Iron Ore Product Development at LKAB

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Abstract: Luossavaara-Kiirunavaara AB – LKAB, a wholly Swedish state-owned and a public limited company, is an international high-tech minerals group and one of the world’s leading producers of upgraded iron ore products. LKAB’s mission is, based on the Swedish ore field, to manufacture and deliver upgraded iron ore products and services that create added value for its customers.

LKAB’s iron ore product portfolio consists of blast furnace pellets, direct reduction pellet and sinter feeds for iron ore sintering. As the No. 1 iron ore producer in Europe, who produces over 90% of iron ore products of Europe, LKAB does not own any commercial process for ironmaking. To be able to always provide customers with high-quality iron ore products especially iron ore pellets, product developments usually follow some special routines and are often conducted together with customers, for instance: laboratory test-pilot scale trials-final product launching for blast furnace pellet. This paper presents briefly some successful stories about the product development at LKAB.

Key works: LKAB, EBF®, iron ore pellet, iron ore product, AggloLab, blast furnace, iron making

1. Introduction

Luossavaara-Kiirunavaara AB – LKAB is an international high-tech minerals group, one of the world’s leading producers of upgraded iron ore products for the steel industry and a growing supplier of industrial minerals products to other sectors. LKAB is wholly owned by the Swedish state and a public limited company with headquarter in Luleå, Sweden. LKAB’s mission is, based on the Swedish ore field, to manufacture and deliver upgraded iron ore products and services that create added value for customers.

LKAB’s iron ore products can be divided into three categories; namely, blast furnace pellet constituting of olivine and acid pellets; Direct Reduction pellet for direct reduction processes; and fines as sinter feed. The major market for LKAB’s iron ore product is in Europe but with more and more volumes during the recent years to China. The DR pellet is mainly delivered to customers in Middle East and North Africa.

The initial iron ore pellet at LKAB was developed and launched in 1980s for the use in a blast furnace iron making process. Since then different types of pellets were designed and tested during the developing phase and some of them were successfully put into the market. This paper mainly reports the development of blast furnace pellets at LKAB.

2. Product Development History

As the No. 1 iron ore producer in Europe and the No. 3 iron ore pellet manufacturer globally, LKAB does not own a commercial blast furnace for ironmaking. Iron ore pellet product development was conducted directly from laboratory tests to full scale trials at customer’s production furnace at LKAB before 1997. One of the present blast furnace pellet i.e.MPBO olivine pellet, which also was the prime BF pellet at LKAB, was developed through a tight cooperation between SSAB and LKAB, and initially introduced to blast furnace operation at SSAB in 1982[2]. Outstanding operation results have been achieved since the use of 100% MPBO pellet at SSAB Luleå Works, and during the last decade the product has been optimized to meet customers’ demands.

However, in the course of developing a new type of fluxed pellet during 1990s, difficulties through this Lab-BF development route was encountered. The
new type of pellet which appeared to have an excellent properties in the laboratory tests did not function well in a commercial blast furnace process. Contrarily, it did caused some severe irregularities for the BF process during the full scale trials, such as higher pressure drop, higher fuel consumption but unstable process. The reason for the problems occurred in the blast furnace process could not be understood due to the difficulties in taking burden samples on-line from a production furnace. It was then decided to conduct some pilot scale trials in a small primitive pilot blast furnace of British Steel[2]. The pilot blast furnace was quenched after finishing the trials and excavated samples was taken for further laboratory examination. It was found that the abnormal process conditions occurred in the production furnace through the trial resulted from the catastrophic swelling of pellet during the reduction in the furnace. Metallic iron formed in the shape of whiskers in the blast furnace, but did not appear in the standard swelling test. The result may indicate that with the development of modern blast furnace iron making technology, one step product development from laboratory to commercial blast furnace can be too risky for a production furnace and too ineffective for product development. To accelerate the product development and to be able to always provide customers with high-quality iron ore pellets, it was decided in 1996 to build an Experimental Blast Furnace - EBF® for total 5 campaigns of about 6 weeks each and 2-campaign per year for developing iron ore pellet products between 1997 and 1999.

The EBF was built and commissioned in 1997. During the first 5 campaigns, both LKAB’s internal product development projects and external projects for optimizing the blast furnace process were carried out. It became very obvious that the EBF is a valuable tool not only for iron ore pellet product development but for other research and development of blast furnace ironmaking technologies. As a result, the EBF with consecutive improvement was continued to use for product development and for exploring the blast furnace ironmaking technologies after 1999. So far 27 campaigns have been carried out successfully for different purposes. New iron ore pellet products have been designed and presented to customers as the commercial products; improved burden structures were reconstructed for customers with trials at EBF with desired raw materials of customers for blast furnace operation.

3. The Experiment Blast Furnace

Although the EBF as shown in Figure 1 is not as large as a commercial blast furnace in size it is fully equipped as a commercial one, or even better. The on-line measurements of the top gas composition of high accuracy as well as the gas temperature measurements in crossed two diametrical directions can provide valuable information about the gas utilization and distributions inside the furnace. The high top pressure up to 2.5 bar makes it possible to operate the furnace at high blast volume without deteriorating process performance. The advanced top charger developed by Z&J Technologies GmbH and verified at LKAB’s EBF gives great flexibility for adjusting the burden distribution. ‘Live sampling’ during the operation through upper and lower shaft gas and burden probes, as well as the inclined burden probe can provide more detailed ‘inside information’ for improved analysis of the furnace process. Tuyere optical cameras can help the operator to enhance the thermal state control to some extent.

Figure 2 shows a schematic layout of the EBF plant. Four ferrous material bins, slag former bins and one coke bin facilitate greatly the test of different burden structure during a campaign. The charging system with skip car can serve the furnace well up to a production rate of about 1.85 t/h. Advanced flexible injection system can admit multiple injections of pulverized coal together with other solid pulverized materials, e.g. BOF slag and flue dust, simultaneously. Oil or reducing gas injection is also possible.

For heating up the cold blast two pebble heaters, functioning as hot stove, are used and are able to heat up the air from ambient temperature to a temperature of about 1250°C. High oxygen
enrichment ratio of up to 40% to blast was tested without any problem during one campaign. The gas cleaning system with sampling function makes it very easy to take flue dust and sludge samples for further analysis when necessary.

The tapping system consists of a drilling machine for opening the tap hole and a mud gun for closing. Sampling of hot metal and slag as well as the measurement of the hot metal temperature during tapping are manually conducted. On-site chemical analysis of hot metal and slag can provide quick thermal information to process engineers for controlling the furnace.

The EBF has been fully financed and is owned by LKAB, but situated on the MEFOS premises. Design of campaign and process control during each campaign are usually conducted by LKAB’s engineers and researchers, and sometimes jointly with partners if a trial was for a joint project. Dissection of the EBF after each campaign, sampling the burden materials during the excavation, as well as the further evaluations of the probing and excavation samples are carried out independently by LKAB.

Figure 1: The LKAB’s experimental blast furnace

Figure 2: Schematic diagram of the LKAB’s EBF

Technical Data of EBF
- Working volume: 9 m³
- Hearth diameter: 1.4 m
- Working height: 6.0 m
- 3 Tuyeres: 54 mm
- Max. top pressure: 1.5 bar
- Throat diameter: 1.0 m

Typical production figures
- Blast volume: 1700m³/h
- O₂ in blast: 25%
- Blast temp.: 1250° C
- Fuel rate: 530 kg/tHM
- Top pressure: 1.0 bar
- Production: 36 t/d
4. Iron Ore Product Development

4.1. Development of the LKAB Acid Pellet\[^{5}\]

LKAB’s olivine pellets were introduced to the market in the early 1980s and great successes have been attained in commercial blast furnaces with 100% olivine pellet operations. For the first time better operating results were achieved with pellets than with sinter in terms of productivity and fuel rate\[^{5}\]. The appropriate high softening and melting properties make it possible for blast furnaces with 100% pellet as ferrous burden to decrease the fuel consumption.

At the end of the last century demand on acid pellets which could be used together with sinter in mixed burden was quite strong. A new acid blast furnace pellet called KPBA with higher iron content than previous acid pellet and appropriate metallurgical properties was then designed and tested in the laboratory. Thanks to the EBF, KPBA was tested and optimized before successfully introducing to customers. In the year of 2000, the new product – KPBA with quartzite as main additive and specially aimed for blast furnace operation with sinter, was launched. Table 1 presents the major chemical compositions of one olivine pellet and KPBA. Currently KPBA has been in regular use in European steel works for more than 10 years. Once again, the improved operation stability in the production blast furnaces – Table 2, demonstrated effectiveness of EBF in pellet development at LKAB.

4.2. Burden Structure Development\[^{6}\]

After the KPBA pellet was launched customers were not 100% convinced by the properties of the new acid pellet, especially one customer demanded fluxed pellet with a basicity of about CaO/SiO\(_2\)=1.05 for use to mix with its own sinter. To fully demonstrate the fitness of KPBA to the mixed burden with sinter for blast furnace operation trials of two periods with mixed burdens of sinter/KPBA/lump ore (SKL) and sinter/fluxed pellet/lump ore (SFL) were carried out respectively at EBF in 2002. To facilitate the evaluation of the trial results the operational process parameters were kept as identical as possible for two trial periods; and the pellet ratio in the burden mix was about 38% following the customer’s request.

![Figure 3: Variations in coke rate and hot metal temp](image)

The trial results as shown briefly in Table 3 indicated that operation with mixed burden SKL did consume lesser reducing agents than that with SFL, but still had higher hot metal temperature - Figure 3. Comparisons of other process parameter e.g. top gas utilization, burden descent and permeability of the burden column, etc. also demonstrated a more stable process with mixed burden SKL. Therefore, it could be concluded that KPBA is indeed a more favorable

<table>
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<th>Table 1: LKAB’s BF pellets</th>
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<tbody>
<tr>
<td>wt%</td>
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<tr>
<td>-----</td>
</tr>
<tr>
<td>Fe</td>
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<tr>
<td>SiO(_2)</td>
</tr>
<tr>
<td>CaO</td>
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<tr>
<td>MgO</td>
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<tr>
<td>Al(_2)O(_3)</td>
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<th>Table 2: Some comparisons between the EBF and an industrial BF</th>
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<tr>
<td>EBF (1.2 m)</td>
</tr>
<tr>
<td>KPBO</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>(\eta_{co})</td>
</tr>
<tr>
<td>(\sigma(\eta_{co}))</td>
</tr>
<tr>
<td>PV bosh</td>
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<tr>
<td>(\sigma(PV))</td>
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\(\eta_{co}\): Top gas utilization \(\eta_{co}=\text{CO}_2/(\text{CO}_2+\text{CO})\); 
\(\sigma\): standard deviation of \(\eta_{co}\) 
PV bosh: permeability index of burden column.
choice in formulating the mixed burden for blast furnace operation.

Table 3: Reducing agent consumption

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<tr>
<th>Burden</th>
<th>KPBA+sinter</th>
<th>Fluxed P+sinter</th>
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<tbody>
<tr>
<td>Coke rate, kg/tHM</td>
<td>415</td>
<td>421</td>
</tr>
<tr>
<td>Oil rate, kg/tHM</td>
<td>114</td>
<td>113</td>
</tr>
<tr>
<td>Red. rate, kg/tHM</td>
<td>529</td>
<td>534</td>
</tr>
<tr>
<td>EtaCO, %</td>
<td>44.87</td>
<td>43.38</td>
</tr>
<tr>
<td>Slag rate, kg/tHM</td>
<td>236</td>
<td>236</td>
</tr>
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</table>

Softening and melting tests of mixed burdens used during trial excluding the lump ore were performed in the laboratory. In-depth analysis of the EBF process phenomena and the laboratory test results indicated that when using mixed burden SFL re-solidification of primary slag might have occurred in the course of slag formation. The reason might be the gradual reduction of wüstite in the primary slag, and as a result raising melting temperature of primary slag. When the re-solidification occurred in the coke layers around the cohesive zone smooth operation of the furnace process would be disturbed. After the trials with two types of mixed burden as mentioned above the customer was indeed convinced by the appropriate properties of KPBA and certainly accepted KPBA as the excellent ferrous material in its mixed burden. Actually KPBA has been in regular use in European steel works for more than 10 years.

4.3. Improving the Properties of Olivine Pellet

To further improve the performance of a blast furnace with 100% olivine pellets as the ferrous burden material a new ideas of coating the olivine pellets with slag formers, which was inspired by the successful technique of coating direct reduction iron ore pellets, was put forward in the year of 2000. After a series of theoretical investigations and laboratory tests, pellets coated with different flux materials were produced and put into trials at LKAB’s EBF. Table 4 presents a comparison of some major process parameters of the trials.

In comparison with the operation of standard olivine pellet – MPBO-3, the performance of the EBF was indeed improved by the use of the coated olivine pellets. The gas utilization was increased, while the fuel rate was decreased as shown in the table. The reason could be that the coating materials may have enhanced the slag formation process in the furnace and permeability of the burden column.

4.4. The AggloLab

As well-known the properties of the original iron ore as well as the wet green pellets during the agglomeration process can affect significantly the quality of the final pellet product. To be able to always supply customers with high quality iron pellet product and to maintain the leading position in the iron ore market, LKAB in 2011 complemented the EBF with an Agglomeration laboratory – called AggloLab in Malmberget. It was expected to conduct cutting-edge research in a modern facility that has everything needed, including full-scale equipment for agglomeration. It will further enhance the product development process and accelerate the transfer of know-how from research result to high quality of iron ore pellet products.

Currently the operational areas of the AggloLab covers:

- Ore preparation – crushing, comminution, screening, separation, concentration, flotation, dewatering, characteriza-tion, structural analysis and ore base inventory
- Agglomeration – micro balling, balling circuit development, oxidation, sintering, development of binding additives, thermo analysis, simulation of
firing process, coating
- Training – of process engineers, process operators, junior researchers etc.

In the near future, an experimental pelletizing plant and probably also an experimental direct reduction plant, will be constructed too. The world-class unique leading product development for iron ore pellet will be formulated.

5. Summary
During the last decade LKAB, as the world leading iron ore product producer and supplier, has put considerable efforts on the product development. The erection of the EBF® in 1997 and its use afterwards for exploring the optimized pellet quality as well as the burden structure for blast furnace ironmaking process have given great helps for LKAB in developing new iron ore pellet products and in the meantime enhancing properties of the existing pellet. As a result, LKAB currently is able to supply the steel industry with world’s best iron ore product package, enabling the optimal function of the modern, larger and fewer blast furnaces of steel producers.

To satisfy the customers’ further demands on iron ore pellet products, an AggloLab was started to build in 2011 and will be commissioned soon. An experimental pelletizing plant and maybe an experimental direct reduction plant will be constructed too. A world leading research centre for iron ore product development and for testing the modern ironmaking technology will be erected at LKAB.

ACKNOWLEDGEMENTS
The authors are grateful to all colleagues and staff at LKAB, MEFOS and project partners as well as contractors that contributed to the EBF operation and campaigns.

References
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