Trial with low slag volume at LKAB Experimental Blast Furnace

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Summary
During co-operation between LKAB and SSAB Oxelosund a trial with low slag volume was carried out at LKAB Experimental BF. The aim of this trial was to more clearly understand how the process reacts and how the alkali and zinc re-circulation were affected by the very low slag volumes.

With increased coal injection the coke consumption will be decreased. The load of acid slag components will therefore be reduced, and the total slag volume will consequently be decreased. The normal slag rate at SSAB Oxelosund is today 145 kg/tonne of Hot Metal (tHM). In this trial the furnace were operated at 120 kg/tHM and at this slag volume the slag basicity was varied slightly to see the effect on sulphur distribution and alkali cleaning capacity of the slag.

The results show that it’s possible to operate the furnace with such a low slag volume, but the process was more sensitive and disturbances occurs more frequently than usual. The sulphur distribution was varying more than what we normal can se. The Na₂O in slag was relatively stable in all periods, but the K₂O was fluctuating.

The main reason for the unstable process conditions was probably the uneven outtake of K₂O in the slag, as a consequence of accretions formation at the shaft walls. It can also be noticed that the sulphur distribution was varying, and the diffusion was higher in the periods with low slag volume.

Key Words
LKAB, Experimental Blast Furnace, Pellets, SSAB, Slag

Introduction
The favourable production results achieved with blast furnaces in Sweden are mainly attributable to the use of high-quality olivine pellets (MPBO and KPBO) produced by LKAB in Malmberget and Kiruna. The pellets have, in general, stable reduction behaviour, low gangue content and a very narrow softening and melting interval. Very high productivity, low slag volume and a low consumption of reducing agents have been achieved when using 100% olivine pellets [1]. With a focused on attaining even better blast-furnace performance, LKAB operate the Experimental Blast Furnace to develop raw material properties as well as blast furnace techniques.

With increased coal injection at SSAB Oxelosund the coke consumption will be decreased. The load of acid slag components will therefore be reduced, and the total slag volume will consequently be decreased. SSAB Oxelosund is today operating at 145 kg slag/tHM.
When operating at low slag volume, slag properties are more critical for optimal operation than when operating with higher slag amounts, especially considering the uptake of circulating materials such as alkalis and zinc as well as the slag’s sulphur capacity.

With all that in mind, a trial at the LKAB Experimental Blast Furnace was carried out as a joint project between LKAB and SSAB Oxelosund.

The Experimental Blast Furnace

A simplified layout of the Experimental Blast Furnace is shown in Figure 1. It has a working volume of 9 m³ and a hearth diameter of 1.5 m. There are three tuyeres placed at 120 degree intervals. As great effort has been made to keep heat loss at a minimum, insulating refractories were chosen. Only the bosh area and the tuyeres are water-cooled. The blast is normally pre-heated to 1200-1250°C in a new type of pebble heater (figure 2).

The Experimental Blast Furnace is equipped with a bell-less top for burden distribution control. One mechanical stock rod and one radar monitor the burden descent and control the charging of the furnace. The furnace has one tap hole which is opened with a drill and closed with a mud gun. The hot metal and slag are tapped into a ladle.

Probes for temperature measurements, gas analysis and solid sampling over the blast furnace diameter are installed at three different levels (figure 3). To make dissection and repair easy, the hearth is detachable and can be separated from the furnace.

The furnace is equipped with a lock-hopper coal-injection system. Currently, the system is equipped with a rota-feed system for dispensing the coal to the lines for pneumatic transportation to the furnace, but at the time of this trial a cylindrical fluidising chamber fitted at the bottom of the vessel was used to supply coal for transport to the blast furnace.

Operating the Experimental Blast Furnace

The blast furnace is operated in campaigns of 5 - 10 weeks at a productivity ranging from 3.2 to 3.8 t/m³/day. The normal tap-to-tap time is 60 minutes and normal tapping duration 5 - 15 minutes. Process data are logged continuously and stored in a database. The data are transferred at regular intervals to another database where reports and trend charts are generated, and process calculations are carried out.

<table>
<thead>
<tr>
<th>Day</th>
<th>Pellet type</th>
<th>Slag volume (kg/tHM)</th>
<th>Basicity B² (CaO/SiO₂)</th>
<th>Misc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>80%MPBO/20%KPBA</td>
<td>150</td>
<td>0.95</td>
<td>Ref</td>
</tr>
<tr>
<td>3-4</td>
<td>80%MPBO/20%KPBA</td>
<td>120</td>
<td>0.95</td>
<td>Ref</td>
</tr>
<tr>
<td>5-9</td>
<td>80%MPBO/20%KPBA</td>
<td>120</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>10-12</td>
<td>80%MPBO/20%KPBA</td>
<td>120</td>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>13-15</td>
<td>80%MPBO/20%KPBA</td>
<td>150</td>
<td>1.15</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Trial plan.
The Experimental Blast Furnace is a very sensitive tool for detecting differences in properties of different ferrous burden. The response time is much shorter for the experimental furnace compared to a commercial furnace.

The LKAB Experimental Blast Furnace is described more detail in several papers [2], [3] and [4].

## Trial Using the EBF

The initial trial plan was to maintain a constant low slag volume and then provoke a response in the furnace through certain process parameters given below:
- Increase the slag basicity,
- Increase the heat level i.e. fuel rate,
- Decrease fuel rate for a period,
- Adjust the amount of acid pellet.

During the trial the results where quite unexpected due to difficulties increasing the slag basicity so an adjustment was made to the trial plan. The updated plan aimed to solely increase the slag basicity and lower the slag volume. The final plan is shown in tables 1 and 2.

During the entire trial the blast parameters was kept constant, except for when problems in the plant demanded changes. The production rate was calculated to 1.5 t/h and the coal injection rate at 130 kg/tHM. At the above rates the coke rate was adjusted to compare different critical conditions.

The chemical composition of the raw materials is shown in table 4. This analysis was used for the burden calculations and mass balances.
Results

The process was relatively unstable during the trial, with a uneven burden descent rate, and some slip due to earlier accretion formation at the walls in the upper shaft.

During the entire trial it was difficult to increase the slag basicity, in spite of the relatively high limestone additions at the end of the trial. Figure 4 shows that the slag basicity was quite scattered.

In this chapter a brief description of each trial period are presented. Figure 5 shows a summary of the trial, with each period marked. The diagram shows gas utilization (\((\text{CO}+\text{CO}_2)/\text{CO}_2\) (\text{eta}CO), coke-rate and burden (stock line) level. The burden level indicates when a slip has occurred and \text{eta}CO is an indicator of the process stability.

During the entire trial blast parameters, such as blast volume, temperature and moisture were kept constant, except for when plant disturbances occurred.

For evaluation of each period the transition time between the periods, the first hours and last hours of each period, are excluded from the evaluation time.

Slag composition

The sulphur distribution was varying more than what we normal can see. The Na\textsubscript{2}O in slag was relatively stable in all periods, but the K\textsubscript{2}O was fluctuating (figure 6).
A ternary system is shown for each period, with the slag melting point marked.

<table>
<thead>
<tr>
<th>Slag rate</th>
<th>Ref 150 kg B(^2) 0.95</th>
<th>Ref 120 kg B(^2) 0.95</th>
<th>120 kg, B(^2) 1.05</th>
<th>120 kg, B(^2) 1.15</th>
<th>150 kg, B(^2) 1.15</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>29.6</td>
<td>27.2</td>
<td>26.2</td>
<td>28.1</td>
<td>31.5</td>
</tr>
<tr>
<td>SiO(_2)</td>
<td>33.8</td>
<td>32.6</td>
<td>33.1</td>
<td>32.6</td>
<td>32.5</td>
</tr>
<tr>
<td>Al(_2)O(_3)</td>
<td>15.2</td>
<td>16.4</td>
<td>16.4</td>
<td>16.1</td>
<td>14.5</td>
</tr>
<tr>
<td>MgO</td>
<td>15.3</td>
<td>17.4</td>
<td>16.6</td>
<td>16.6</td>
<td>13.7</td>
</tr>
<tr>
<td>Achieved B(^2)</td>
<td>0.88</td>
<td>0.83</td>
<td>0.79</td>
<td>0.86</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Table 5. Average slag analysis for each period.

**Reference period with slag rate 150 kg/tHM**

A reference period with “normal” operation had a duration of 61 hours. The operation was relatively smooth and the time chosen for evaluation was 50,5 hours.

This was a quite normal period for this kind of burden, except for slightly lower slag basicity. The aim was 0.95, but the achieved basicity was 0.88, see table 5.

**Reference period with slag rate 120 kg/tHM**

A reference period with “normal” operation but with lower slag volume was chosen as well. The duration of this period was 52 hours, and the time chosen for evaluation was 44 hours. The target B\(^2\) was 0.95, but the average result was 0.83. This period was slightly more unstable, compared to the reference period with a 150 kg slag rate. In the second half of the period some slips occurred probably as a consequence of operation with a slight low fuel rate.

In this period the MgO content in the slag was increased, due to the lower slag volume. This result moves the slag composition towards a higher melting point in the spinel region.

**Slag rate 120 kg/tHM and basicity 1,05**

This period was 96 hours long, from which two periods were chosen for evaluation. Those periods were 26,5 and 42,5 hours respectively.

During these periods the calculated slag basicity was 1.05, but the measured basicity was between 0.74 and 0.87. In spite of increasing limestone to the burden, the slag remained relatively acidic. No consideration was taken for the increase in energy demand for the limestone addition and the coke-rate was kept constant. As a result, the fuel-rate was slightly inadequate.

During this period the slag composition has a slightly lower melting point due to the decreased MgO content compared to the 120 kg reference period.
Slag rate 120 kg/tHM and basicity 1,15
This period was 41 hours long and the period for evaluation was 33 hours. The calculated slag basicity was 1.15 during the entire period, but again the measured basicity never reached the calculated aim. The average basicity for the period was 0.86. As earlier, no consideration for higher energy demand of extra limestone was made.

In this period the MgO content in the slag was the same as the previous period, but the basicity was increased, which increased the melting point by 30-40 °C.

Slag rate 150 kg/tHM and basicity 1,15
This period had a duration of 53 hours, and the period for evaluation was 47 hours. The slag volume was increased, and the basicity target was kept at 1,15 from previous trial. In this period the fuel-rate was increased to compensate for the increased limestone addition. The operation was not very stable, with a very uneven burden descent rate.

In this period the slag basicity was increased further, which should move the melting point to a higher temperature. But on the other hand, the MgO content was decreased due to the higher slag volume, which substantially decreases the melting point for the slag. So, over all, this was the best slag composition of all the periods.

**Hot metal composition**
The ratio of carbon and silicon content in hot metal in relation to the hot metal temperature is shown in figure 12. At high temperatures there are no differences between the periods, but when the hot metal temperature decreases, the silicon content seems to decrease less at “normal” slag volume and “normal” basicity. With lower slag volumes and/or higher basicity we can see a higher C/Si ratio, i.e. a greater decrease in the silicon content.

**Discussion**
The results show that it’s possible to operate the furnace with such a low slag volume as 120 kg/tHM, but the process becomes more sensitive and disturbances such as slips occurred more frequently than normal. The slips were however relatively easy to predict, so it was possible to compensate them with increased coke rate to maintain the proper heat level in the furnace. Furthermore, the heat level in the hot metal was slightly more unstable during operation with low slag amounts in comparison to normal operation.

During a 2-week period in November 2000 [5], co-injection of BOF slag and pulverized coal was tested at LKAB’s experimental blast furnace at MEFOS. The ferrous burden was 100 % pellets. The objective was to improve slag formation by fluxing the tuyere slag and to avoid excessive slag basicity in the lower shaft. During the last part of that trial no additional slag-forming material was charged from the top and all fluxes, i.e. BOF slag, were injected through the tuyeres. Excellent blast furnace performance was achieved during the trial. The operation was very smooth and stable. The slag volume was around 100 kg/tHM and the reductant rate was lowered by 11 kg/tHM.
compared to the reference period. A significant reduction in the hot metal silicon content (-0.3 %) was reached and analyses showed very small variation in the silicon content. Sulphur distribution between slag and hot metal was improved, as well as the output of K$_2$O by the slag.

If we compare the trial in 2000 with the current trial, we can see that some additional fluxes in the lower part of the furnace would be beneficial for the slag formation when operating at a lower slag rate. This would also improve the sulphur distribution and the absorption of alkali by the slag compared to the current trial.

The unstable process conditions in this trial can partly be attributed to the run-down system for pulverised coal injection, which today has been replaced with a new system with very stable flow and precise distribution. But the main reason for the unstable process conditions was probably the uneven outtake of K$_2$O in the slag, as a consequence of build ups of accretions at the shaft walls. It can also be noticed that the sulphur distribution was varying, and the diffusion was higher in the periods with low slag volume.

It can also be established that the period durations of two to three days was too short in this case to see the long term effects of a lowered slag volume. The conditions created in the blast furnace remain for a quite long time and will influence the conditions and results of the following period.

References


