heat application and 2) proper descend speed to the melting area. For transformation this effect to metal (steel) production with specified chemistry it is necessary 3rd factor – assign the ore proportion in the charge mixture. Additionally the 4th correction factor for transformation of “Totermann” to high technology area it is necessary to remove the coke layer on the descend way. In the practice it can be realized by rearrangement of charge mixture spreading from horizontal spreading to vertical so it will be possible to create high vertical “Totermann” column that is surrounded by coke layer (porous) and through it permanently flows HRG and maintains heat supply.

Horizontal movement of coke layer excludes by proper spreading of charge mixture and coke [7]. “Totermann” charge column pressure at horizontal section in the bottom is 5-6 times more then in the coke column. Metal reduction occurs not only by solid carbon, but by CO gas so it is necessary to take it into account its share in the gasification of charge mixture oxygen. In the reduction process participates gas that passes through “Totermann” porous area. For evaluation of actual quantity of gas that passes trough porous layer can be used known equation [8]:

\[ Dp = \lambda \cdot \frac{g_2 \cdot \omega_0^2}{2 \cdot g \cdot d_n \cdot \varepsilon^2} \]

where \( \Delta p \) – resistance of charge layer (pressure difference Pa/m);
\( \lambda \) – total factor of resistance;
\( \gamma, \omega_0 \) – specific mass \((\text{kg/m}^3)\) and gas speed \((\text{m/s})\) respectively.
\( d_n, \varepsilon \) – dia of canals in the layer \((\text{m})\) and fractional void volume of charge layer \((\text{dimensionless quantity})\).

Further taking into account the fluid dynamics parameter of charge mixture stack it is possible to evaluate the specific gas consumption for 1 MT of ore part for “Totermann” process according with equation:

\[ u_g = \frac{3600 \cdot \omega_0 \cdot F \cdot R \cdot Fe, [Fe]}{P \cdot \text{[Fe]}}, \text{m}^3/\text{h} \]

where \( R \) – maximal degree of iron reduction \((R\approx 0.99)\);
\( \text{Fe, [Fe]} \) – iron content in the ore of charge and in the smelted metal, %;
\( P \) – productivity of smelting area for metal production, MT/h.

This gas quantity with CO content is gasifying following oxygen quantity of charge mixture:

\[ O_{(g)} = 0.714 \cdot 10^{-2} \cdot \text{CO} \cdot u_g \cdot \eta_{CO} \]

where \( \eta_{CO} \) – degree of \text{CO}≈0.4 gas usage.

Total quantity of gasified oxygen of charge mixture can be evaluated depending from mixture composition by equation:
\[ \text{O}_{\text{cm}}=0.4285 \times 10^{-2} (\text{Fe}-0.259 \times \text{FeO}) \times \text{P}, \text{ kg/kg of charge mixture} \]

Hence for solid carbon quantity leaves following quantity of gasifying oxygen of mixture:

\[ \text{O}_{\text{(C)}}=\text{R}(\text{O}_{\text{cm}}-\text{O}_g), \text{ kg} \]

For this oxygen quantity must be added stoichiometry quantity of carbon as coke fines or coal.

On the fig. 1 are presented the variation of iron reduction degree according with sequential phase transformation. Taking into account this mechanism there are conducted experiments and obtained the results of iron ore materials reduction by solid carbon with following smelting of reduced materials. In the laboratory experiments used iron ore concentrates: hematite, magnetite with FeO content 10 and 18 %, as well carbon containing pellets produced from the same concentrates. As carbon containing component have been used charcoal with carbon content 95%. Results of reduction and smelting are presented in the table 1. Presented in the table first rows of metal chemistry the points 4, 5, 6 are corresponded strictly to stoichiometric carbon quantity for charge mixture oxygen gasification. Second rows of metal's chemistry are corresponded premeditated assigned of carbon’s abundant coefficient above stoichiometry in the limits \( K_{\text{abund}} = 1.04 - 1.06 \). As can be seen added abundant carbon quantity directly influenced at carbon content in the metal and increased till 0.8 - 1.25%.

### Table 1. The chemistry of metals obtained by reduction melting of iron ore concentrates

<table>
<thead>
<tr>
<th>#</th>
<th>Material description</th>
<th>The chemistry of smelted metal samples, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[C]</td>
</tr>
<tr>
<td>1</td>
<td>Hematite concentrate + charcoal</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.26</td>
</tr>
<tr>
<td>2</td>
<td>Magnetite concentrate with FeO=10% + charcoal</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td>3</td>
<td>Magnetite concentrate with FeO=18% + charcoal</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.88</td>
</tr>
<tr>
<td>4</td>
<td>Carbon containing pallets (hematite)</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.86</td>
</tr>
<tr>
<td>5</td>
<td>Carbon containing pallets (magnetite FeO=10%)</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.22</td>
</tr>
<tr>
<td>6</td>
<td>Carbon containing pallets, FeO=18%</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.09</td>
</tr>
</tbody>
</table>

In the vertical shaft reduction-smelting furnace according with fig. 2 the part of gas reduction can be at \( \Delta R_j = 0.2 - 0.3 \) level. The degree of direct metal’s reduction by carbon can reach \( R_a = 0.7 - 0.8 \), without breakage of procedures and runs of reduction-melting process. Degree of direct reduction in the considering technology has another idea then in traditional blast furnace process. Published new theoretical statements [4] and proposed technology take into account factual carbon workability and open up new opportunities of reaction potential and carbon workability compare with gases. In multi century practice of metallurgy favorable conditions for usage of potential and workability of HRG were created, but ignoring the carbon role.
For effective usage of carbon potential and workability there are special conditions that are described in the works \[7, 8, 9\]. Now is the time to focus our efforts for providing such conditions for achieving effective carbon working when carbon reacts with metal oxides with generation of \( \text{CO}_2 \) and \( \text{CO} \). This is the key issue for practical providing such conditions – creation of “Totermann” in high vertical shaft furnace. At the same time HRG flow can not be refused because it is the main heat-transfer and subsidiary reducer of “Totermann”.

Heat balance of “Totermann” reduction melting consists from following expanse items: 1) charge mixture heating till melting area; 2) endothermic reactions of metals reductions; 3) charge mixture melting for metal and slag liquids constitution; 4) metal and slag overheating for active moving condition. Numerical values of heat expanse items are calculated and presented on fig. 3.

Taking into account listed above expense items the total heat expense for 1 kg of metal can be evaluated by equation:

\[
Q_b = p t_{c.m.} \left( \frac{c_{\text{ore}}}{p_i} C_{\text{ore}} + \left( \frac{c_{\text{coke}}}{p_i} + \frac{Q_0}{T_C} \right) + q_{\text{sm/met}} + L_{\text{sl}} + q_{\text{sm/sl}} + \Delta t \left( C_{\text{met}} + L_{\text{sl}} \right) \right)
\]

where:
- \( p \) – specific ore consumption for 1 kg of metal (kg/kg);
- \( t_{c.m.}, \Delta t \) – charge mixture temperature, metal and slag overheating, °C;
- \( c_{\text{ore}}, c_{\text{coke}}, c_{\text{met}}, c_{\text{sl}} \) – heat capacity of ore, coke, metal and slag (kJ/kg-degree) respectively;
- \( L_{\text{sl}} \) – slag quantity (ration) at 1 kg of metal, kg/kg;
- \( q_{\text{sm/met}}, q_{\text{sm/sl}} \) – smelting latent heats of metal and slag (kJ/kg) respectively;
- \( Q_0 \) – average endothermic effects of charge mixture’s oxygen gasification, kJ/kg of \( \text{O}_2 \), %;
- \( q_{\Sigma 0} \) – quantity of gasified oxygen at 1 kg of charge mixture, kg/kg.
The main sources of heat are the flame with temperature 2500-2600°C that contacts the bottom part of “Totermann” and HRG that airflows through “Totermann” along the full height of stack. When the melt temperature is \( t_{\text{melt}} = 1600-1650°C \) in the bottom part of shaft there is maximal temperature difference \( \Delta t = 1000°C \) between the flame and charge mixture. Such temperature difference assimilates on the height of 3-4 m. On the height of 5-6 m the gas temperature can drop till 1200-1300°C under such temperature the charge mixture will be in the hard and loose conditions. So one part of HRG will go through layers and the rest will flow through “Totermann”. Average temperature of HRG flow on the height of 15-16 m can drop till 350-400°C.

By increasing the height of “Totermann” it is possible to obtain of gas flow temperature drop till 250°C so achieve heat-exchange like in the blast furnace. That is the purpose of organization of reduction melting for steel production in the vertical shaft furnace.

2. **ORGANIZATION OF «TOTERMANN» REDUCTION MELTING**

In new conditions like in the blast furnace process it has real technical solutions by:

1) creation of feeder with special design that ensure the vertical spreading of central charge mixture column and around of it coke filling;

2) revision of furnace design according with optimization of gas flow spreading;

3) installation of jets around of hearth for creation of flame with high temperature 2500-2700°C;

4) injection of hot combined blow (includes air, oxygen, additional fuel, steam) with help of jets with speed more then 100 m/s;

5) Adjusting of blow parameters (especially oxygen and fuel) with purpose of creation strong flame with 500-2700°C temperature that forms reduction gases - CO, H₂. This temperature effect similar to submerged electric arc.

Listed above technical solutions are similar to existing and perfectly can be implemented and at present time this solutions are reflected in the author’s science discoveries.

3. **PROCESS ECOLOGY**

In contrast to blast furnace process new process with creation of central “Totermann” allows to adjust the quantity of fuel additions and oxygen-enriched combustion air trough tuyere injection in the wide ranges. If as a fuel additive use coal dust then its consumption for 1 MT of produced steel can be brought till 400-500 kg while coke consumption will be dropped till 300-350 kg/MT and increasing of oxygen in the blow till 30-40%. Creation of high heat potential flame allows decreasing of gas output till 2500-2700 m³/MT of steel, which means decreasing of gas emissions more then 20%. If to above data add the decreasing of coke production and associated with it gas emissions that will bring to decreasing more then 25-30% of total gas emissions, that means planed by world community decreasing of gas emissions for 20% till 2020 is achievable.
LITERATURE REFERENCES


