BLAST FURNACE TECHNICAL, OPERATIONAL AND ECONOMICAL ASSISTANCE[1]

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Abstract

The luxury of having excellent raw materials to achieve stable, high productivity operations is history. More and more, steel companies are faced with wider varieties of raw material qualities and need to focus on robust operational practices to remain competitive. The main challenge will be to accommodate high slag volumes (e.g. above 325 kg/tHM) while achieving sufficiently high productivity (e.g. above 2.75 tHM/m³WV.24hr) at high rates of fuel injection (coal or natural gas). With a wide reference base for Blast Furnace technology as well as operational assistance, Danieli Corus offers service packages based on an integrated approach focusing on the entire value chain in Blast Furnace Ironmaking, ranging from raw materials up to the BOF plant. This approach incorporates not only the "know how", but also the "know why" of the Blast Furnace process. This article discusses the benefits of these services for the Blast Furnace Operator in terms of Technology, Economy and Operations.

Key words: Blast furnace ironmaking; Operations; Profitability.

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1 INTRODUCTION – PROFITABILITY IN PERSPECTIVE

In order for Blast Furnace Ironmaking operations to remain profitable, plant managers and operators need a way out from under the pressure exerted on plant performance by the low prices that are a result of substantial global overcapacity on the one side and by high raw material costs) on the other. Pressure on profitability has been encountered before, and innovative techniques, such as reducing the cost per tonne of hot metal produced by for instance ramping up Pulverized Coal Injection rates have successfully lowered the potential base costs of hot metal.

Today, however, deteriorating raw material qualities are changing the face of Blast Furnace operability to such an extent that in many situations it has become exceptionally challenging to keep operations profitable. Operational and maintenance philosophies are usually typical for a certain plant, country or company. Having a third party evaluating these is often a very accessible method for finding savings or other improvements for these contributors to the cost per tonne of hot metal. Such a third party is required to have extensive experience in technical, economical and operational assistance for Blast Furnace Ironmaking around the world and under the most widely varying circumstances.

2 TECHNICAL ASPECTS

Technical reviews comprise of assessments of the plant equipment and reviewing maintenance schedules. Many of the factors influencing maintenance requirements are actually operations dependent and will be discussed in the Operations section. On the strictly technical side, plant assessment tends to be a hands–on process.

After assessing the condition of any of the plants or equipment, it is essential to prioritize which areas should be addressed first with the (limited) funds that may be available. Given the practical and economic circumstances, under which this is currently conducted, the way priorities are set should be supported by solid and reproducible arguments. Since covering risk, regardless of whether it's technical, financial, operational or related to health, safety and the environment, always has highest priority, executing a thorough risk analysis is a good way of setting priorities.

One factor is to evaluate the potential consequences of failure. A risk assessment is then completed with the evaluation of these consequences per area including an estimate of the likelihood of each individual failure. This process involves an identification stage whereby all the major components are quickly assessed in terms of their operating life, design life and current condition. From there, the risks may be identified and quantified in terms of the cost of failure, and likelihood of such a failure occurring. This appraisal, presented in a schematic graph shown in Figure 1, gives a very clear overview of which areas should be given highest priority.

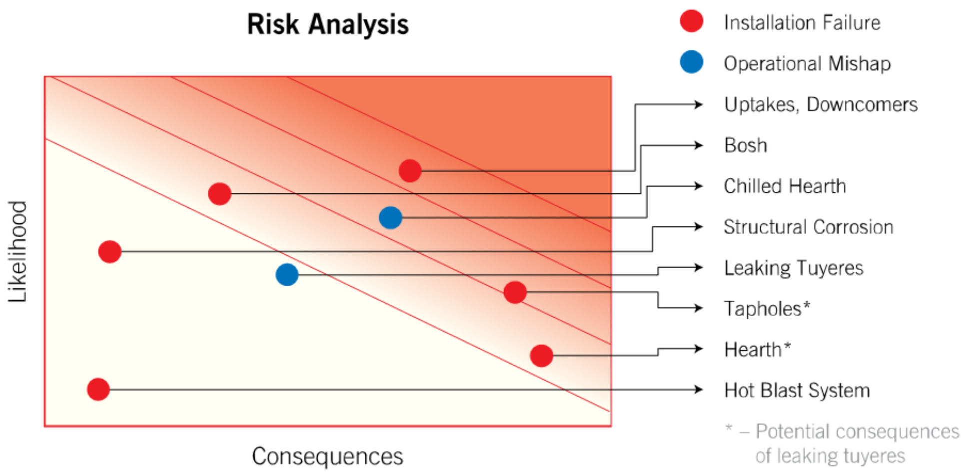

Figure 1. Risk analysis for blast furnace plant.

Once the analysis is complete, the costs of repair or replacement of the essential items in need of attention can be estimated. These can vary depending on whether a 'quick–fix' can be carried out, to make the item last until the next major repair, or indeed if the item requires a major repair in itself. In addition to this risk analysis, an in–depth review of potential escalation of associated cost for maintenance or repair should be conducted for further refining of priorities. In some of these cases, preventive maintenance may be found to not only contribute to reliability and availability, but to be a cost saver for the longer term as well.

When planning future scenarios, criteria should be set for assessing the possible alternatives. In addition to the discussed risk elimination, key issues may relate to expected life after the repair and revised cost structures that come as an additional benefit. A forecast for future demand and prices should be estimated to complete the scenario planning. By planning systematically, all repair scenarios from 'emergency patch repairs' to 'full scale relines' can be reviewed on their business aspects.

Finally, regular checks on the installation that are carried out by the operator, such as preventative water leak detection, are reviewed. These should all be done in a reproducible, controlled manner by all participants, with no variation stemming from the persons involved. Each operator must be familiar with the correct method, whatever that may be. Controls should be in place to ensure that each relevant item is regularly checked, confirmed by both those carrying out the checks and the supervisor responsible. Developing these practices as part of the daily tasks of the operators can go a long way to minimize damages and maintenance cost.

2.1 The Blast Furnace Proper

Being the heart of the ironmaking operations, the condition of the blast furnace proper should be examined thoroughly area by area.

In the bosh and stack, the most significant wear mechanism is cracking of the bricks caused by temperature fluctuations. Bosh and stack monitoring is usually more straightforward compared to the hearth, since thickness can be measured with mechanical rods during short stops. It can also be measured ultrasonically by installing ceramic rods in the refractory lining.

When excessive wear is present and the steel shell is directly exposed to the burden, hot spots will be a near immediate result and embrittlement and cracking of the shell will occur six to twelve months after initial exposure. In this case the only remedy is to replace the shell. When shell replacement is required, it may be combined with a replacement of the cooling and lining system, better suited to the prevailing operating conditions. During the procedure, a detailed relining and refractory maintenance program can be defined, along with longer term strategies for either complete or partial replacement of worn areas.

Figure 2. Limited wear after ten years in operation (plate cooled bosh).

The condition of the refractories in the hearth and around the tapholes is the most critical for campaign extension. The most common method for in depth analysis of the hearth condition is to use thermocouple data, combined with thermal models. In reality, the situation for older furnaces is that the thermocouple grid is not always fully functional or reliable. In addition, thermocouples may show drift or "aging" over time through exposure to high temperatures for a long period of time.

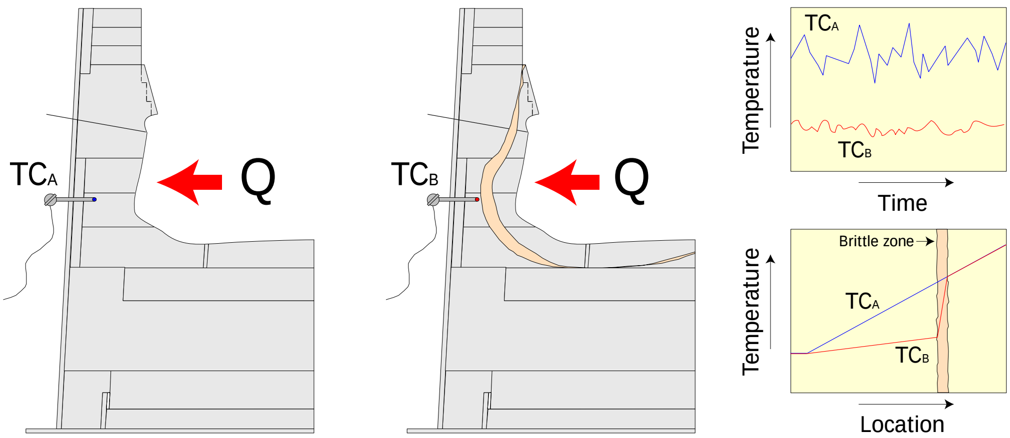

Figure 3. Misleading effect of the brittle zone.

Finally, the brittle zones that may be found in the hearth area can cause major conductivity anomalies leading to false interpretations of measurements. A more direct way of determining the hearth refractory condition is to perform core drilling.

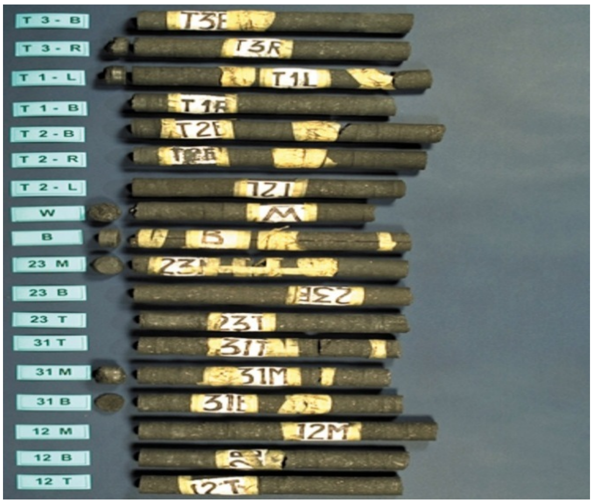

Figure 4. Typical results of core drilling procedure.

Gas leakage through the shell, even in small quantities, can cause major CO attack on hearth refractories and should be eliminated. An important factor for long hearth life is the ability to establish effective cooling of refractory linings. This can be achieved by having good thermal contact between the refractory, the shell and the cooling system. If there are doubts on the cooling efficiency, the thermal contact can be restored by injecting paste. However if this is not done carefully, uncontrolled injection can destroy more than it will solve, since the hearth wall bricks can easily be dislocated.
If the data collected and observations made over time are incomplete or contradictory, further in–depth analysis of the hearth condition is required.

2.2 Hot Blast Stoves and Hot Blast System

Well designed and operated hot blast systems can have a lifetime of over twenty years, but this of course can be considerably shortened if the prescribed conditions are not met. The techniques used to establish the actual condition of stoves are:

- thermographic pictures of critical areas made at regular intervals;
- efficiency calculations by analyzing the operating data and composition of gas, air and flue gas during normal cycles;
- analysis of the timing of the cycles;
- pressure drop measurements over the checker column during firing;
- calibration check of all instruments;
- detailed inspection for the presence of inter–crystalline stress corrosion cracking in the shell and around all welds in the system.

For Hot Blast Systems, inter–crystalline stress corrosion is a serious threat that may be hard to assess. This type of corrosion occurs in high temperature, high stress situations and is caused by NO_x formation and condensation of acids against the steel shell above 1380°C. It appears as a fine divided network of microscopic cracks that are very hard to detect by ultrasonic non–destructive methods (Figure 5). It is usually first found around and across welds or highly stressed parts. Once it becomes evident as through–blowing cracks, it is usually too late to repair it in a simple way. The final solution is generally to replace the shell completely, or to encapsulate the entire hot blast system by a double shell.

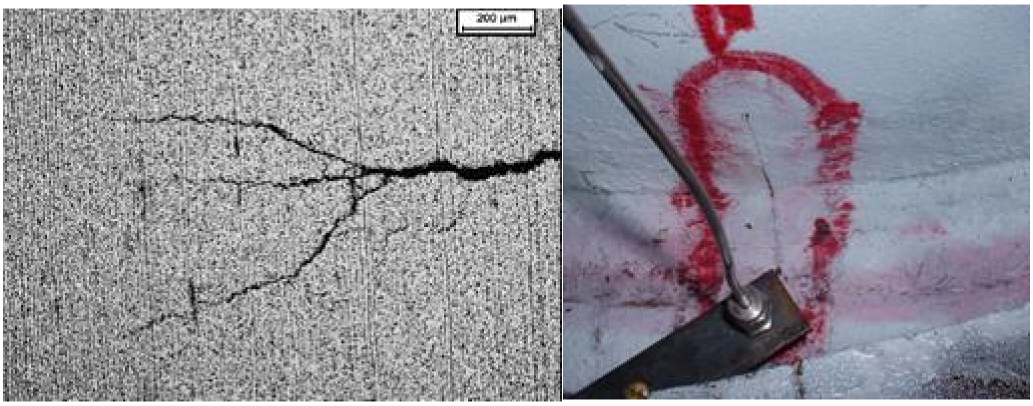

Figure 5. Microscopic detection of Inter–Crystalline Stress Corrosion in Hot Blast system components.

2.3 Structural and Mechanical Parts

Today, data for monitoring the condition of mechanical equipment is very reliable and usually available on–line in real time. This makes it possible to analyze and filter raw data, and to rework this into highly meaningful and presentable results that can be used for condition monitoring and repair planning. Repairs to key equipment such as bell–less top rotating distributor bearings or skip winch motors or bearings can be scheduled with far more certainty than has previously been possible. The condition of structural parts can be monitored successfully with non–destructive testing, such as with ultrasonic devices.

3 OPERATIONAL ASPECTS

The manner in which the Blast Furnace is operated will have a significant impact on operating cost and productivity of that unit. In the long term, it will also have an impact on the potential to achieve longer campaign lifetimes, thus contributing to a lower cost per tonne through more favorable depreciation. During an operational assistance project, it can be indicated where the Blast Furnace is being operated most favorably, and where not.

With overcapacity and price/cost dynamics dominating the face of our industry today, benchmarking or optimizing operations is not targeted at maximizing output or quality. Operators are confronted with their former operating points being beyond boundaries that are imposed by availability of raw materials of sufficient quality. . The penalties that are brought about by these new realities should be accepted and left behind to find new operating points with new optimums within the boundaries of today, but can also accommodate tomorrow's headlines.

A plant's performance is measured against new perspectives. In a situation of global overcapacity, maximizing plant output may be called for in only very few situations. However, the majority of plants will need to match output and demand – either from the market or downstream operations – while optimizing profitability.

Operating envelopes are being made stricter and stricter by these mechanisms, taking room for error out of every dimensions along which a plant may measure performance. Finding operating points at the boundaries of the envelope is also not about minimizing penalties, but about balancing them. However, whichever the dimensions for performance are chosen by or forced upon the operator, the cornerstone for continued performance is consistency in the operation. In addition, throughout any process of finding and defining new operating points, risk mitigation is pivotal. The process should always include an assessment of whether or not an operating point introduces a higher risk of e.g. hearth chills.

As a starting point for an operational review, the main process parameters may be studied covering a period of e.g. the past twelve months. Given the highly dynamic nature of the current operating environment, covering a long history may be an option that adds valuable information in only very few situations. An analysis of the operating history allows for comparison of current practices against a plant's own history for any desired (or required) set of operating parameters. The outcome may be further benchmarked against similar furnaces or sites operating under whichever conditions may be chosen relevant.

Whether benchmark analysis is performed on current vs. best on the same furnace or site, or on representative data for comparable furnaces or sites, the result is the same. Differential factors are determined, leading to a list of priorities for further review.

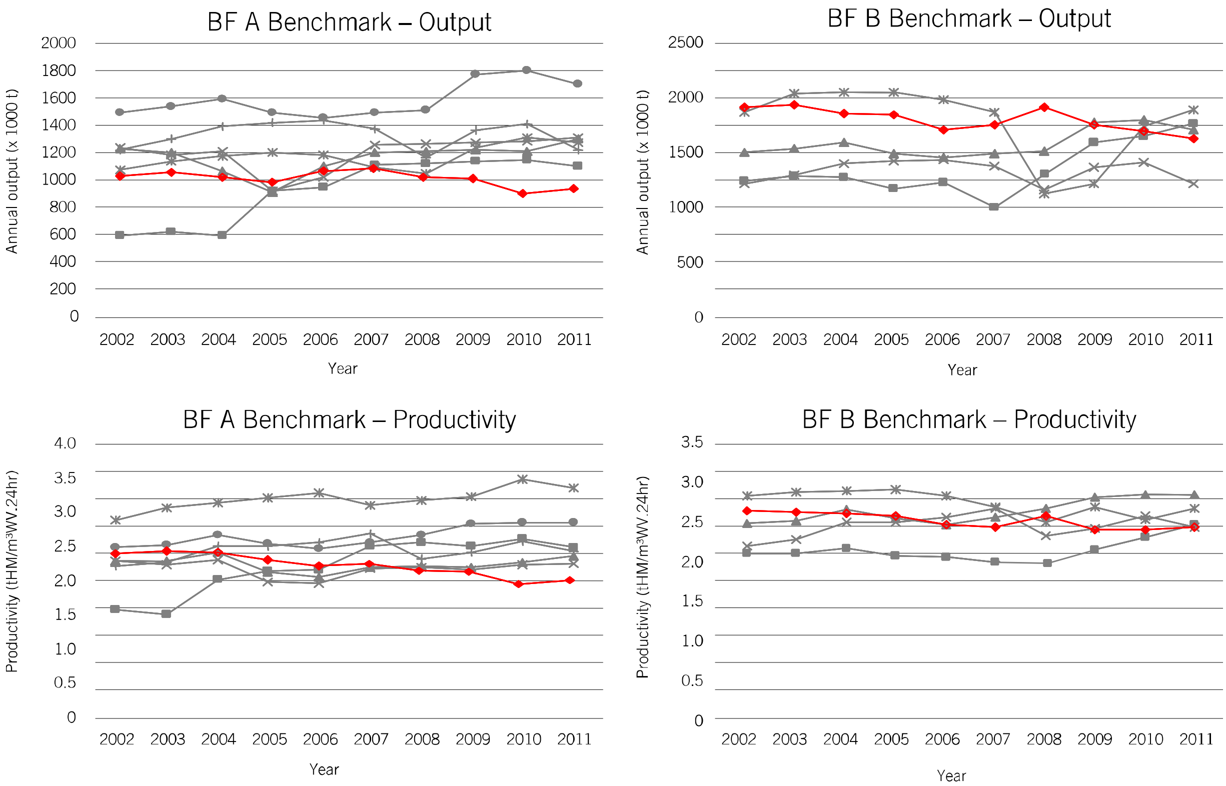

Figure 6. Benchmarking against similarly dimensioned Blast Furnaces indicating the need for further review of operating parameters

Benchmark activities give a good overview of all the operational differences; however there are a few selected areas where more detailed investigations should always be carried out due to the high impact they have on the process. The first of these is the casthouse practice and liquid management, since these influence wear of not only the trough and runner system, but also that of the furnace lining. Opening and plugging practice of the tapholes is observed and analyzed, to identify potential problem or improvement areas. The information logged by the operator is audited to see if it contains all the pertinent data to characterize the cast fully, so allowing improvement programs to be monitored on medium to long term basis.

The gas flow pattern upwards from tuyeres to furnace top is also a key indicator for the operational performance of the furnace. The burdening philosophy of the plant is studied in depth, with the desired aims compared with the actual results. The pressure difference between the tuyere and the top gives a very quick overall impression of the gas flow and this may be added to with information from other sources, such as:

- probes;
- stack thermocouples;
- top gas analyzers;
- burden resistance and blast parameters.

This will give a far more detailed insight. The regularity of the burden descent is assessed using the stockine indicators, such as mechanical stockrods or radar devices.

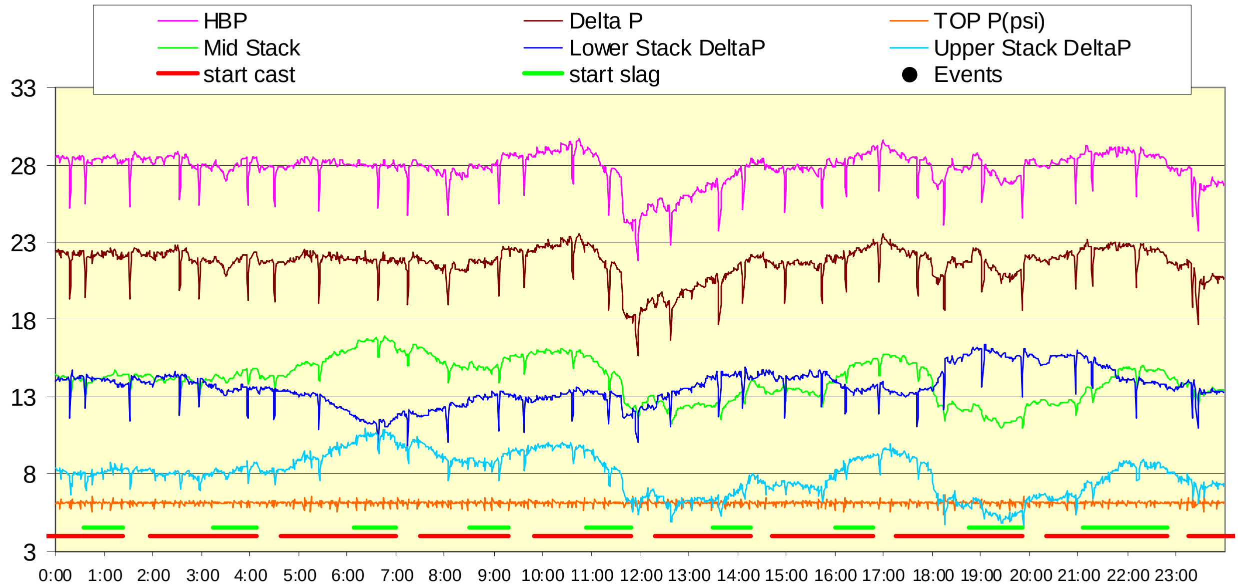

Figure 7. Process information to analyze furnace pressure differential.

The interaction between all these parameters delivers a very good overview of the gas ascent, burden descent and areas were improvements can be made. The improvements in the gas flow pattern will bring improved efficiency to the process, which may also be seen in lower heat losses, and an improvement in total fuel rate.

Along with the burden distribution, raw materials have a huge impact on the permeability of the descending burden, and so also on the ascending gas flow. The usual coke and ferrous burdens are assessed in terms of size, shape, chemistry and low temperature breakdown. Depending on the required output and hot metal composition, the burden quality can be assessed in terms of its ability to meet these targets.

The selection of raw materials available in a specific site is usually rather limited and quality and consistency can be very variable. The purpose of an audit in this case is not merely to corroborate the variability, or lack thereof, but to quantify precisely where the variability counts in terms of its impact on blast furnace performance. Since raw materials quality also largely determines chemical attack upon the Blast Furnace lining, a review also focuses on raw material selection with the intention to keep related risks in this respect manageable.

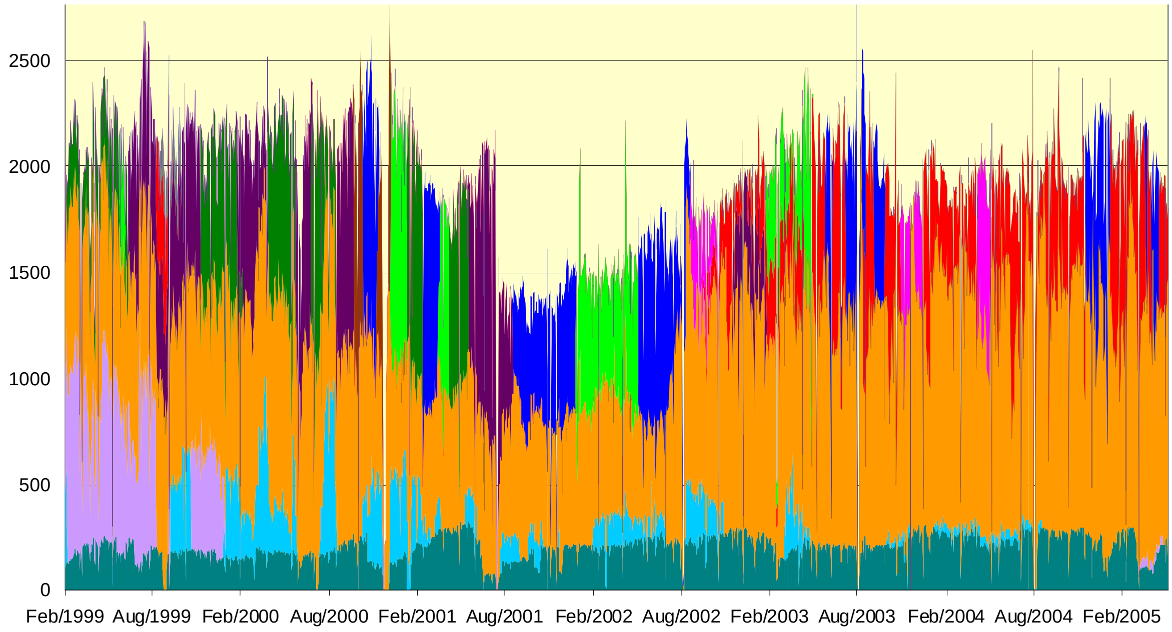

Figure 1. Coke burden composition: each colour represents type of coke, consequences of variability to be analyzed.

Where relevant, the on–site cokemaking, sintering and pelletizing facilities are investigated for potential optimization areas, with a view to realizing through–cost benefits. Although many on–site coke or agglomeration plants are operated to achieve lowest cost product, it is often the case that running the plant with higher quality, albeit at higher cost, may produce a raw material that realizes a higher cost benefit in the blast furnace or more strongly reduced associated cost of processing further downstream. Each of the blast furnace raw material inputs can be scrutinized independently, and then in their interaction with one another. Using this information, an improved raw material use scenario can be formulated within the constraints of economy.

The operating practice of a plant can be a difficult area to benchmark, as many of the operating practices will be sensitive to cultural differences and also management styles. An audit of operating practices does not have the goal of erasing these local differences, but to assess the practice in terms of success in achieving whatever the objective(s) may be.

Many of the items discussed will be represented in the Standard Operating Procedures (SOPs). These documents are designed to standardize the operations from one shift to another, so that the same, correct, actions will be carried out regardless of who is on duty. It is therefore important that the SOPs accurately reflect the required actions, and are accepted by all concerned, with no ambiguity or contradictory statements contained therein. SOPs often cover a wide range of subject matter; however those that relate to the stable operation of the furnace can be reduced to fifteen to twenty key documents. These few will categorize the actions to be taken under any operational difficulties or changing circumstances beyond the control of the plant or site operators, with the aim to return to stable process at a pre–defined operating point as quickly as possible.

4 ECONOMIC ASPECTS

4.1 Raw Materials

More often than not, process operators find themselves working with the raw materials that are made available to them through existing supply contracts. The possibility to select raw material feedstock based on quality parameters is in many cases a phenomenon belonging to the past. Prices are jeopardizing profitability while lacking quality is only adding to this effect.

Nevertheless, thorough analysis of quality parameters and associated cost for each type of feedstock may allow for optimization of the financial performance of the blast furnace plant. Every quality parameter has consequences for processes downstream.
Any of these process consequences can be translated into economic consequences. Associated costs for compensation, and similarly benefits for the value of the finished product, should be taken into account when optimizing the burden based on the sub–optimal qualities that are or may simply happen to be available.

Table 1. Financial evaluation of (ferrous) raw material types

Material	Associated cost effect (US$/t)	Price Effect (US$/t)	Total cost effect (US$/t)	Total cost effect (US$/tFe)	Ranking
Current	0	0	0	0	2
Alt. A	15.8	-12.5	3.3	5.8	5
Alt. B	6.0	-2.5	3.5	5.2	4
Alt. C	6.1	-3.8	2.3	3.4	3
Alt. D	2.0	-3.8	-1.8	-2.7	**1**

With this evaluation, the cost structure for the ironmaking operations can be optimized taking into account the desired hot metal quality, demand from downstream operations as well as associated cost for compensation of the detrimental effects of using certain types of raw material. A typical financial evaluation of several types of feedstock, with their differing quality parameters, can be found in Table 1. The financial consequences of switching materials (e.g. associated cost), along with those of the ferrous content, finally translate into savings or additional cost compared to the base case.

4.2 Plant Configuration

With global overcapacity being a given and local demand being likely far below a site's usual output, substantial room for (cost) improvement may be found by investigating a site's plant configuration, i.e. reviewing different scenarios for plant being (temporarily) shut down or put back into operation and with different operational parameters for the individual plants. In some cases, it may be e.g. beneficiary to shut down one of the site's Blast Furnaces while operating the remaining on higher quality raw materials to meet the (reduced) demand at optimized cost.
None of these scenarios are trivial, since they each incorporate a complex of operational parameters that each contribute to cost per ton and, in addition, may be correlated. Reviewing a site's operations with the option of shutting individual plants

or equipment down adds another level of complexity. A simple example of a capacity analysis is shown below.

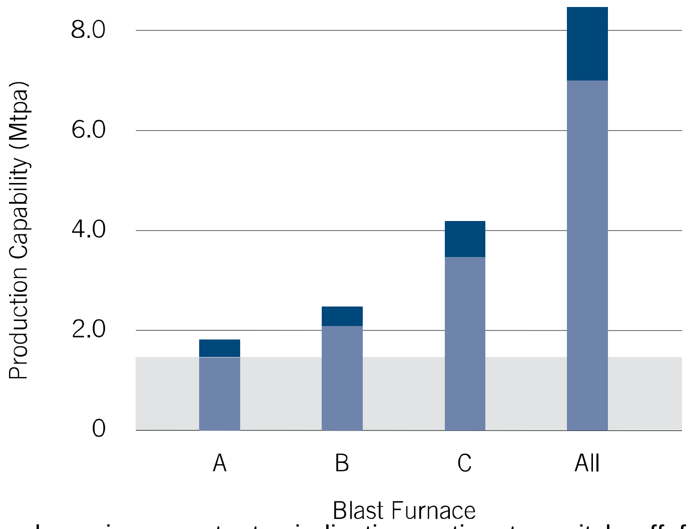

Figure 9. Minimum and maximum outputs, indicating option to switch off furnace depending on demand

Based on a prognosis for demand, it may be evaluated which furnaces should be kept in operation in order to meet it. This should be based on all relevant cost parameters, among which the direct and associated cost for producing with a maximum number of furnaces on cheaper raw materials, versus with a minimum number of furnaces on more expensive raw materials.
Here, maintenance and revamp schedules should also be taken into account: some scenarios may allow for financially more attractive maintenance or revamp projects during longer planned outages if the activities can be planned e.g. with only day shifts.

5 CONCLUSIONS

- Today's operating circumstances with respect to overcapacity, higher cost and lower quality raw materials and pressure on prices for the finished product require revised operating points in Blast Furnace Ironmaking operations. The process of developing these operating points benefits greatly from the new thinking brought about by parties that do not share the same local, corporate or cultural thinking;
- operations should be first and foremost optimized to meet demand not only in terms of volume, but also with respect to quality. Every tonne produced beyond demand or beyond spec comes at a financial penalty that is unacceptable in the current climate;
- optimizing operations should be based on technical (maintenance, renovation), operations (process, practices, raw materials) and economical (raw materials, plant configuration scenarios) aspects;
- assessing associated risks along every step of the process, both technical and operational, is crucial.