EFFECT OF SIMULATED PCI RATE ON OLIVINE PELLET REDUCTION

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ABSTRACT

Reduction behaviour and textures formed during laboratory simulated BF tests with olivine pellets are presented and discussed. Test design is based on gas and temperature profiles during operation at a high and a low pulverized coal injection (PCI) rate with a low-volatile coal in the LKAB experimental blast furnace (EBF). Texture differences, introduced prior to a reduction degree of 40 percent, are observed in the iron oxide in the pellet core and in the Fe met pellet periphery. A simulated high PCI rate decreases the reduction time of the pellets. The olivine pellets investigated are well suited for blast furnace operation at different PCI rates and accordingly different production rates.

1. INTRODUCTION

Modern blast furnace iron making continuously strives at an increase of the amount of injected pulverized coal and a decrease in the coke consumption. The increased PCI will affect parameters important for the reduction of iron oxides as for example the composition of the ascending reduction gases, the in-furnace temperature isotherms and the position of the cohesive zone. Measurements, for example temperature profiles and reduction gas compositions, made during operation of the EBF are the basis of laboratory reduction profiles corresponding to differences in a blast furnace operated at various PCI rates. The reduction behaviour of olivine pellets and textures formed during laboratory reduction simulating a high and a low PCI rate at a centre and an intermediate position in the furnace are presented and discussed.

2. MATERIAL

In the investigations performed the commercial olivine pellets MPBO produced by LKAB are used. The chemical composition of the MPBO can be seen in Table 1.

<table>
<thead>
<tr>
<th>Pellet</th>
<th>Fe</th>
<th>FeO</th>
<th>CaO</th>
<th>SiO2</th>
<th>MgO</th>
<th>Al2O3</th>
<th>CaO/SiO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPBO</td>
<td>66.8</td>
<td>0.5</td>
<td>0.35</td>
<td>1.7</td>
<td>1.5</td>
<td>0.32</td>
<td>0.21</td>
</tr>
</tbody>
</table>

3. EXPERIMENTS

3.1 EBF

The EBF has a working volume of 8.2 m³, a diameter at tuyere level of 1.2 m and is equipped with a system for injection of reduction agents. During operation, in-burden probes are used for the measurement of the horizontal temperature- and gas profiles. Estimation of the positions of the in-furnace temperature isotherms is enabled by a thermocouple which descends with the burden. A drawing of the EBF can be seen in Fig. 1.

Measurements in the EBF are carried out during operation at different average PCI rates, 150 and 80 kg/tHM, respectively. A low-volatile coal containing 19.6 percent volatile compounds is used. Process data, including the top gas temperature and composition and burden decent rate, are stored during operation.

3.2 The laboratory reduction furnace

The experimental apparatus used for reduction tests is shown in Fig. 2. The furnace is a vertical steel tube-type furnace with an inner diameter of about 60 mm and is heated electrically by U-shaped Super-Kanthal elements with a constant temperature zone of about 80 mm in height. Digital Multi-Bus Flow-Bus regulators control the gas flows of H₂, CO, CO₂ and N₂. The gas is introduced in the bottom of the tube and heated in a bed of Al₂O₃ balls. A thermocouple for temperature measurement and control is introduced from the bottom of the tube and situated approximately 20 mm below the sample, which is suspended in the balance with metal wires. The sample material is placed in a basket. A water-cooled top for cooling of the sample after test completion is situated on top of the steel tube. Input gas composition and temperature are controlled by a computer that stores data with a frequency chosen for each parameter.

At the test start temperature a nitrogen flow at 12
l/min is introduced. The temperature and gas flow are held at constant values for a few minutes before the sample is introduced into the furnace. Sample start weight is between 80 and 83 grams of pellets. Drying of the pellets is carried out outside the furnace prior to reduction. As soon as the sample has been introduced into the constant temperature zone, the test is started and the temperature program starts at the same time as the gas composition is changed into a reducing atmosphere. After the test, which can be interrupted at any point, the gas is changed into pure N₂ and the sample is transferred into the cooling top. Total gas flow is maintained at 12 l/min during the entire test.

3.3 Heating rate and gas composition profiles

In the laboratory test programs the heating rate and gas profiles are estimated from measurements made in the EBF during operation at the high and the low PCI rates. The heating rate profiles are estimated from:

- Vertical temperature measurements
- Average burden decent rates
- Horizontal temperature profiles at the position of the shaft probes
- CO/CO₂ ratio at the position of the lower shaft probe

For the high and the low PCI rates, a fast heating rate is estimated to simulate a centre profile and a slow heating rate is estimated to simulate an intermediate/wall profile.

The reduction gas compositions are estimated from the top gas analysis and the gas composition at the position of the upper and lower shaft probes. The gas compositions used together with the fast heating rates are estimated from the centre gas composition in the EBF. For the slow heating rates, the gas compositions at an intermediate position in the EBF are the basis of the reduction gas composition. N₂ is filled up to a gas flow of 100 percent. Test conditions are shown in Fig. 3 and Fig. 4.

One set of experiments is interrupted at a reduction degree of approximately 40 percent and one set is interrupted at a furnace temperature of 1100 °C. Table 2 gives an overview of the experiments performed.

### Table 2: Schematic overview of blast furnace simulating experiments performed

<table>
<thead>
<tr>
<th>Test</th>
<th>PCI Rate</th>
<th>Heating Rate</th>
<th>Test End</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>High</td>
<td>Fast, CO₂</td>
<td>X</td>
</tr>
<tr>
<td>II</td>
<td>Low</td>
<td>Slow, CO₂</td>
<td>X</td>
</tr>
<tr>
<td>III</td>
<td>High</td>
<td>Fast, CO₂</td>
<td>X</td>
</tr>
<tr>
<td>IV</td>
<td>Low</td>
<td>Slow, CO₂</td>
<td>X</td>
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<tr>
<td>V</td>
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<td>Fast, CO₂</td>
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<tr>
<td>VI</td>
<td>Low</td>
<td>Slow, CO₂</td>
<td>X</td>
</tr>
<tr>
<td>VII</td>
<td>High</td>
<td>Slow, CO₂</td>
<td>X</td>
</tr>
<tr>
<td>VIII</td>
<td>Low</td>
<td>Slow, CO₂</td>
<td>X</td>
</tr>
</tbody>
</table>

4. RESULTS

4.1 Reduction profiles

Fig. 5 shows the reduction profiles for tests I-VIII. For the same level of simulated PCI rate, at the test end temperature of 1100°C, a higher reduction degree is attained for the slow heating rates when tests IV and II and tests VIII and VI, are compared. After reduction simulating the fast heating rate profiles, tests II and VI, approximately equal reduction degrees are attained independent of simulated PCI rate. A higher reduction degree is attained for the slow heating rates at the end of test IV, simulated high PCI rate, compared to test VIII, simulated low PCI rate. In tests I, III, V and VII, the reduction is interrupted at a reduction degree of approximately 40 percent.
The rate of reducibility at 40 percent reduction and the average rate of reduction during the total test time to reach 1100°C for tests II, IV, VI and VIII are presented in Table 3.

Table 3 Reduction rates for tests II, IV, VI and VIII

<table>
<thead>
<tr>
<th>Test</th>
<th>R40 (%/min)</th>
<th>Average Red. Rate (%/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>IV</td>
<td>0.87</td>
<td>0.77</td>
</tr>
<tr>
<td>VI</td>
<td>0.81</td>
<td>0.77</td>
</tr>
<tr>
<td>VIII</td>
<td>0.71</td>
<td>0.59</td>
</tr>
</tbody>
</table>

4.2 Pellet textures

Significant differences in the iron oxide textures are observed in the pellet core when pellets from the reduction tests simulating the high and low PCI rate are compared. A grain texture is observed in the pellet core of samples after tests V-VIII, simulating the low PCI rate, an observation that is not discernible after tests I-IV, simulating the high PCI rate. Textures from the pellet core and periphery from tests I-VIII are presented in Fig. 6.

Together with the areas of Fe_met in the pellet periphery, a few areas of iron oxide are present after tests II and IV, which are full-length tests simulating the high PCI rate. After full-length tests simulating the low PCI rate, tests VI and VIII, the corresponding areas in the pellet periphery show noticeable areas of iron oxide surrounded by Fe_met within the texture dominated by Fe_met.

A few areas of Fe_met are observed in the pellet core from test samples interrupted at the test end temperature of 1100°C. Fe_met is not observed in the core of pellets reduced to a reduction degree of approximately 40 percent. Significant differences in the Fe_met texture of the pellet periphery, independent of final reduction degree, are not observed between pellets reduced according to similar reduction profile. The distribution between the pellet core, mainly made up of iron oxide, and the pellet periphery dominated by Fe_met varies, however, in accordance with the reduction degrees attained.

Fig. 6 Pellet textures observed in light optical microscope after reduction tests I-VIII. Pellet core (left) and pellet periphery (right). Iron oxides = Grey, Fe_met = White, Pores = Black
5. DISCUSSION

Although the laboratory reduction profiles are estimated from measurements in the EBF during operation using different PCI rates it cannot be determined that they completely correspond to changes in PCI rates. Many factors influence the position of the in-furnace temperature isotherms, the ascending gas composition, the burden descent rate and the entire blast furnace process. However, the characteristics of the laboratory reduction profiles correspond to the different process conditions obtained during operation at a high and a low PCI rate.

The reduction degrees attained at 1100°C are from the fast heating rate profiles, tests II and VI, approximately equal. The extensions of the peripherical zones dominated by Fe<sub>met</sub> are the same size. Comparing pellets from test VI with pellets from test II, a denser texture, also containing iron oxide in the pellet periphery, is observed in pellets from test VI. A few Fe<sub>met</sub> areas are found in the pellet cores. In the cores of pellets from test II no grain texture is observed, which is the case in pellets from test VI. For test II, the R40 is 0.95 %/min and for test VI 0.81 %/min. The average rate of reduction during the total reduction time to reach 1100°C is higher for test II compared to test VI.

A higher reduction degree is at the test end temperature of 1100°C attained for test IV than observed for test VIII when the slow heating rates are compared. The Fe<sub>met</sub> texture in the pellet periphery is denser in pellets from test VIII than test IV and also contains iron oxide surrounded by Fe<sub>met</sub>. A few Fe<sub>met</sub> areas are found in the pellet cores. In pellets from test VIII a grain texture is observed in the pellet core, which is not the case in pellets from test IV. The R40 is for test IV 0.87 %/min and for test VIII 0.71 %/min. The average rate of reduction during the total reduction time to reach 1100°C is higher for test IV compared to test VIII.

Comparisons of the results from tests II and VI and IV and VIII, respectively, show an increased reduction rate for the test simulating the high PCI rate. Reduction degrees, at least as high as for the simulated low PCI rates, are attained for the simulated high PCI rates. The increased reduction potential of the gas and the increase in the temperature level compensate for the loss in reduction time between the simulated low and high PCI rates in tests VI and II and IV and VIII. It has been previously observed that an increase in hypothetical PCI rate is necessary to compensate for a decrease in reduction time.<sup>3)</sup>

According to the results from the laboratory experiments, a sufficient pellet reduction will take place at an increase of the PCI rate and at an increase of the production rate in the blast furnace. Based on the present results it can therefore be concluded that the pellets are well suited for blast furnace reduction at different PCI rates.

Differences in the pellet texture are to be found in pellet cores where a grain texture is observed after test VI, but not after test IV. The Fe<sub>met</sub> texture in the pellet periphery is dense and contains some iron oxides in pellets after test VI, whereas the Fe<sub>met</sub> texture after test IV shows more pores. The average reduction rates are equal. The R40 of test IV exceeds the R40 of test VI. Since reduction profiles are similar above a reduction degree of 25 percent the texture differences are most likely to occur already in the beginning of the reduction.

Differences in the pellet textures that are observed in samples after reduction to 1100°C are already found at a reduction degree of 40 percent. These observations support the claim that the observed texture differences are introduced at the beginning of reduction. A higher start reduction temperature and a more rapid temperature increase in combination with an increase in the reduction potential of the reduction gas counteract the formation of a grain texture in the pellet core. At the same time, a porous Fe<sub>met</sub> texture is formed in the pellet periphery. It should, however, be noted that the influence of the original pellet texture has not been considered in the investigation.

In the blast furnace, elements such as alkalis are present and influence the pellet reduction and most probably the pellet texture. These effects combined with influences of PCI rates are not studied in the present investigation.

6. CONCLUSIONS

The performed laboratory reduction experiments show that the initial reduction conditions, in terms of temperature level and reduction gas composition, will determine the pellet texture up to a reduction degree of at least 60 percent.

Based on the present results it can be concluded that the pellets are well suited for blast furnace reduction at different PCI rates. Although the reduction time decreases with an increase in PCI rate the present result indicates that this is compensated by increased reduction potential, temperature and porosity in the Fe<sub>met</sub> pellet periphery.

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REFERENCES