IMPROVING BF OPERATION THROUGH SACHEM® (INTELLIGENT SUPERVISION SYSTEM) AND PROCESS OPTIMIZATION MODELS [1]

Claude Thirion [2]
Gianluca Odicino [3]
Piergiorgio Fontana [3]

Abstract

The evolution and the instability of the raw material market are claiming for greater flexibility and proper reaction of blast furnace operation to achieve high level performances. As a matter of fact operation stability and high plant availability are the key targets to fulfil. To reach this goal, various blast furnace components are essential: good mechanical equipment, adequate process instrumentation and best operating practice. The achievement of the objectives is made possible by the adoption of a specific operating style, consisting of the continuous and accurate use and interpretation of process measurements and data. The continuous assistance of SACHEM® (Intelligent Supervision System) and mathematical models will not only help in reaching high performances but also in maintaining such levels over the furnace lifetime. The application of this kind of system has shown a significant reduction in hot metal silicon content and hot metal temperature standard deviations and an important reduction of all process anomalies.

Key words: Operating guidance system; Process models; Blast furnace performance.

GANHOS NA OPERAÇÃO DE ALTOS-FORNOS ATRAVÉS DO SACHEM® (SISTEMA DE SUPERVISÃO INTELIGENTE) E MODELOS DE OTIMIZAÇÃO DE PROCESSO

Resumo

A evolução e instabilidade do mercado de matérias-primas exigem uma maior flexibilidade e rápida reação na operação de Altos-fornos para se atingir elevados níveis de desempenho. De fato, a estabilidade operacional e uma elevada disponibilidade da planta são os fatores chave para o sucesso. Para alcançar este objetivo, vários componentes dos Altos-fornos são essenciais: bons equipamentos mecânicos, instrumentação de processo adequada e as melhores práticas operacionais. Alcançar os objetivos é possível pela adoção de um modo de operação específico, através do uso contínuo e preciso de dados e medições do processo e sua interpretação. A assistência contínua pelo SACHEM® (Sistema de supervisão inteligente) e de modelos matemáticos ajudará na obtenção de elevado desempenho e também manterá tal performance durante toda a vida do Alto-forno. A aplicação deste tipo de sistema tem mostrado uma redução significativa no conteúdo de silício, redução dos desvios de temperatura do gusa e redução de todas as anomalias de processo.

Palavras-chaves: Sistema de orientação operacional; Modelos de processo; Desempenho do alto-forno.

---

[1] *Technical contribution to the 3rd International Meeting on Ironmaking, September 22 – 26, 2008, São Luís City – Maranhão State – Brazil*

[2] *Paul Wurth SA, 32 rue d'Alsace, L-1122 Luxembourg*

[3] *Paul Wurth Italia S.p.A., Via di Francia 1, I-16149 Genova, Italy*

1 INTRODUCTION

In a fine restaurant, it is important to have good ingredients, good tools and a good chef, able to successfully prepare the best recipes even if the ingredients market is continuously changing. Similarly, success in the achievement of excellent blast furnace operational results is subject to three basic conditions:

a) Raw materials characteristics and quality
b) Design of the BF equipment including instrumentation
c) Know-how and its daily use.

The main activities of Paul Wurth focus on point b) and c). Aim of this paper is to show how important is to complete the utilization of state of the art equipment with suitable control tools incorporating high level know how, in order to reach valuable performances.

Bf Performance Evolution

In the seventies, some 'specialists' predicted the extinction of the blast furnace by 2020 as the right tool for iron production. They predicted a fifty year period of time to develop alternative solutions which would replace the traditional blast furnace process i.e. the direct reduction or smelting processes.

Although the innovation challenge encouraged the development of new alternative processes compared to the "royal process route" (represented by the integrated chain of iron production: cokemaking-sintering-ironmaking), it is important to note that in parallel to the development of new ironmaking technologies - the traditional blast furnace iron making business also took benefit of the evolution of techniques throughout those same years.

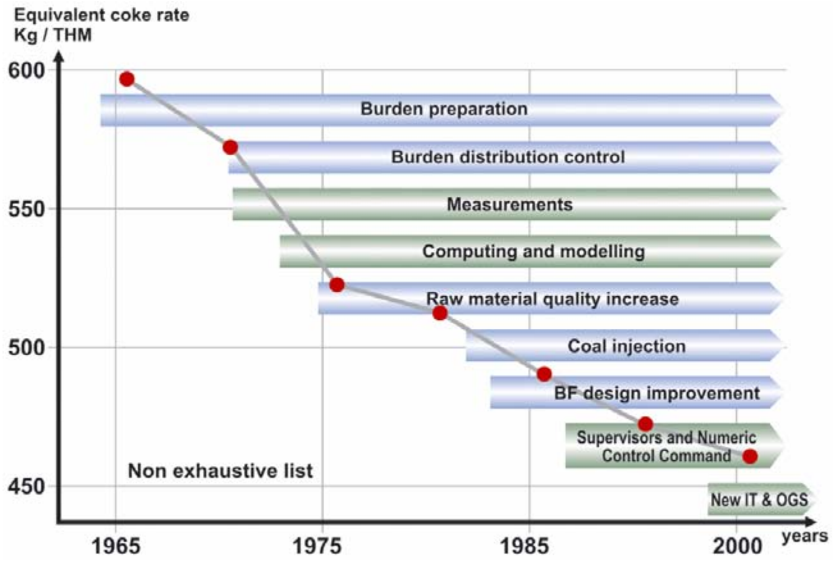


Figure 1 – BF average fuel consumption evolution in France (source ATS France)

This evolution is similar in most of the Western Europe countries (see the example of France in Figure 1) where the improvements result from both the raw material supply with an increase of quality, and progressive technological innovation having a positive effect on blast furnace equipment, measurement techniques and associated data analysis.

Innovation and Know How

Thanks to a large number of studies and experiments, the knowledge related to physical-chemical modelling of the blast furnace process has increased tremendously. It leads today to a detailed modelling and an almost full understanding of the correlation of the multitude of physical-chemical phenomena over the entire blast furnace process.

During the last thirty years, improvements in the field of blast furnace modelling have reached a high level, as the need for these control tools has been understood worldwide. This increased the demand for the measuring of more and more physical and chemical parameters to identify and calibrate. Hence, this phenomenon drives the demand for new and more sophisticated measuring devices to be used within the blast furnace iron making process. However, the increased number of sensors, which are essential from the point of view of effective blast furnace managing tools provide the operator with a huge flow of information coming partly from the field and partly from the laboratory and giving indication for some action in order to achieve the optimum blast furnace operation mode. Unfortunately it is a fact that no human operator can follow-up and handle more than few parameters at a time. The increasing volume of information available, far from making the human decision process easier, is often generating confusion, thus representing a risk factor in itself. Moreover, even when the operator skill is sufficient to take the correct action at the correct time, uninterrupted attention and reasoning capability is required, not always possible in a real working environment.

To this purpose, all the ironmakers have developed standard operating practices to help the operator to deal with the most likely situations. A logical step forward to make the application of these practices easier is to incorporate them into an automatic tool usually called Operating Guidance System (OGS).

2 MATERIALS AND METHODS

In this paragraph we briefly describe the main models really needed to increase performances on a BF and the Operating Guidance System called SACHEM® [1] that we prefer to define as Intelligent Supervision System.

2.1 Optimization and Monitoring Models

The main purpose of mathematical models is to complete the representation of the process supplied by the field instruments by means of physical or statistical correlations capable to predict the parameters not directly measured. In this way the operator has an improved data set to take proper actions to prevent anomalies and to optimize the plant performances. The general architecture of a typical PW BF process automation system is shown in Figure 2.

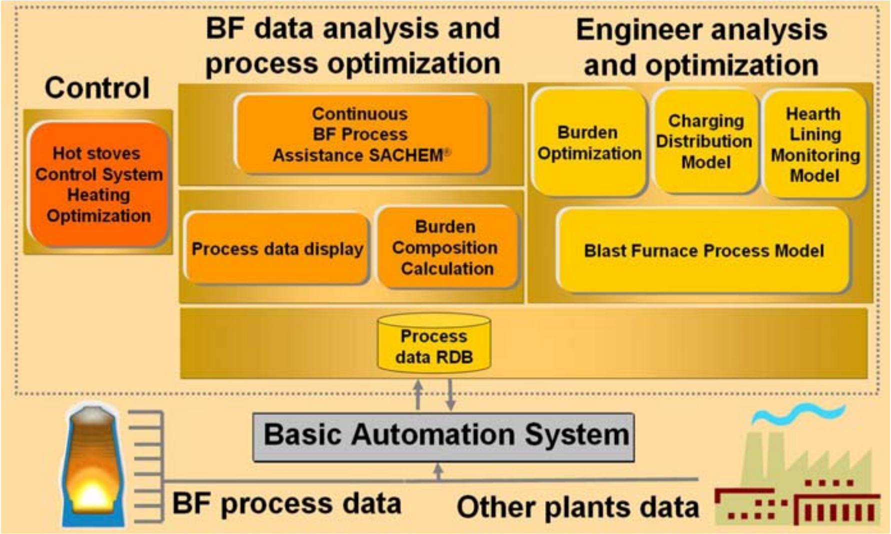


Figure 2 - Typical architecture of a Paul Wurth BF process computer system

Here below a brief description of essential items used to fulfil the target of improving operation, is reported.

- Blast furnace process model (steady state)
- Burden calculation and optimization model
- Burden distribution model
- Hearth lining monitoring model
- Hot stoves heating control model
- Other local models (utility parameters)

Examples of utility parameters are: oxygen excess for fuel combustion, blast velocity, blast kinetic energy, RAFT, partial and overall permeability factor, top gas volume and velocity, bosh gas composition and rate, top gas CO and H2 efficiency.

2.1.1 Blast furnace process model (steady state)

The Blast Furnace Model is a steady state calculation providing heat and mass balances, top gas temperature gas efficiency, gas composition, estimation of metal and slag compositions etc. With this application, it is possible to evaluate the efficiency of the operation in the past, and to evaluate the impact on the process operation of possible changes of the BF settings, burden and coke characteristics, etc. As an example, it is able to estimate the coke rate change corresponding to a certain change in tuyere set points, or to calculate the necessary oxygen enrichment to reach a certain flame temperature (RAFT). This mathematical model is intended as an aid to technical staff for the planning and optimization of Blast Furnace operation.

2.1.2 Burden calculation and optimization model

The burden calculation model computes the optimum burden composition (iron-bearings materials and fluxes) in order to obtain the requested quality of hot metal and slag. The model consists in an optimization procedure that minimizes an economic function, taking into account the constraints specified on charging materials, the constraints specified on products and the actual chemical analysis of charging materials.

The optimum solution (nearest quasi-solution when constraints are incompatible) will supply the following results:

- % of iron burden materials (or weight per charge batch)
- specific amount of fluxes (or weight per charge batch)

- expected hot metal and slag analysis and properties
- objective function value (hot metal cost)

When used as an off-line program, this model is a powerful tool, available to technical staff, to evaluate different charging choices and to carry out planning calculations. (Burden Optimization)

In daily practice, the model suggests the corrections to make to the weight set-points in order to compensate possible changes in chemical composition of the raw materials.

The models can be also activated without the optimizing option, just to estimate the products that will be obtained from the current charged materials. (Burden Calculation).

2.1.3 Burden distribution model

This model calculates the radial distribution of materials charged with the bell-less top system.

The model incorporates the following aspects:

- Physical phenomena on the chute.
- Weight, rebound, centrifugal force of inertia, Coriolis force of inertia, friction on the chute.
- Physical phenomena for the free falling.
- Trajectories integrating Newton falling curves (2-D) and Coriolis curves (3-D).
- Piling up of elements of raw materials, with interactions between grains (percolation, pushing force, burden descent velocity.

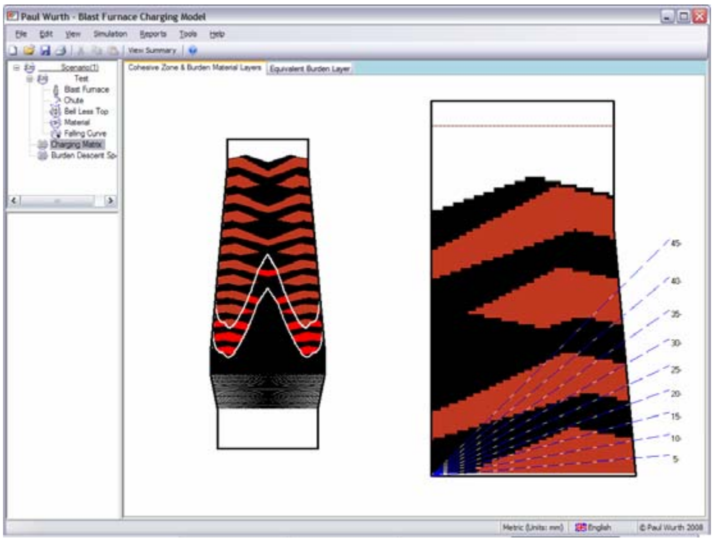


Figure 3 - Vertical section simulation of burden distribution model

As the data calculated by the model are strictly correlated with important process parameters (top gas distribution, furnace permeability, coke consumption, hot metal production, etc.), the model represents a useful tool to optimize the use of the bell less top system. Main feature of this model are:

- Layer construction based on the laws of physics
- Easy calibration and adjustment
- Robustness of the calibration along the time
- Less work requested for model tuning and follow up
- Radial segregation is taken into account

2.1.4 Hearth lining monitoring model

This model provides an estimate of the hearth lining wear profile, so that proper measures can be taken before the hearth wear becomes critical. The model keeps track of the time evolution of the thermal and erosion profiles, and therefore takes into account the material build-up when the hearth thermal level decreases. The first calculation step consists of the numerical solution of the Fourier equation. The second step (the self-tuning procedure) is the correction of the adjustable model parameters, to minimize the deviation between calculated and measured temperatures. The final result is obtained by the iterative application of these two steps.

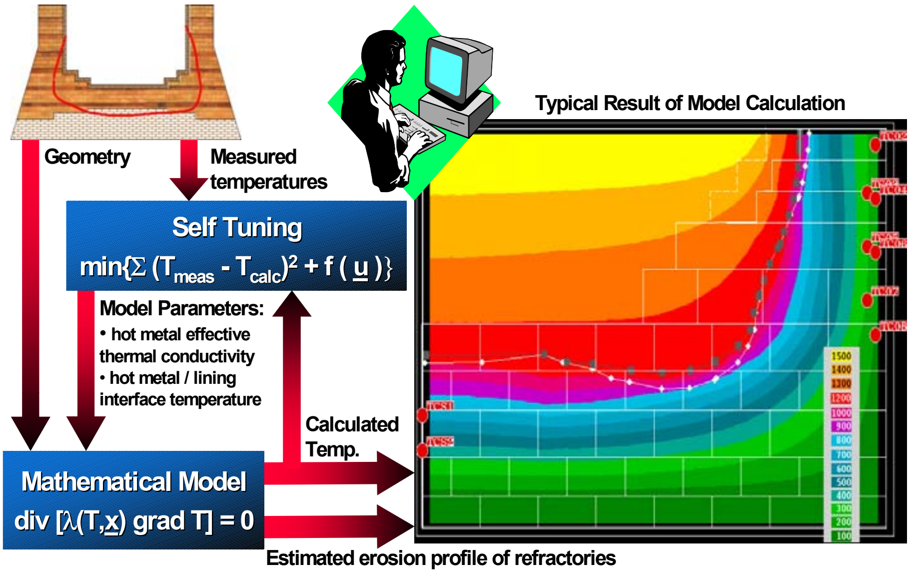


Figure 4 - Flow diagram of the hearth lining monitoring model

This procedure, applied to a significant set of vertical two-dimensional sections, produces a three-dimensional representation of the hearth, showing its wear profile and thermal status.

This monitoring model can be activated cyclically, on a daily basis, and its results is stored over the whole BF campaign. In order to get reliable results, a minimum thermocouple set is necessary. The adopted procedure to “best-fit” measured with calculated temperatures allows to minimize the influence of failed sensor and makes the best use of the information available.

2.1.5 Hot stoves heating control model

The Hot Stoves Closed Loop Control System performs the fully automatic management of the plant.

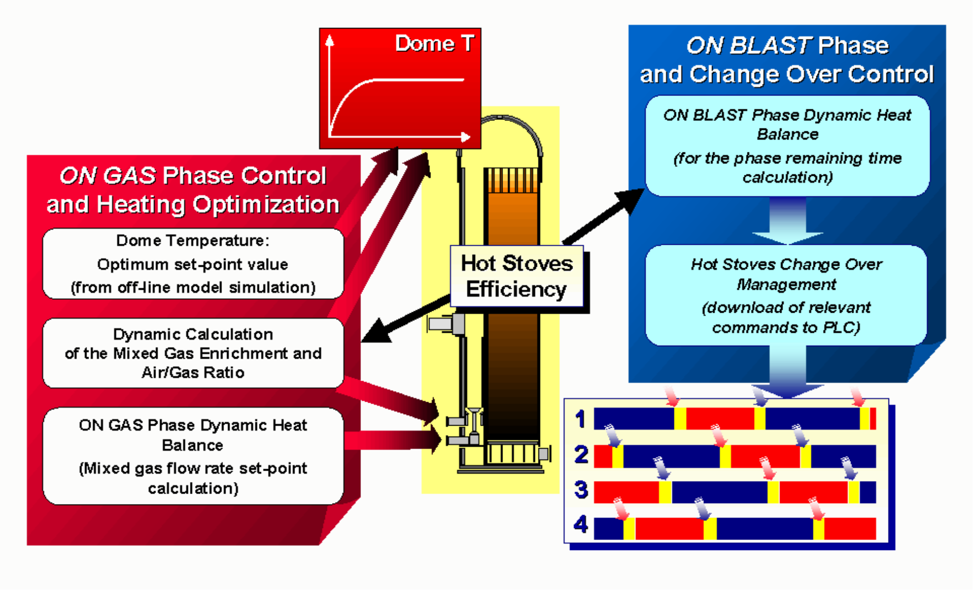


Figure 5 – Flow diagram of the hot stoves heating control model

The normal operation mode envisaged for a three-stove plant is cyclic (one stove on blast and two stoves on gas), while is parallel staggered (two stoves on blast and two stoves on gas) for a four-stove plant. For a four-stove plant cyclic mode operation is also foreseen. A two/three stoves mode is also foreseen to manage emergency plant conditions, whenever one stove is out of service.

The hot stoves control system is performed by two basic functions: Heating Control and Change-over Control.

The Heating Control performs:

a) The calculation of the optimum set-point of dome temperature, in order to minimize the rich gas consumption for each stove at the beginning of the gas phase.

b) The dome temperature control, the combustion stoichiometric calculation (gas enrichment ratio, the air/gas ratio and the fumes/gas ratio) and the thermal balance during the gas phase

c) The thermal balance, in order to calculate the heat removed by the blast and the on blast remaining time during the blast phase.

d) Efficiency calculation for the last operating cycle (gas, blast and change over stages) at the end of each blast phase.

The mathematical model sends gas and air flow rate set-points to the Level 1 system. Set points are calculated using historical efficiency values, dynamically adjusted.

2.2 Operating Guidance System

To support the systematic interpretation of the information arising from measured or calculated parameters, Arcelor Mittal has developed the Expert System named SACHEM®. The approach used to develop SACHEM® relies on metallurgical knowledge and on the human model of analysis, reasoning, and decision making.

In every approach, the role of data validation is essential in order to be sure to have the correct data for the correct conclusion. However, data validation cannot be done without a deep knowledge of the meaning and the behaviours of the process parameters underlying these data.

The SACHEM® system, marketed by Paul Wurth, represents a control tool independent from the physical structure of the automation system.

2.2.1 The need: to help the operator in the control of processes [2]

It is a common experience that some operators are more efficient than others in process analysis and control. On the other hand, the time allocated to the analysis of blast furnace operation events is short and fragmented (8% of operator shift time in periods of 2 to 3 minutes maximum in the case of blast furnace control). It appears necessary to have a system in which the knowledge of the **best** operators is available 24 hours a day - 7 days a week to **any** of the operators in the control room, so that the limited available time can be devoted to the determination of the best action to be taken in a recognized situation.

Availability and promptness are key requirements for a system of this type. As availability, 99% of the time is a good target. As promptness, the target is the ability to supply information to the operator without significant delay over the real events affecting the process.

2.2.2 Practical targets and benefits of SACHEM®

The main operational targets of SACHEM® system are:

- To assure a stable BF operation despite of the change of operators and the limited human performance. This requirement is getting stronger and more complex, day after day, in relation with the introduction of new measuring systems,
- To avoid operation disturbances taking advantage of expert knowledge, especially aiming at early identification of operational events or trends,
- To extend the life of the blast furnace, resulting from a better and smoother operation,
- To take advantage of the accumulated knowledge to better analyze past operations and to better train operators.

Finally, the entire field of blast furnace technology is covered by the expertise integrated into a set of knowledge data base, which are independent on the underlying measurement system.

2.2.3 Process domains

Concerning the characteristics of the system itself, it is important to point out its adaptability to an existing blast furnace.

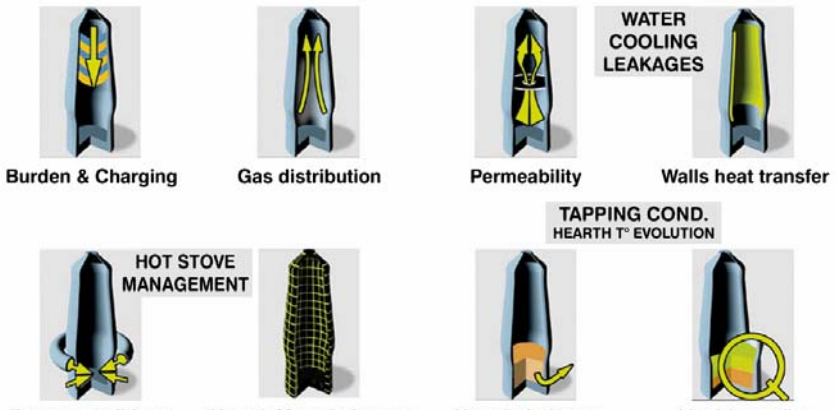


Figure 6 - SACHEM® covered domains

The areas covered by SACHEM® are those of the BF process: raw material quality and characteristics, burden composition, gas distribution, thermal and mass balances, heat transfer, tuyere condition, permeability, hearth drainage, liquid products quality and balance, thermal transfer in the wall and hearth brick temperature control & cooling devices leakage. Figure 6 shows that all BF process areas are covered by SACHEM®.

2.2.4 SACHEM® system architecture

The basic function of a knowledge-based system is to transform (using knowledge) a large amount of data, poor in information - into a small amount of data rich in information. The design used for SACHEM® consists in a series of modules (see Figure 7) making this concentration of data information possible. The functional architecture comprises:

- an acquisition module (interface with the blast furnace process database)
- a calculation module in which the existing physical models are integrated
- a perception module whose role is to ensure the symbolic digital transformation by simulating expert perception (pattern recognition)
- a reasoning module that combines the elementary knowledge required to produce the alarms and recommendations for actions filtered and adapted to the current status of the process.
- an interface module ensuring interaction with the operator. It is designed on the basis of a newspaper metaphor: the front page headlines, the inside pages and the "what's new" section (since the operator is not always in front of his screen)

It is important to note that the system displays the information in accordance with the targets chosen by the BF managers and the reality of the current situation (regarding risks).

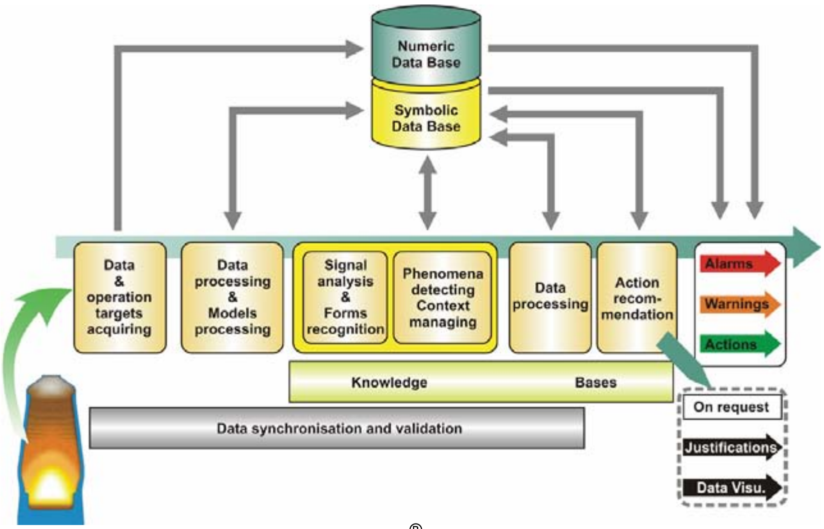


Figure 7 - SACHEM® system architecture

The signal and data invalidation detection function is integrated in these above mentioned modules. Each matter has been solved with the most robust and suitable technology.

3 RESULTS

3.1 Industrial References of SACHEM®

SACHEM® has already been implemented on seven different blast furnaces in France. Two more installations are under customization and planned to be released in 2009 (Vizag Steel India, Novolipestk Russia). At the same time, the same technology has been used, with the corresponding knowledge, on other processes in several countries, with always the same success.

3.2 Industrial Results and Benefits of SACHEM®

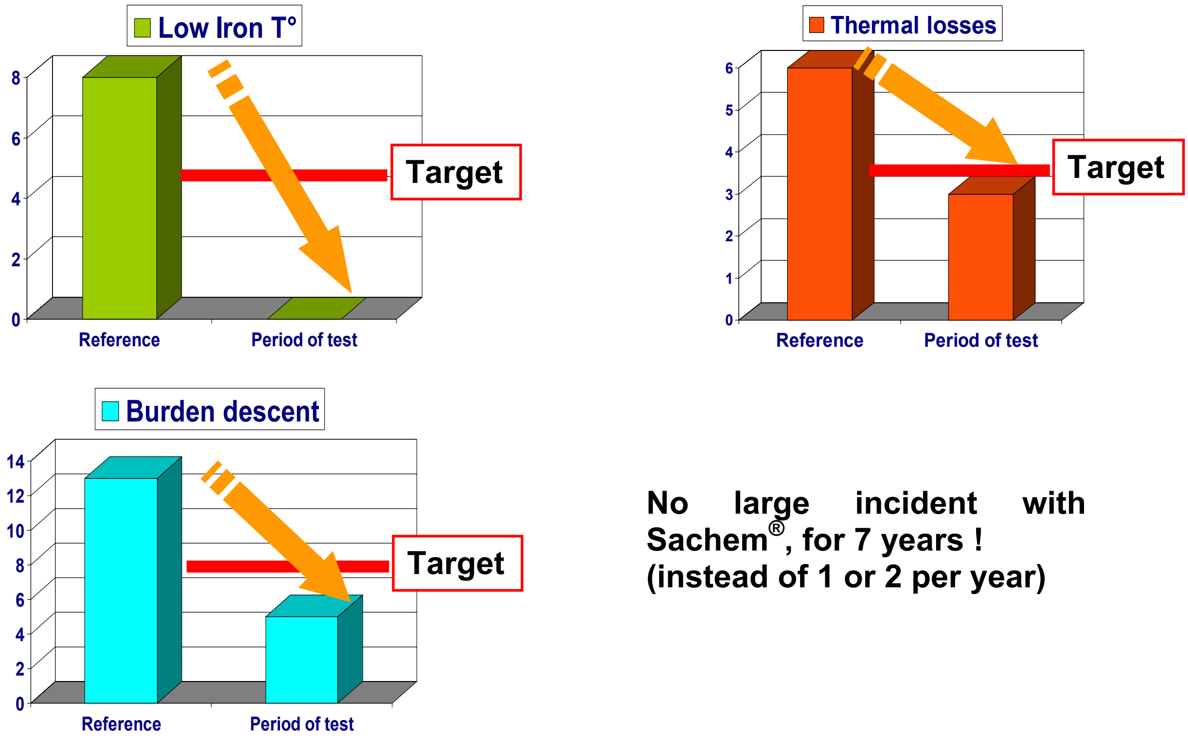
A detailed estimation of the industrial results of the SACHEM® implementation has been performed comparing two different blast furnaces in the same site Fos-sur-Mer BF Plant (France) for one year. One BF was equipped with Sachem while the other one wasn't. According to the expected objectives, the benefits can be summarised as follows:

- Smoother process operation with "anticipation" - the operator knows what is essential as soon as possible. This resulted in a higher BF availability, which also means fewer incidents, lesser blowing reductions or shutdowns.
- Improved hot metal quality
- Higher metallurgical efficiency - which results in lower coke consumption, and eventually in a reduction of the hot metal costs.

In addition to the benefits of process efficiency, we can add those due to the reduced risk for the workforce as well as the emissions reduction.

With regard to the blast furnace itself, the main benefit is the extension of the BF equipment lifetime (especially in the shaft) due to a smoother operation which generates less mechanical stress.

The evaluation of the corresponding direct return on investment on a yearly basis has been done (Table 1)



No large incident with Sachem®, for 7 years ! (instead of 1 or 2 per year)

Figure 8 - Reduction of BF process anomalies

Table 1. Return of investment

	Mean shutdown equivalent time	Yearly production capacity increase	Gain on PCI	Gain on iron quality	Gain on BF life duration	Miscellaneous for productivity increase
Without Sachem	19 hours					
With Sachem	14 hours	30000 t_{HM}		Sigma[Si] =0.03	1 year	
Return (€/t_{HM})		0.15	0.80	0.11	0.30	0.5

4 DISCUSSION AND CONCLUSION

What has been shown up to now is the result of the evolution of PW from a mainly mechanical provider to a complete technology provider. To be a technology provider there is the need to enhance the offer with all the features that allow a customer to achieve the best performance with the acquired plant.

This evolution has been well developed in the past with the access of PW in the Arcelor Group and recently fully consolidated being part of the Arcelor Mittal family. Belonging to the most important steel making group has given even more experience and know-how. These experience and know-how is essential in the field of high level control, supervision and intelligent assistance of blast furnaces.

Similar experiences has been realised by other competitors as well. This experience led to define a considerable role of the Operating Guidance System and Mathematical Models in the achievement of best performances.

As expressed in the introduction the achievement of this kind of performances is also a cultural matter. A knowledge based system like the one described in this paper can be totally exploited if and only if it becomes a daily work tool used in a fully conscious way. This tool should stimulate the reasoning capability of operators and engineers and not act only like a deputy of the human being. As a matter of fact it is not only needed to install these tools but to have people that will use them every day.

Sharing a patented technology with other different process systems, industrial references now represent more than 30 real time implementations in Europe and America.

Definitely more a knowledge system than an automation system, SACHEM® is able to assist people in the control of the BF process. Contributing to the reliability and best efficiency of the operation it continuously checks the data and advises the operators, by anticipation.

The system can be easily installed on any blast furnace, independently of its technological equipment. It allows the operator to achieve the highest benefit and return on investment for the BF equipment, particularly for BLT burden distribution, shaft cooling, probes and PCI, during an extended furnace campaign.

REFERENCES

1 DOLENC, N.; GOBRECHT, A.; HELLEISEN, M; LALLIER, M; LEMUET, D; LESAFFRE, F.M.; LIBRALESSO, J.M.; STEILER, J.M.; THIRION ,C.; The Sachem Project: Computer Assisted Blast Furnace Control System – Prospects Opportunities, Development and Initial results. *Proceedings of the 3rd European Ironmaking Congress, Gent, Belgium, September 16-18, p. 120-127, 1996*.

2 THIRION ,C.; STEILER, J.M.; LEBONVALLET J.L.; METZ, B.; LAO, D.; LACHAT, J.C.; The Sachem Experience with BF Control. Proceedings of the International Conference on New Developments in Metallurgical Process Technology. Düsseldorf, June 13-15, p 91-97, 1999.

3 GIROLDINI ,F.; HELLEISEN, M.; CARMICHAEL I.; GOFFIN, R.; THIRION, C.; Combining up-to-date design of equipment and best practice, aided by knowledge engineering (Sachem). A guarantee for top class BF efficiency. *The 5th European Coke and Ironmaking Congress. Stockholm, June 12-15, 2005.*