TECHNICAL AND OPERATIONAL AUDITING OF BLAST FURNACE IRONMAKING UNITS[1]

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Abstract

The highly efficient use of raw materials (a significant cost in Iron- and Steelmaking) in the Blast furnace will have a large impact on the total through-cost chain. High utilization and increased productivity of the unit will further have a great positive impact. Large differences exist in Blast furnace operation, when looking to producing units worldwide. By carrying out an independent blast furnace audit these differences may be highlighted. When the difference are identified, the first step toward overcoming any significant deficiencies is made. Increasing the length of the campaign of the blast furnace to an almost endless time span is an obvious way of limiting spending of investment money and having less production loss of Hot metal by higher availability of the unit. The flip side however is increased risk of equipment failure. An audit can identify these risks and quantify the likelihood of occurrence and the associated consequences. Inspection and testing programs may be implemented to increase knowledge of the unit and quantify the risks more accurately. With this information at hand, educated decisions can be made with regards to productivity levels, intermediate repair plans, contingency plans, and long term planning, all with the aim of securing the profitable future of the operating unit.

Key words: Blast furnace; Auditing; Risk; Campaign.

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[1] *Technical contribution to the 41th International Meeting on Ironmaking and 12h International Symposium on Iron Ore, September 12 – 16, 2011, Belo Horizonte, Vila Velha, ES.*

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1 INTRODUCTION

Auditing of a blast furnace, and associated equipment, is a useful tool in order to gain a snapshot of the installation. This snapshot can then be used for various applications, such as determining reline and repair strategies, for identification (and elimination) of process bottlenecks, campaign extension planning, as well as benchmarking against past performance, or future goals. By looking at the design, current condition and maintenance of the equipment with experienced specialists in each field, it is possible to assess the potential remaining lifetime of different component parts, and that, coupled with the operating characteristics at the plant, can either set the capacity and lifetime of the plant, or can act as a guideline for target values, should appropriate changes be made.

This paper goes through the principles involved during such an audit, as well as some of the examples where the results have been applied.

1.1 Why a Blast Furnace Audit?

A significant proportion of the cost of steelmaking is determined in the primary end: raw material cost, coke and other energy sources. The highly efficient use of these materials in the Blast Furnace (BF) will have a large impact on the total through-cost. A high utilization factor and an increase in productivity will also improve the bottom line on these costs. A BF audit will identify areas where the unit is already operating at, or above the industry standard, as well as areas where improvements can still be made.

Lengthening the campaign of the furnace is an obvious way to delay having to spend a large amount of money, while at the same time avoiding an expensive production loss during the repair time. This strategy, if not properly managed, can however lead to an increased frequency of unplanned downtime as components reach end of life. A BF audit can identify these risks and quantify the likelihood of occurrence and the associated consequences. In the case where insufficient information is available for a comprehensive risk assessment, dedicated inspection and testing programs can be implemented, for instance hearth assessment and monitoring, to increase the information available and so quantify the risks more accurately.

With this information at hand, informed decisions can be made with regards to productivity levels, intermediate repair plans, contingency plans, and long term reline planning. All with the aim of securing the profitable long term future of the operating unit.

1.2 Why an External Auditor?

There are many benefits to asking someone from outside the company to carry out an audit. These are mentioned below:

- independent, non-biased view;
- short, dedicated, focused effort;
- guaranteed deadlines;
- benchmarking against international BF practice;
- immediate reporting to entire BF team on site on completion of the audit;
- multi-disciplined team encompassing Process Technology, Operations, Maintenance, Repair and Reline engineering options;
- does not rely on personnel being released from normal duties.

2 PROCESS TECHNOLOGY

The manner in which the blast furnace ironmaking unit 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. The audit will identify where the BF is being operated to the best of its capability, and where it is not. The cornerstone for good, continued performance is stability and consistency in the operation: 24 hours a day, over the shifts, over the weeks, over the years.

As a starting point, the main BF parameters are studied over the past twelve to twenty-four months, and the last operating month will be compared with the best month in the screened period. This gives an internal benchmark of current vs. best achieved operation. The outcome can be further benchmarked with similar sized furnaces operating under comparable conditions. Raw materials, their quality but also their consistency, has a major impact on stable operation. The importance of coke quality on BF performance is well known; less known but equally important are the low and mid-temperature degradation characteristics of the burden materials. For this reason, items such as raw materials are also included in such a benchmark study.

Whether this benchmark analysis is performed on current vs. best on the same furnace, or on representative data for two comparable furnaces, the result is the same. The larger differential factors are found, and from those a priority list of areas to be further investigated is made. One example shown here (Figure 1) is the case of two North American blast furnaces on one site where the silicon standard deviation had a very large differential factor with that for a similarly sized European blast furnace.

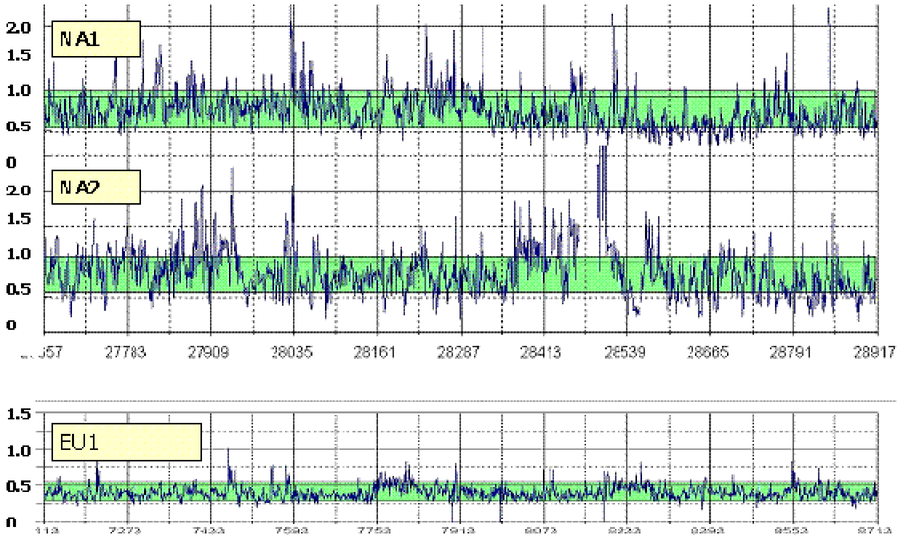

Figure 1. Hot metal Silicon in two North American furnaces identified to have a high differential silicon standard deviation as compared with a benchmark European furnace.

The significant difference in values triggered further investigation, starting with the graphs for hot metal silicon over time. Such variability had a negative cost impact on the steel plant, leading to an investigation to the causes for the high variability. As a result an action plan for improvement was recommended, with specific goals for realistic improvement, based on local operating conditions.

The benchmark activities give a good overview of all the operational differences; however there are a few selected areas where more detailed investigations should be carried out due to the high impact they have on the process. The first of these is the casthouse practice and liquid management techniques. The problems caused by poor or irregular liquid removal from the hearth are more apparent in single taphole furnaces. However twin taphole furnaces are also vulnerable during periods of casthouse repair when only one taphole is available. The maintenance schedules for the casthouses are therefore scrutinized to identify where improvements are possible, always on the basis of zero to minimum investment with maximum returns. Opening and plugging practice of the taphole 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.

This casting information makes a direct comparison with other process events on the furnace possible. Increases in blast pressure (Figure 2), stockline irregularities, and drops in hot metal temperature can often be related to hearth drainage problems. By combining all this information, the influence of the casting practice on any instances of irregular operation can be immediately assessed by the operator, and so appropriate actions can be taken.

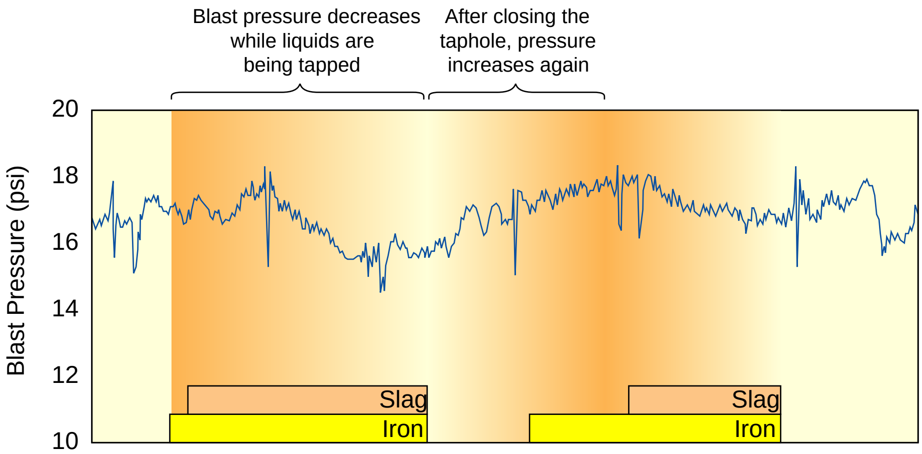

Figure 2. Effect of fluctuating liquid levels on the blast pressure.

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 the probes, stack thermocouples, top gas analyzers, burden resistance and blast parameters to 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.

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.

3 REVIEW OF RAW MATERIALS

Along with the burden distribution, the raw materials themselves 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, 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.

Where relevant, the on-site coke-making, 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, will produce a higher quality raw material that realizes a higher cost benefit in the blast furnace. This benefit will then outweigh the additional costs, achieving lower end-product costs, and so greater profitability for the company. 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. This encompasses the original source, the handling method and practice, bulk storage and a recommendation as to the combination of raw materials that may be used to best effect.

The handling, screening and stockhouse facilities do not escape the scrutiny of the BF audit procedure. The value of the raw materials that have been carefully produced or procured can be dramatically reduced by excessive handling, poor stockhouse logistics or insufficient screening. Each of the handling and processing stages are assessed in terms of necessity against penalty, with the overall material handling logistics subject to review. Recommended screening sizes are given, to achieve the optimal balance between quality raw materials for the blast furnace and optimizing yield of the screened material.

Certain constituents of the burden, such as scrap, steelmaking slag, fines and briquettes are often attractive additives in terms of their price per carbon and iron units. There is, however an associated cost in using a large proportion of these additives in the burden. The furnace will normally show a higher and irregular resistance, lower productivity and a higher fuel rate. Return streams and plant revert usage are reviewed in terms of the entire through-cost, taking into account additional handling and preparation steps, balanced against the realized benefits.

Once the optimal burden is determined, the objective is to maintain this on a regular basis, and to eliminate areas where variability is a problem. Items such as fines segregation, and chemistry variations are relatively hidden effects, which may not be identified until after the material has been charged to the furnace. In these instances the importance of regular sampling and rapid availability of these results to the blast furnace operators is of prime concern. Further to this, the appropriate actions to take in the case of known variability in the input materials should be determined and incorporated into Standard Operating Procedures (SOPs). These action are aimed at preserving the stable operation of the furnace under any circumstance, so that problems in one area, such as raw materials, is localized only to the raw materials and not magnified by disruption to the process itself.

4 OPERATING PRACTICE

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.

Regular checks on the installation that are carried out by the operator, such as preventative water leak detection, should be done in a comparable, controlled manner. Whatever the method that is employed, it should be representative and repeatable and for that to be the case, each operator must be familiar with the correct method. Controls should be in place to ensure that each sector of the cooling system is regularly checked, confirmed by both those carrying out the checks and the supervisor responsible. Developing preventative water leak detection practice as part of the daily tasks of the operators can go a long way to minimizing the damage to the carbon hearth refractory caused by undetected water leakages.

Many of the items above will be represented in the 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, with the aim to return to stable process, at aim production rate as quickly as possible.

5 MAINTENANCE CONDITION

Reviewing maintenance plans and budgets can be helpful in assessing the maintenance level of a plant. However a far more representative test is to analyze the stoppage frequency and causes and relate this to the known or logged wind rate data. Usually the analysis can separate the causes into a few main areas, such as:

- planned stops;
- BOF/Caster down;
- HM logistics;
- raw material supply ;
- tuyere or cooling elements change;
- charging system or raw material problems;
- unplanned stops caused by breakdown of mechanical, electrical, or control systems.

As this type of analysis is usually carried out in terms of “time off-wind” rather than number of occurrences, a clear view is given as to the magnitude of the delays attributable to each area. Although a frequently recurring problem should be given attention, it may not warrant as much attention as a less regular problem which nonetheless results in more down-time. The balance between planned and unplanned stops can also be benchmarked to determine whether sufficient planned maintenance is being done in the correct areas to reduce the number of unplanned breakdowns in those areas. The total number of maintenance hours spent can similarly be compared, as well as the quantity of maintenance that is carried out during stops for other reasons, such as downstream problems.

6 MECHANICAL EQUIPMENT CONDITION MONITORING

The sophistication and reliability of condition monitoring systems has moved on from the early days of holding a screwdriver on a gearbox and listening to the rumbling noises. Today the sensitivity of sensors has improved dramatically, and phenomenal calculation power is available at low cost. 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.(1)

Areas where critical failures can occur receive particular attention during the auditing process, as these items will largely define the remaining useful lifetime of the plant. Some of these areas are described in the following paragraphs.

6.1 Structural Steel Condition and Inter-Crystalline Stress Corrosion

Wear and tear of structural parts can usually be monitored successfully with non-destructive testing (NDT) testing, often using ultrasonic devices. There is one exception to this rule, that being inter-crystalline stress corrosion (ISC)(2) in Hot Blast Systems. This type of corrosion is caused by NO_x formation and condensation of acids against the steel shell in hot blast systems above 1.380°C (2.500°F).

It appears as a fine divided network of microscopic cracks that are very hard to detect by conventional ultrasonic NDT methods (Figure 3). 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.

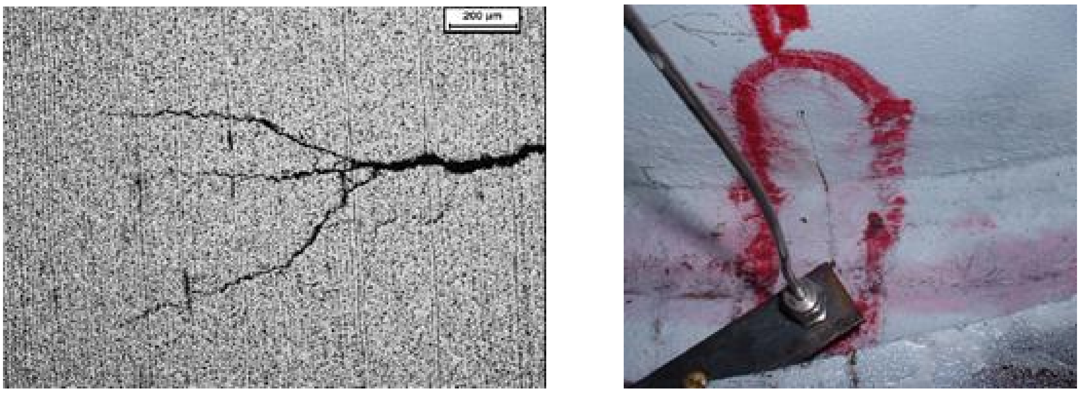

Figure 3. Microscopic detection of ISC in Hot Blast system components.

6.2 BF Hearth

The hearth and tapholes refractory condition is usually considered as most critical for campaign extension.(3) It has been found that refractory wear is usually attributable to unusual or exceptional conditions such as water or gas leakage, than to normal operational wear and tear.

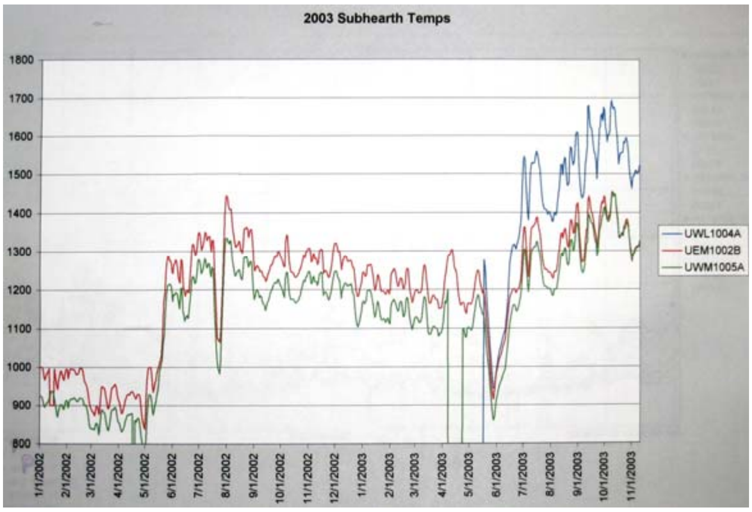

Figure 4. Under hearth thermocouple temperatures showing progressively higher temperatures, indicating a reduction in remaining refractory thickness.

An in depth analysis of the hearth condition can be made using thermocouple data (Figure 4), combined with thermal models. In reality the situation for older furnaces is that the thermocouple (TC) grid is not always fully functional or reliable. Tag numbers and physical positions get mixed up; electrical connections become unreliable or completely lost. After ten to fifteen years, data may have been lost in irretrievable archives. Last but not least thermocouples themselves show drift or "aging" over time through exposure to high temperatures for a long period of time.

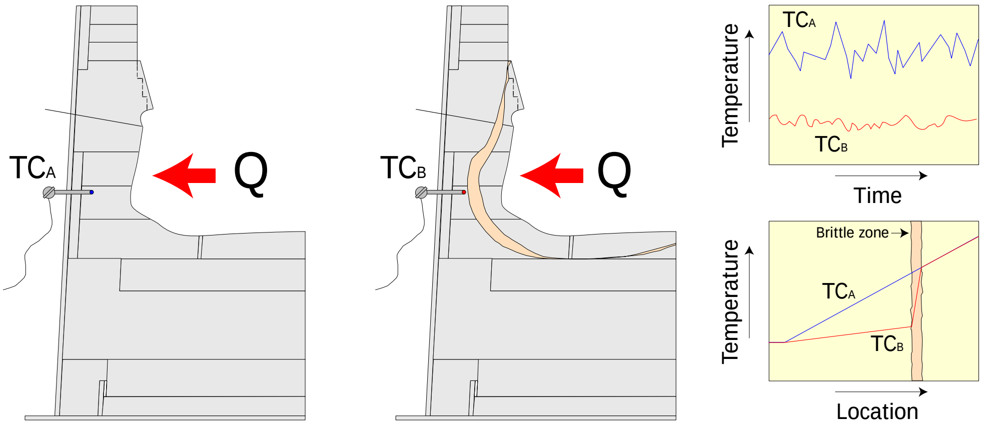

Figure 5. Schematic of the hearth thermocouples and how a brittle zone in the hearth refractory can give misleading temperatures readings, until the point the brittle zone is exposed to hot metal.

The brittle zones that can form over time in carbon hearths can cause major conductivity anomalies leading to false interpretations of the measurements. A more direct way of determining the hearth refractory condition is to perform core drilling which nowadays can be done safely under controlled conditions. Gas leakage through the shell, even in small quantities, can cause major CO attack on carbon hearths 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 carbon paste. However if this is not done carefully, uncontrolled injection can destroy more that it will solve, since the carbon 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.

6.3 Bosh and Stack

The most significant refractory wear mechanism in bosh and stack is cracking, or spalling, of the bricks caused by temperature fluctuations.(4) 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. Wear in the bosh and stack regions can easily be repaired by regular gunning or shot-creting of pumpable refractory material.

When excessive wear is present and the steel shell is directly exposed to the burden, 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 BF audit 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 6. Example of a plate cooled bosh, demonstrating very limited wear after ten years in operation.

6.4 Hot Blast Stoves and Hot Blast System

No audit would be complete without an assessment of the Hot Blast Stoves (HBS) condition. Well designed and operated HBS can have a lifetime of over twenty years, but this of course can be considerably shortened if the prior 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 ISC cracking in the shell and around all welds in the system.

6.5 Likelihood & Consequence

The risk analysis of the blast furnace and auxiliary equipment centers on those items of equipment that are the most essential to continue operations. Of course this is not to say that there are so many non-essentials, but in many cases it will still be possible to charge a blast furnace with raw materials if a screening station fails. Operations may suffer slightly with unscreened materials, and the decision may be taken that that is not acceptable so the furnace will be stopped until it is repaired, but that presents a choice to the operator. During failures of items such as the charging system, or the bosh, or the hearth, this choice does not exist. Without those items, the furnace can not be operated, and can even enter into a danger zone, so it is for these items the risk analysis is performed.

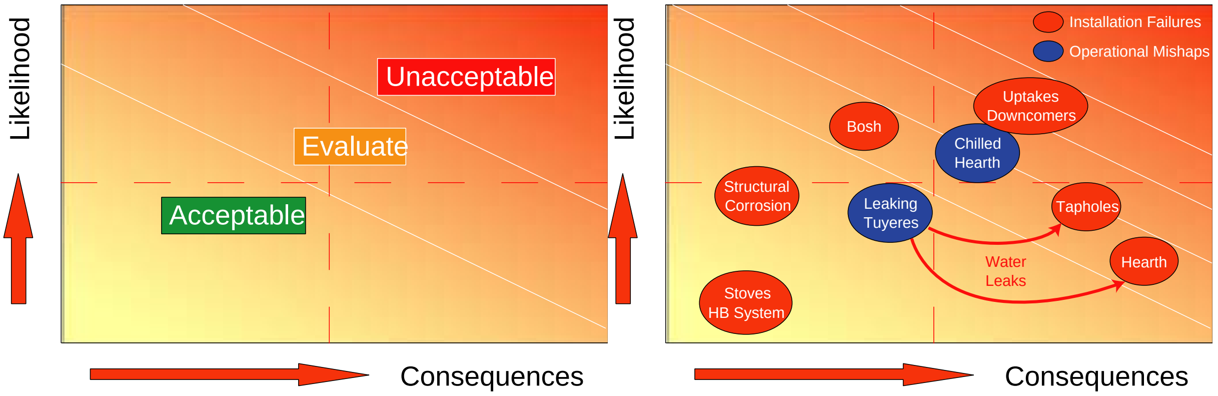

Figure 7. a) Risk analysis matrix (left); and b) risk analysis matrix completed (right).

The risk analysis 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 (Figure 7a), gives a very clear overview of where the priorities for attention should lie.

Once the analysis is complete (Figure 7b), 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.

7 RELINE PLANNING

Once the current state of the Blast Furnace and associated equipment are known, with the risks and consequences evaluated, and the operating level determined, future scenario planning is then possible.

The numbers of scenarios, if not infinite, are certainly numerous, and so certain criteria should be set for assessing the possible alternatives.

The key questions of each reline or repair scenario are:

- how soon will repairs be necessary to eliminate or reduce the risk?
- how much will it cost?
- how long will it take?
- what will be the expected life after the repair?

To answer these questions effectively, the forecast for future demand and prices should be estimated, and from that the necessary investment to meet these demands can be identified. It is in this latter part that the many possibilities may be discussed. Depending on the current plant configuration it may be appropriate to discuss reline plans over a number of years for a succession of furnaces. Alternatively the challenge may be to maintain output while planning and even beginning a rebuild project.

By addressing these points in a systematic way, all repair scenarios form ‘emergency patch repairs’ to ‘full scale relines’ can be reviewed on their business aspects. An independent auditor can help in making the most realistic risk assessment.

8 CONCLUSION

The insight that auditing a blast furnace ironmaking unit delivers in terms of clarity and justifiability for decision making and making strategic choices is invaluable. The ability to plan for repairs at the right time to get the most out of the installation, while avoiding breakdown scenarios, secures any production target in a sustainable and reproducible way.

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