ABSTRACT

Product development is an important part of LKAB's strategy. Much effort is spent on developing new pellets with better properties, contributing to decreased hot metal cost. New pellets were traditionally developed in the laboratory and tested in a production blast furnace. Such trials are risky and evaluation is difficult. To overcome these problems the LKAB board of directors, in October 1996, took the decision to build an experimental blast furnace. A year later hot commissioning started. A first test campaign was run in May and a second in November and December 1998. Two campaigns are planned for 1999.

The experimental blast furnace has a working volume of 8.2 m³ and a diameter at tuyere level of 1.2 m. It is designed to operate at a low fuel rate. During hot commissioning a coke rate of 510-515 kg/thm was reached. This meets our demands well, and is important as it ensures that the composition of the reducing gas is similar to that in a large furnace. Therefore the reduction degree of the pellets when they reach the lower part of the furnace should also agree with larger furnaces and hence the softening, melting and slag formation.

The mechanical load on the burden materials in a large furnace is not fully simulated. Instead, the furnace is equipped with probes making it possible to test the strength of material sampled from the furnace during operation. From operational results presented, it will be shown that low pellet strength during reduction have significant influence on operational results also in the small experimental blast furnace. Even though, the load might be smaller compared to in a large furnace degradation causes uneven gas distribution which results in inefficient furnace operation. In this example, the low strength and degradation resulted from swelling, caused by growth of fibrous metallic iron.

After each campaign the furnace is quenched and dissected. From probings and dissections, large numbers of samples are collected for further analysis to add to our knowledge of the mechanisms of reactions inside the blast furnace and the differences between pellet types.
LIST OF SYMBOLS

MPBO Standard LKAB olivine pellet, produced in Malmberget
KPBO Standard LKAB olivine pellet, produced from Kiruna ore.
TTH Tumbling test for unreduced pellets, fraction >6.3mm
ATH Same tumbling test, fraction <0.5mm
CCS Compression strength, in daN
LTD Low temperature disintegration test (reduction to magnetite at 500°C)
ISO 4695 Reducibility test, at 950°C to 65% reduction
ITH Tumbling test on reduced material from ISO4695
η CO Gas utilisation [ %CO / (%CO + %CO2)]
BRI Burden Resistance Index (modified Ergun-equation)

1 INTRODUCTION

LKAB's experimental blast furnace in Luleå is a strategic investment that enables faster, assured product development. The furnace is a cornerstone of LKAB's research and development effort. By building an experimental blast furnace to use in the process of product development, LKAB expects to reach the position as the world's leading supplier of blast furnace pellets, in terms of product quality and performance. This is important as we work to increase our pellet production. The goal is to design and produce pellets that, when used, creates added value in the customer's process, compared to the use of sinter or pellets from any competitor. Previous experience from work on pellet development shows that the step from laboratory testing to a trial in a full-scale blast furnace is big and risky. Proper evaluation of pellet performance from such trials is also rather difficult and when trials can be conducted is governed by a number of factors, other than the needs from the product development work.

1.1 LKAB's product strategy

The total production of LKAB has slowly increased since the mid-eighties and was last year about 22 million tons. In the same time pellet production has almost doubled while the deliveries of high phosphorous fines and lump has ceased. Today almost two thirds of our production is made up of pellets. Blast furnace pellets dominate but pellets for direct reduction is also produced, and amounts to about 25% of the pellet production. The strategy is to continue to increase pellet production.

The blast furnace is still the dominating process for reduction of iron ore, and will continue to be so for the foreseeable future. Thanks to new technologies used in blast furnace operation, the challenges from new reduction processes are met. Therefore, blast furnace pellets can be expected to remain the most important product for LKAB. The changes in the process put new demands on the raw materials, and the development of blast furnace pellets to meet these is therefore a high priority task for LKAB.

1.2 Pellet development in LKAB

Our present blast furnace pellet was first introduced in 1982. It is produced from magnetite ores, mined in Kiruna or Malmberget. The concentrate itself has a very low gangue content. Bentonite is added as a binder and olivine to adjust the composition before pellets are formed.
and fired. Outstanding operational results have been achieved using 100% LKAB olivine pellets and over the years, the product has been optimised to meet customer demands.

In the late eighties work on developing a successor for the present pellet was intensified. The aim was to create a highly reducible pellet with a high iron content, without compromising the high reduction strength or well defined melting properties of the olivine pellet. The idea was to decrease the need of reductants by making the pellet more reducible and also to allow for decreased slag volumes, by lowering the silica content to a minimum. A pellet that met the demands well and showed very good results in all laboratory tests used at the time was tested in one of SSAB's furnaces here in Luleå in 1991, with devastating results. Gas utilisation decreased, as did permeability while heat losses became high in the upper part of the furnace and the hearth got cold. The reason for the problems encountered was not evident and could be evaluated only after trials in a small pilot blast furnace of British Steel. There it was possible to quench the furnace after a period of operation. The reason for the problems was catastrophic swelling. Metallic iron formed in the shape of whiskers in the blast furnace, but not in ordinary swelling tests with idealised gas composition. Two more trials in the small pilot blast furnace resulted in a modified pellet ready for full scale testing.

1.3 The need for an experimental blast furnace

The need for a step in between laboratory scale metallurgical testing and full-scale tests of new blast furnace pellets is evident from this example. It is a way to reduce the risks when full-scale tests are performed. The possibility to use a furnace that is not used for hot metal production can also allow for faster progress in pellet development and for testing of pellets one would not dare to test in a full-scale furnace.

The reason for LKAB to build its own experimental blast furnace instead of continue to use the British Steel pilot blast furnace was primarily to overcome some of the problems with that very small furnace. Although the furnace had proved very useful, a weakness is the very high rate of reductants. From a pellet developing point of view, it can be used to simulate the upper part of the blast furnace but conditions in the lower part will differ significantly from a full-scale furnace. Therefor it is not sufficient for testing of neither, softening and melting behaviour, or slag formation. The small furnace also had an open top, which made gas sampling impossible and prevented a full mass and heat balance to be made.

1.4 The decision to build a small blast furnace

A feasibility study was initiated in 1994 to evaluate the possibilities to build an experimental blast furnace and later a project to work out the construction. Representatives from both MEFOS and SSAB took active part in the work and views on the construction were gathered from all over the world. In October of 1996 the LKAB board of directors decided to build the furnace and also to run five campaigns in 1997-1999. A year later hot commissioning started and in 1998 two test campaigns to try out new pellets were carried out.

2 THE EXPERIMENTAL BLAST FURNACE

The experimental blast furnace was fully financed by LKAB. It is owned by LKAB and situated on the MEFOS premises, next to the Luleå plant of SSAB. It is built inside a building used for coal gasification trials in the eighties and during operation SSAB supplies raw materials,
including gases, carry out analyses on hot metal and slag, etc. This has had an instrumental influence on the costs of building and operating the experimental blast furnace. It is operated in co-operation with MEFOS, whose in-depth knowledge of blast furnace operation has been invaluable in planning and conducting trials.

2.1 Description of the furnace

The experimental blast furnace is shown in Figure 1. It has a working volume of 8.2 m$^3$ and a diameter of 1.2 m at tuyere level. From tuyere level to stock line the height is 6 m. There are three tuyeres placed with 120 degrees separation. We use tuyeres with a diameter of 54 mm, resulting in a blast velocity of 150 m/s at normal blast volume. The furnace is equipped with systems for injecting pulverised coal, oil and slag formers.

Great effort has been taken to keep heat losses to a minimum and therefore insulating refractories were chosen. Only the bosh and tuyeres are water-cooled. The blast is normally preheated to 1200°C in pebble heaters, also to compensate for heat losses. There are two pebble heaters. One is used for heating blast while the other is fired with propane. Small alumina balls are used for heat storage.

The raw materials system consists of four bins for pellets or sinter, one bin for coke and two small bins for slag formers. Each material is weighed separately according to the actual recipe and put to a receiving hopper, located at the lower part of the Skip Bridge. The material is transported to the furnace top by a skip and emptied to a receiving hopper. Below the receiving hopper there is a pressure equalising lock hopper. The top pressure can be controlled up to 1.5 bar overpressure.

The experimental blast furnace is equipped with a bell top. The bell is fixed and the material is charged to the furnace by lifting the bell ring. There is no moveable armour, so the burden distribution control is made by controlling the lifting speed of the ring and by adjusting the charging level. Two mechanical stock rods are used to monitor the burden descent and to control the charging into the furnace. The top gas is transported through the uptakes and downcomer to a dust catcher. The gas is further cleaned in a venturi scrubber and a wet electrostatic precipitator. Finally, the top gas is flared in a torch.

The furnace has one tap hole. It is opened with a drill. After each tap, the tap hole is closed with a mud gun. The hot metal and the slag is tapped into a ladle, transported to the SSAB steel plant, and used as scrap.

Burden probes are installed at three different levels. There are two horizontal probes, one at tuyere level and one in the shaft, and one inclined probe to sample in the bosh. The shaft probe and the inclined probe at the bosh parallel are equipped with two different heads. One is used to collect material samples from the furnace. The other is used to collect furnace gas for analysis and to measure the temperature. The tuyere probe is equipped with a gas collecting and temperature-measuring head.

To make dissection and repair easy the hearth is detachable and can be separated from the furnace in one to two hours.
2.2 Operating the experimental blast furnace

The operation of the blast furnace is very similar to a commercial blast furnace. At blow in, charcoal is used as start up burden in front of the tuyeres. Within the first hour, full wind is reached and blast temperature is in the range of 800 to 850 degrees. The blast temperature is increased to the set point in the first 24 hours of operation. The amount of reducing agents is slowly decreased during the first 72 hours, to a level corresponding to about 110%, compared to normal operation. After this period injection of coal or oil is started. Operation is stabilised during the next 48 to 72 hours.

The furnace is operated at productivity ranging from 3.2 to 3.8 t/m³day. Hot metal and slag composition is kept at set points decided before the campaign. Normal tap-to-tap time is 70-80 minutes, and normal tapping times are five to fifteen minutes. Drill diameter varies between 25 and 28 mm, depending on tapping conditions in previous tap. The hot metal temperature is measured with a temperature probe. Hot metal and slag are sampled at every tap and analysed at SSAB. Normal analyse response time is 20 minutes.

The test periods normally starts with a transition period where the test material (pellets) is charged to the furnace for a period of 24-36 hours, corresponding to six to nine throughputs. After that period the actual test starts. The test time depends on what objectives that are to be met for the test. A typical test period range from two days up to six days. During this time operational data is logged and monitored closely. Measurements are normally logged every second. Sampling of raw materials and burden materials, using the burden probes, are done. Raw materials are always sampled when filled into the bins, after screening. Sampling from the furnace is done once or twice every shift. During campaigns, reference material is charged to the furnace several times to check if there has been any change in the furnace or auxiliary equipment that influence the operation of the blast furnace and the results from operation.

We know from excavations that there are rather large variations between the material in the centre of the furnace and material closer to the wall. Not all sampling results in a completely filled probe and for this reason comparison between materials require a rather thorough analysis, to separate between effects of material sampling and material properties. The material retrieved is divided into samples representing different positions on the radius of the furnace. We screen all material taken out of the furnace and the fraction >6,3 mm is sorted, so that pellets, coke and slag formers are separated. Breakdown and strength of material are tested and samples are prepared for microscopy investigations. Chemical analysis is also done, primarily to determine overall reduction degree.

Process data are logged every second and stored in a database, together with ten-second and minute averages. The data in this database is transferred at regular intervals to another database where process data calculations are carried out. Data in this database is used for reports, trend charts and mass- and heat balance calculations. Chemical analyses for raw materials, hot metal and slag are also stored in this database.

As to now our experience is that the experimental blast furnace is a very sensitive tool for detecting differences in properties for different pellets. The response time is much shorter for the experimental furnace compared to a commercial furnace.
2.3 Dissecting the furnace

At the end of each campaign, the furnace is quenched. During the final hours of operation a number of basket-samples are introduced into the furnace. After this is done, operation is interrupted. To stop chemical reactions as fast as possible nitrogen is added from the top and, after that, the blast volume decreased and stopped. The nitrogen then blows down the furnace. Within minutes, the reducing gases are removed. As the cooling gas is added from the top a heat wave, moving upwards is avoided and therefore changes in the material during cooling is kept to a minimum. The material in the furnace and the refractories needs to be cooled for at least ten days before dissection of the furnace can start. To facilitate access to the interior of the furnace, the top section of the Skip Bridge, the receiving hoppers and the furnace top can be dismounted.

Dissection is carried out much like an archaeological excavation. As long as it is possible, the original pellet and coke layers are followed. The work is concentrated on the pellet layers. Samples are taken from every pellet layer, according to a predetermined plan. We take out both small samples for microanalysis and larger samples for chemical and mechanical testing. Throughout the work great effort is spent on documenting all observations.

3 RESULTS FROM EXPERIMENTAL BLAST FURNACE OPERATION

For LKAB there are both long term and short term results to achieve from the work carried out in the experimental blast furnace. Short term results are gained when we test a number of pellets, previously tested in laboratory scale, to evaluate if any of them behave well enough in the blast furnace process to be tested in full scale trials. From operational results, we can give a good description of pellet behaviour to the potential customer.

In some cases, we have tested pellets, previously tested in full-scale trials with confusing results. To distinguish between problems caused by disintegration of pellets and slag formation problems can be tricky from full-scale trials. By testing the same pellets in the small blast furnace and take samples during operation, we can find the cause to various observations. This knowledge is used to make necessary changes in operation, to modify the pellet or to altogether skip work on a proposed pellet type.

The possibility to sample material during operation gives enormous possibilities to learn how material properties and process status relates, for different burden materials. We can also use information from material taken out of the experimental blast furnace to design improved laboratory tests for pellet testing in the future. The long-term goal is to use this new knowledge to design the "perfect blast furnace pellet".

3.1 Example of pellets tested in the experimental blast furnace

Results from two new types of pellets will be discussed in some detail. The first is FP05, a pellet with lower magnesia content compared to regular LKAB olivine pellets, and the second is FP14, a fluxed pellet. FP14 was tested in full-scale trials in 1996 and left us with questions about reduction properties. MPBO, our present commercial olivine pellet produced in Malmberget, is used as reference material in all campaigns. Operational results will be compared to observations on material from the furnace. The compositions of the pellets are presented in Table 1 along with results from mechanical and metallurgical testing.
MPBO is produced in Malmberget and used by SSAB in Sweden and by Fundia in Finland. Outstanding blast furnace operation results have been achieved with MPBO. It is produced from high-grade concentrate, mainly made from magnetite but with some hematite added. Bentonite binder and magnesia-silicate mineral (olivine/serpentine) are added before pellets are formed and fired. FP05 is similar to MPBO. Part of the addition of magnesia-silicate mineral is exchanged for quartzite. This results in a lower magnesia content while silica is kept at the same level as for MPBO. FP14 is a pellet produced using bentonite binder and addition of limestone and magnesia-silicate mineral. The result is a fluxed pellet containing close to one per cent magnesia with a rather high iron content.

Table 1 presents actual data for FP05 and FP14 used in the experimental blast furnace in December of 1998. FP05 was produced in February and FP14 in September. Pellets for tests in the experimental blast furnace are produced in a small pellet plant in Malmberget, with a capacity of 1000-1500 ton/day. About 500 ton of each pellet type is made in about 12 hours and time is not spent on process optimisation at this stage of the work. MPBO was taken from SSAB and rather "fresh from the plant". The data are typical values for MPBO.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Pellet data</th>
</tr>
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<tbody>
<tr>
<td><strong>Composition</strong></td>
<td><strong>MPBO</strong></td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>1.95&lt;sup&gt;2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>MgO</td>
<td>1.45&lt;sup&gt;2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>CaO</td>
<td>0.25&lt;sup&gt;2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>0.4&lt;sup&gt;2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fe</td>
<td>66.7&lt;sup&gt;2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>B&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.13</td>
</tr>
</tbody>
</table>

| Mechanical testing | | | |
| ISO 3271 | Tumble Index > 6.3 mm (%) | 94<sup>2)</sup> | 95<sup>1)</sup> | 92<sup>1)</sup> |
| Abrasion Index < 0.5 mm (%) | 5<sup>2)</sup> | 4<sup>1)</sup> | 7<sup>1)</sup> |

| Metallurgical testing | ISO 13930 | Low Temp Dis >6.3mm (%) | 73<sup>3)</sup> | 76<sup>3)</sup> | 84<sup>3)</sup> |
| <0.5mm (%) | 7<sup>3)</sup> | 6<sup>3)</sup> | 10<sup>3)</sup> |

| ISO 4695 | Reducibility R<sub>40</sub> | 0.49<sup>3)</sup> | 0.49<sup>3)</sup> | 1.25<sup>3)</sup> |
| I-tumbling after ISO 4695 >6.3mm (%) | 78<sup>3)</sup> | 85<sup>3)</sup> | 23<sup>3)</sup> |
| <0.5mm (%) | 14<sup>3)</sup> | 11<sup>3)</sup> | 32<sup>3)</sup> |

1) Sampled during production
2) Typical values for the product
3) Sampled prior to charging into the blast furnace
FP05 was designed to decrease the magnesia content of the blast furnace slag. In olivine pellets a substantial amount of the olivine added does not take part in the slag formation inside the pellets during firing. It is found as "remaining olivine" in the pellets. By exchanging some of the silica added together with magnesia for quartzite more silicate should form and give extra mechanical strength to the pellet.

From compositional point, FP14 was designed to enable operation with very low (130 kg) slag volume containing no more than 12% magnesia. Limestone is added to form a slag phase of calcium silicate, giving good reducibility and high strength to the pellet. Magnesia gives good high temperature properties. Mechanical properties are good and no alarming swelling is observed. The melting temperature is high. In 1996 FP14 produced in Malmberget was tested in full-scale trials in one of SSAB's blast furnaces in Oxelösund. It was possible to operate the blast furnace with 100% FP14, at a high production rate. However, the anticipated decrease in reductants rate was not experienced and the central gas flow was lost. Why this happened was not clear but a rather low strength after reduction can be observed.

### 3.2 Operational data

FP05 and FP14 were tested five and six days respectively in the experimental blast furnace. A period of 36 hours of operation with each pellet type is chosen for this example. Operational parameters for the periods are given in Table 2.

<table>
<thead>
<tr>
<th>Pellet</th>
<th>Blast Volume (Nm³/h)</th>
<th>Flame Temperature (°C)</th>
<th>Top Pressure(kPa)</th>
<th>Reducing agents (kg/tHM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP05</td>
<td>1641</td>
<td>2229</td>
<td>99</td>
<td>516</td>
</tr>
<tr>
<td>FP14</td>
<td>1630</td>
<td>2220</td>
<td>98</td>
<td>541</td>
</tr>
</tbody>
</table>

The operational results for the two pellets are quite different. This can be seen, from most operating parameters and some examples will be given. Gas utilisation ($\eta_{CO}$) is shown in Figure 2. During FP05 operation, $\eta_{CO}$ is rather stable, varying between 45 and 51%. There is, however, a tendency of irregular behaviour at the end of the period. The results for FP14 are very different, with drops in gas utilisation from the level 48–51% down to 40%, at more or less regular intervals. The drops last for 1 to 1.5 hours and then the gas utilisation recovers to the previous level.

Burden resistance index (BRI) is shown in Figure 3 and pressure drop in the lower shaft in Figure 4. BRI is very stable for FP05. The pressure drop in the lower shaft also shows small variations for FP05. The pressure drop at this level reflects the pressure drop over the cohesive zone. For FP14 BRI first increases and then suddenly drops to lower levels, stays there for a few hours and then rise to higher levels. This pattern is repeated with about six hours intervals. The pressure drop in the lower shaft also shows periodic irregularities of a similar nature as BRI but there are also other variations, which will not be dealt with here.

The burden descent rate is plotted in Figure 5. For FP05 the burden descent rate, is varying in the range 3.0 to 6.0 cm/min over the entire 36-hour period. The average is 4.4 cm/min and the
standard deviation is 0.6 cm/min. The burden descent rate for FP14 shows the same cyclic behaviour as for the other measured parameters. The average for the period is 4.0 cm/min with a standard deviation of 1.4 cm/min

From Table 2, it can be seen that the consumption of reducing agents (coke and coal) was 516 kg/tHM for FP05 and 541 kg/tHM for FP14, a difference of 25 kg/tHM. Hot metal temperatures are presented in Figure 6. Also tapping temperatures were more stable when the furnace was operated on FP05 compared to FP14. The average hot metal temperature is 1462 °C for FP05 with a standard deviation of 15°C. For FP14 the average temperature is 1414°C and the standard deviation 26°C. The set point for hot metal temperature is 1430°C. As each tap is small heat losses to the refractories during tapping are large and the temperature drop substantial. Carbon and silicon analyses for the hot metal are given in Figure 7. The average carbon and silicon content for the period with FP05 is 4.6 % and 1.5% respectively. The corresponding values for the period with FP14 is 4.2 % and 1.0 %. As the tap hole cannot be scaled down to the same extent as the furnace itself tapping time is short and tap to tap time long, resulting in higher silicon levels compared to commercial blast furnaces.

As can be seen from the data presented the experimental blast furnace runs well on FP05. The process is very stable and the rate of reductants is low compared to most other materials tested so far. The hot metal temperature was comparatively high and this indicates potential to decrease the amount of reductants further. Operational results are at approximately the same level as we experience with MPBO but process stability is slightly better.

From the data presented, it can be seen that operation with FP14 is much less stable compared to FP05. There are periodic disturbances resulting in a high consumption of reductants as well as poorer hot metal quality. These results from the period with FP14, also give the conclusion that some of the reduction properties of this pellet causes a disturbance in the gas distribution. During operation with FP14 uneven gas temperatures were observed on the cross probe and skin flow thermocouples. These temperatures did also vary. This was interpreted as formation of gas channels. The effect of this is local areas with a poor gas contact, channelling of gas and an unbalance between the reserve zone and the cohesive zone.

3.3 Observations on material from the furnace

Material was taken out with probes during operation for FP05 and FP14 as well as for MPBO. At this time, the complete investigations have not been carried out. When FP14 was sampled comparatively large amounts of fines was present, especially close to the wall.

The experimental blast furnace has been quenched and dissected three times so far. This includes one excavation with MPBO, one with KPBO (commercial olivine pellet from Kiruna) and one with FP14. Rather large differences between olivine pellets and FP14 could be observed. In the upper part of the furnace, the materials appeared rather similar. Pellets looked good and not much fines or dust could be observed. For MPBO, this continued all the way down the furnace. Low in the furnace pellets were metallic and bonded together in rather open "networks" and a cohesive zone of one or two pellet layers was found. KPBO looked similar. For FP14 channels could be observed in the shaft and further down some swelled pellets was discovered. Soon the cohesive zone was found, at a much higher position in the furnace compared to MPBO and KPBO. It lasted for about eight pellet layers and in these, swelled pellets formed an impermeable mass. This means that the cohesive zone of FP14 is three to four
times thicker, compared to that of olivine pellets. In FP14 pellets the metallic iron had formed as whiskers to a large extent.

### 3.4 Conclusions about pellet behaviour

Operational data from FP05 shows very stable operation. MPBO behaves in a similar way. FP14 operation is much less stable, resulting in higher consumption of reductants and inferior hot metal quality. The operational data together with probe samples and results from dissection leads to the conclusion that reduction strength and swelling properties for FP14 is not sufficient for good blast furnace operation. This results in high and fluctuating burden resistance, gas channelling with associated high top gas temperature, irregular burden descent and varying gas utilisation. These are all phenomena well known from blast furnaces all over the world.

When the furnace was quenched with FP14, the process had just recovered from a period of bad operation, as discussed in 3.2. The cyclic nature of operation indicates that the state of the material could have been quite different if some other stop time had been chosen. What can be concluded from the observation of swelled pellets and impermeable layers is that the contact between pellets and gas has been hampered.

Speed of reduction influences the structure of reduced phases and therefore the strength of reduced pellets. This is one explanation to the periodicity of operational data with FP14. When operation is good, reduction may be so fast that swelling becomes a problem. The result is bad gas permeability, formation of channels and inefficient furnace operation resulting in decreased reduction rate in the upper shaft. This means less swelling, better pellet strength, improved gas distribution and a period of better furnace operation. Reduction degree influences softening and melting behaviour of pellets and this may further accentuate the periodicity of operation.

Operation during the full-scale trial with FP14 was not as bad as operation in the experimental blast furnace. There were, however, problems to maintain a good gas distribution, observed from the loss of central gas flow and high consumption of coke and coal. This shows that low reduction strength have strong effect on operation in the small experimental blast furnace.

The examples given also points out the paramount importance the raw materials have on blast furnace operation. In this case the two types of pellets have the same basic concentrate and is produced in the same pellet plant. The amount of additives is about the same and only 3.0 to 3.5%. It is amazing that these small differences can cause two completely different operations in the same blast furnace.

### 4 SUMMARY

The experimental blast furnace is a unique test facility for blast furnace burden materials. It presents great possibilities for product development and process research. Many of the risks involved in full-scale production trials can be avoided and evaluation is facilitated thanks to the possibilities to take material out of the furnace for investigation. The furnace was built mainly for purpose of product development, but is also used in other blast furnace related research projects.
The efforts to keep heat losses to a minimum have proven sufficient. The result is a consumption of reducing agents similar to many full-scale blast furnaces. The chemical and thermal treatment the pellets undergo in the experimental blast furnace can therefore be said to simulate a full-scale blast furnace. The example from operation with FP14 also proves that the furnace is sensitive to inferior pellet strength during reduction. In this case, the effect is more pronounced in the experimental furnace compared to when the same pellet was tested in a full-scale blast furnace.

As material can be recovered from the furnace during operation or after quenching, reduction mechanisms for various material types and process conditions can be investigated. From material investigations improved test methods for laboratory scale testing and criteria for evaluation can be developed. This will aid future design of blast furnace pellets.

If the experimental blast furnace is used to its full potential, it will serve as a valuable tool for blast furnace development to improve process efficiency. Challenges from alternative reduction processes for iron ores and increased environmental demands will necessitate further process research and technical development. The small blast furnace can prove very important in this work. Two campaigns to test new pellets will be run by LKAB in 1999. In the next millennium, there will be possibilities also for others to use it. The experimental blast furnace strengthens Luleå's position as an internationally significant centre of metallurgical development.

ACKNOWLEDGEMENTS

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