Reduction of pellet under different reducing conditions and shaft temperatures

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Abstract
During 2007 and 2009, tests within the ULCOS project was performed at the LKAB Experimental Blast Furnace, EBF. The tests have indicated that a process with top gas recycling can result in carbon savings around 24% [6][7]. The process with recycled top gas clearly changes the conditions in the blast furnace shaft compared to normal blast furnace operation.

The burden during the initial tests consisted of pellet and sinter. Changing gas and temperature conditions in the shaft will subsequently lead to changed demands on the burden. Studies of pellets during different reducing conditions will help in understanding how the burden materials are affected by changes in gas and temperature profiles in the blast furnace shaft. Knowledge about how the burden reacts under new conditions can help to further optimize this process and further develop the pellets for the process.

1. Introduction

It is a well known fact that ores, pellets and sinters, disintegrate in the blast furnace process at varying degrees [1]. This is something that can lead to disturbances due to softening or generation of fines and finally effect the blast furnace operation. Research is continuously performed in ore properties in order to keep these issues at a minimum. Today, a large number of standard reduction and disintegration tests exist with the reference to the blast furnace process. The temperature profile and gas composition in these test have been chosen according to how the blast furnace process is operated today.

There are different ideas in how to improve and operate the blast furnace process in new ways. Many of these ideas are still at the stadium of laboratory or pilot scale testing. Many of the ideas can lead to that pellet and sinter has to withstand different reducing conditions compared to what is encountered today. During the last years, high coal injection rates together with increased amounts of oxygen enrichment have been operated throughout blast furnace over the world. This has lead to further development and research of iron ores in order to optimize the blast furnace process according to new standards and operating points. The raw materials are adapted to meet demands of changes in the process regarding for example metallurgical, mechanical and melting properties.

2. LKAB’s Experimental Blast Furnace, EBF

The LKAB EBF has been described in detail in many other papers [2], below is a summary of the history, and the layout of the plant.

The LKAB experimental blast furnace, EBF, was built and commissioned in 1997. The primary intention was pellet development. During the years, 26 campaigns have been conducted with different types of blast furnace operation. Various ferrous burdens have been tested throughout the years for example iron ore pellets, sinter, lump ore and pre reduced iron ores. Different process concepts have also been tested, high oxygen enrichment, high PCI injection, high oil injection and gas injection. Also tests with injection of fluxes and injection of BF dust have been performed. The EBF has also been used for the development of a new type of charging equipment. Since 2007, three ULCOS campaigns have been
conducted operating different process modes based on injection of decarbonated top gas.

2.1. Technical description

The EBF has a working volume of 8.2m³ and a diameter at the tuyere level of 1.2m. The working height from the stock line to the tuyere level is 6 meter and there are three tuyers with a 120 degree separation. The tuyere diameter is during normal operation 54mm, resulting in a blast velocity at approximately 150m/s. Hot blast is heated in two pebble bed heaters. The heaters can produce a hot blast with temperatures up to 1250°C. The EBF is equipped with a raw material system consisting of 4 bins for iron ore which can be used simultaneously. This makes it possible to mix 4 types of iron burdens at once. Also 4 bins for additives are installed to charge fluxes to the blast furnace. A schematic view over the furnace can be seen in figure 1.

The EBF is equipped with a charging system of bell-less top type. This makes it possible to charge the burden with great accuracy. The tap to tap time is normally 60 minutes at a production rate of approximately 1.5tHM/h. All burden materials except for pellets are adapted for the pilot scale by crushing and screening. The coke normally bought from SSAB is prepared at the fraction 15-30mm while the fluxes are prepared at 10-20mm. Top size of sinter is in general kept at 40mm and pellet burden is of a commercial size with the largest fraction within, 10-12.5mm.

3. ULCOS project

Since autumn 2007, three campaigns within the ULCOS project has been carried out at the LKAB EBF [5][6][7]. These campaigns have all included blast furnace processes with recycled top gas injected at normal tuyeres as well as in the shaft of the blast furnace. The results have been very promising and the aim has been to ensure that the top gas recycling process can be operated at a blast furnace with a stable process and no safety issues.

The project has up till now not handled the optimization of burden materials. The burden used for the tests has been a mixed burden with sinter and a LKAB pellet. The burden has not caused any problems during the campaigns that have been operated until autumn 2010 but can surely be optimized in order to further improve the results.

A new process also introduces new conditions for the burden compared to normal blast furnace operation. The gas composition during the tests show large differences compared to normal operation. Together with a change in temperature profile, this can cause problems such as disintegration and breakdown especially in the upper part of the blast furnace.
4. EBF sampling possibilities

The LKAB experimental blast furnace has a large number of sampling and measurement possibilities. During operation, gas and temperature profiles can be obtained over the diameter at two different levels of the blast furnace shaft. At these positions, also material sampling can be performed. Combining these two sources of information gives a very good idea about the conditions in the blast furnace shaft, and which conditions the iron burden has to withstand.

5. Probes

Gas and temperature probes are normally installed at two specific levels of the blast furnace, although, they can be moved to two other positions on the shaft. The upper probe is positioned approximately 1 meter below the stock line and the lower probe approximately 3.3 meter below stock line. The gas and temperature probes, seen in figure 3, can be exchanged by material probes in only 5-10 minutes. This makes it possible to compare gas and temperature profiles with material samples taken during operation. Normally, 4-5 kg of material can be collected from each probe when these are operated.

6. Excavation

Material collected from the probes is sorted and screened and finally sent for further analyses. Material is also taken for microscopy characterisation.

When completing a campaign, the furnace can be quenched in a few hours, lowering the temperature and gas composition in the shaft to a level where further reduction of the burden is not possible. By introducing cold nitrogen through the top of the blast furnace while keeping the tap hole open, the heat front is pushed downwards and the reactions are stopped.

When the furnace shaft has cooled down, the top is removed and the furnace can be excavated. The excavation is a time consuming work were a lot of samples are collected in order to study the conditions in the blast furnace shaft. From the excavation, important information regarding disintegration and swelling of pellet can be collected.

8. Breakdown of pellets in the blast furnace

There are many factors that affect the possible breakdown of pellet in the blast furnace. Some of these factors are for example the reduction temperature in the shaft, the reduction potential of the gas and also the reduction time[1][3][4].

Figure 2 Possible probe positions at the EBF

Figure 3 Gas and temperature probe at the LKAB EBF
It is important to relate to all these factors, when trying to develop a pellet with excellent process properties. It has been stated earlier that the maximum breakdown occurs between 400-600°C and with CO/CO₂ close to 1[1]. The reduction between hexagonal hematite to cubic magnetite results in a volume change which can cause cracks. Some authors also mention carbon deposition as a contribution to low temperature disintegration since this has its maximum in nearly the same temperature interval as the change between hematite to magnetite. As soon as a metallic layer is formed at the surface of a pellet, the strength of the pellet is yet again recovered.

9. Observations from tests

A higher reduction potential of the blast furnace gas will give a faster reduction of the iron ore in the shaft, although the temperature profile is limiting the possible reduction that can take place. The mechanical strength of iron ore pellets decreases during the reduction and the change between hematite to magnetite. To optimize the process and minimize the risk of disintegration the relationship between reduction potential and temperature profile has to be controlled in the blast furnace process.

10. Laboratory tests

Reduction tests have been performed during different reducing conditions. First the reduction potential of the gas has been changed keeping the temperature constant. During the second test, gas composition of the reduction gas is kept constant while increasing the temperature.

10.1. Varied gas composition at constant reducing temperature

The equipment used for the test is the same as for the standard LTD test ISO13930. The gas composition during the tests is changed according to table 1. The temperature for the tests is kept at 500°C as for the standard LTD test. The samples are reduced for 60 minutes.

<table>
<thead>
<tr>
<th>Table 1 Composition of gas varied, while keeping temperature constant.</th>
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<tbody>
<tr>
<td>Test</td>
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<tr>
<td>------</td>
</tr>
<tr>
<td>LTD1</td>
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<tr>
<td>LTD2</td>
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<tr>
<td>LTD3</td>
</tr>
</tbody>
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10.1.1. Low temperature disintegration

Testing the change in reduction potential of the gas during constant temperature was done with three different types of pellets. The reducing time was in all tests kept at 60 minutes.

When studying the three different types of pellets, it becomes clear that the breakdown especially at high concentrations of CO varies between the three. There is a trend with increasing breakdown with increasing reduction potential as can be seen in figure 4, a result that can be expected.

Figure 4 LTD tests with varied reducing potential of reduction gas
It is also interesting to see how the fraction -6.3mm can differ between different types of pellets at the same reduction potential of the gas.

Keeping the temperature at 500°C clearly limits the possible reduction as can be seen in figure 5. The three tests and three types of pellets show small or no changed in reduction degree although the amount of CO is drastically changed. A reduction degree between 10 – 12 % seems to be what is possible to reach at these conditions and at 500°C. Calculations show that at 13% reduction degree, hematite is completely reduced into magnetite, and at 33%, magnetite is fully reduced to wustite [8].

Another clear effect with increased reduction potential of the reducing gas is that carbon deposition increases severely with higher content of CO.

Increasing the reduction potential without changing reduction time or reduction temperature can give unwanted effects on the raw material, both regarding breakdown but also carbon deposition.

10.2. Reduction tests with constant reduction potential and varying temperature.

In further laboratory tests, the reduction potential of reducing gas was kept constant while varying the temperature.

The composition of the reducing gas that was chosen can be seen in table 2.

Table 2 Composition for reducing gas during tests with varied temperature

<table>
<thead>
<tr>
<th>Composition</th>
<th>(%)</th>
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<tbody>
<tr>
<td>CO</td>
<td>50</td>
</tr>
<tr>
<td>CO₂</td>
<td>30</td>
</tr>
<tr>
<td>H₂</td>
<td>7</td>
</tr>
<tr>
<td>N₂</td>
<td>13</td>
</tr>
</tbody>
</table>

The temperature for the tests was varied from 600°C to 900°C in order to study how a varied temperature affects the difference in reduction degree after 60 minutes.

For this test, two of the materials used also for the tumble tests were used. During this test, no tumbling of the samples was applied during reduction. Even without tumbling, a breakdown of the material could be seen. When studying the reduction degree in figure 6, showing results from tests with varied temperature, it becomes clear that even at 900°C the material is not reaching a reduction degree of more
than approximately 20 % using the reducing gas stated in table 2.

Samples reduced at 600°C also clearly show signs of carbon deposition. Samples reduced at 700°C show a much smaller amount of carbon deposition.

![Reduction test with varied temperature](image)

**Figure 6** Reduction degree for samples with constant reduction potential on gas and varied temperature

The ratio CO/(CO+CO₂)*100 is during the test kept at 62.5. In figure 7, the compositions of reducing gas used during the laboratory tests have been plotted into the Fe-C-O diagram. Squares indicating compositions used for LTD tumble tests and circles, indicating the composition during the reduction tests with varied temperatures.

![Fe-C-O diagram](image)

**Figure 7** CO/CO+CO₂ quote for laboratory tests

### 11. EBF tests

When performing tests in the EBF, material probes have been run frequently. From these probes, material samples are collected, screened, sorted and sent for chemical analysis. When evaluating gas and temperature probings together with studies of burden materials it becomes clear that periods with a high reducing potential of BF gas also show a higher tendency of breakdown. Material samples taken during different operating periods show that the disintegration is almost doubled during periods with high reduction potential. This is also something that becomes clear when evaluating laboratory tests with increased amount of CO, keeping temperature constant.

Although, operating a sinter burden, results in a fraction -6,3mm that is once again doubled compared to pellet operation as can be seen in figure 8. This is periods with comparable temperature profiles in the shaft. The temperature at upper probe varies on average between 600-800°C between wall and centre positions.

Sinter charged to the EBF has an average fraction larger than 12,5mm around 60%, another 20% is larger than 9mm. When studying probe samples, there are almost no sinter pieces larger than 12,5mm.

After screening the probe samples, the sinter seems to have disintegrated from the larger fractions quite rapidly in the blast furnace.

![Fraction less than 6,3mm for pellet and sinter samples](image)

**Figure 8** Fraction less than 6,3mm for pellet and sinter samples collected from the upper probe at the EBF
When comparing the reduction degree between different samples, pellets clearly show a higher reduction degree compared to sinter as can be seen in figure 9. Sinter samples and pellet samples are sampled during periods were the gas and temperature profile inside the blast furnace has been monitored.

The difference in reduction degree shown in figure 10, can be explained as a result from a higher temperature at the level of upper probe. The samples with the highest reduction degree seem to be taken during a period with an increased temperature in the shaft.

Figure 9 Reduction degree for pellet and sinter samples taken with upper material probe at the EBF

Figure 10 Reduction as a result of the temperature in the upper part of the EBF

12. Conclusion

From laboratory tests it can be seen that with an increase of reducing potential of the gas while keeping temperature constant at 500°C, a larger breakdown can be observed. The reduction of the material is limited by temperature and not by choice of burden material. All three materials tested show more or less the same reduction degree after 60 minutes. The choice of iron burden seems to have a big impact on breakdown, especially during tests with high reduction potential.

From samples taken at the EBF, the same trend as for the laboratory tests can be observed. An increase of the fraction -6.3mm can be observed for both pellet and sinter. From the samples, sinter seem to have about 18 % in the fraction less than 6.3mm while pellets have an fraction less than 6.3mm of around 9%.

From laboratory tests, the reduction degree of pellets is clearly limited by temperature. When this temperature is increased, the reduction rate also increases to about 20 % after 60 minutes. From EBF samples, the reduction degree of pellets at the level of upper probe can be as high as up to 60%.

Samples reduced with gas at high reduction potential and at a temperature around 500-600°C show signs of carbon deposition. This will be investigated further to evaluate the effects on the raw material.

When trying to operate and optimise a blast furnace process with an increasing reduction potential of the blast furnace gas, the temperature profile over the shaft as well as the choice of burden material becomes very important. It is clear that different burden materials will cope better with changes in gas and temperature profile compared to others.

13. Acknowledgment

The authors would like to thank fellow research colleagues at LKAB for important and interesting discussions about the blast furnace process and the important choice of burden materials. The authors would also like to thank the partners within the ULCOS project for fruitful discussions during tests and meetings. Special thanks go also to the technicians at the EBF for the important work with sampling during campaigns.
14. References

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