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BFXpert™ - THE BENEFITS OF PAUL WURTH'S INTEGRATED BLAST FURNACE LEVEL 2 SYSTEM[1]

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Abstract

Today's market imposes a new flexibility to the blast furnace process in terms of raw materials (quality, supply sources) and operating conditions (e.g. production level). However, in order to achieve a high level of performance (hot metal quality, increased availability, cost reduction) a consistent design and instrumentation as well as in-depth process knowledge is required. The present paper highlights the latest developments of Paul Wurth's level 2 automation system BFXpert and how it copes with these challenging conditions. All relevant measurements and analyses are continuously monitored by BFXpert. The implemented functionalities detect phenomena and abnormalities at an early stage in order to avoid perturbations. Control, process and simulation models as well as the knowledge based intelligent supervision system SACHEM® are fully integrated in BFXpert ensuring a continuous assistance in order to stay within defined targets while applying 'best practices'. Interface and compatibility problems are eliminated by having a one-package solution with interacting models based on a dedicated database. The innovative concept of 'relative recipe definition' and the integrated plausibility checks minimize the error-proneness. An ergonomically designed interface as well as a coherent usage of control and computed variables common for all BFXpert elements considerably reduce the work load and focus the user on the process itself.

Keywords: Level 2; Blast furnace; Models; Expert system.

Resumo

Hoje o mercado impõe uma maior flexibilidade ao processo do alto-forno, em termos de matérias-primas (qualidade, fornecedores etc.) e as condições de operação (por exemplo, nível de produção). No entanto, para atingir um elevado nível de desempenho (qualidade da gusa, maior disponibilidade, redução de custos) é necessário um projeto consistente do alto forno e instrumentação, assim como um profundo conhecimento do processo. O presente trabalho destaca o mais recente desenvolvimento da Paul Wurth em sistemas de automação em nível 2, o BFXpert, e como ele lida com estas condições desafiadoras. Todas as medições e análises pertinentes são monitoradas continuamente pelo BFXpert. As funções implementadas detectam fenômenos e anomalias em um estágio inicial, a fim de garantir uma operação suave. Modelos de controle, de processo e de simulação, bem como das informações do sistema inteligente de supervisão Sachem® estão plenamente integrados no BFXpert assegurando uma assistência contínua, a fim de permanecer dentro de metas definidas, ao aplicar as "melhores práticas". Interface e problemas de compatibilidade são eliminados por ter uma gama de soluções com modelos interagindo com base em um banco de dados dedicado. O conceito inovador de "definição de receita" e a integração de verificações plausíveis minimizam a propensão ao erro. Uma interface ergonomicamente projetada, bem como uma utilização coerente do controle e das variáveis computadas e comum para todos os elementos BFXpert reduz consideravelmente a carga de trabalho e concentra o usuário no processo em si.

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1 INTRODUCTION

Constantly changing market conditions impose flexibility in terms of raw material quality and operation conditions. The last 2 years have shown that many operators had to repeatedly switch the blast furnace process conditions between high productivity and low productivity, between high injection rates and all coke operation whilst coping with a wide range of different raw material qualities.

Achieving a high level of performance and thus competitiveness in the market is an important motor for the evolution of blast furnace technology and operation. New Paul Wurth and TMT developments have enlarged the productivity range in which the blast furnace can be operated and increased the degree of instrumentation in order to achieve a more accurate process control adapted to current process conditions.

Operating a blast furnace at high performance under any imposed conditions implies controlling in-time every aspect of the process. A swift process adaptation to changing operation conditions and an early detection of phenomena which could perturb or even cause an un-planned shut-down of the blast furnace, have an immediate positive impact on the production cost and on the availability of the plant.

The growing amount of data necessary to monitor and optimize the hot metal quality and production cost is becoming more and more challenging for expert operators. This flood of information coming from all the measurements and partly from laboratory is literally drowning operators. Unfortunately, it is a fact that intelligent human beings can only follow-up a limited amount of parameters simultaneously [**Erro! Fonte de referência não encontrada.**].

Some operators are more efficient than others thus leading to operational differences between shifts. In addition, the time allocated to analysis of events and phenomena is both low and fragmented. The associated risk management is hardly controllable.

In order to continuously achieve a high level of performance it is absolutely necessary to have an expert system in which the ‘best practice’ process and operational knowledge as well as effective process analysis models and tools are supporting all the operators 24 hours a day – 7 days a week [**Erro! Fonte de referência não encontrada.**].

The required reliability, both for the daily achievement of production targets within optimized production costs and extended campaign life, needs sharing the work load and co-operation between involved partners; operators, process engineers and BFXpert™.

2 BFXpert™

BFXpert™ is the advanced process control system that integrates the knowledge based supervision and operating guidance expert system SACHEM®, process and simulation models as well as software tools on a common platform.

It consists of a set of integrated powerful on-line and off-line tools to compute process data, calculate set points, simulate new production set points, generate ‘recipes’ and provide diagnostics as well as recommendations to assist blast furnace managers, process engineers and operators in their daily tasks to achieve the target production at optimized cost and anyhow ensure a long life campaign.

BFXpert™ is sub-divided into five major groups:

- Real time control models
- Real time operating guidance expert system SACHEM®
- Real time process models

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- Monitoring, simulation and optimization models
- Configurable system tools and functionalities

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Last year Paul Wurth has conducted a major customer survey in Europe revealed the importance and the needs of a level 2 system. The results of this survey have been combined in a study and used to improve and increase the functionalities of BFXpert.
A team of dedicated, specialized ergonomist, blast furnace process and automation engineers have developed BFXpert according to ergonomics and to the needs specified by blast furnace operators during the customer survey.
The ergonomist team has been involved in the design of some European blast furnace control rooms. In an early stage of SACHEM® development, this team has conducted long term observation and tests with blast furnace operators to conceive intuitive interfaces.
The survey and ergonomic study have demonstrated the necessity to integrate all blast furnace models and expert system taking advantage of common monitoring, analysis, reporting and administrative tools.
This integration means the user is not dealing with a set of separate models but with one system in which models pass on data and benefit from the results of others to increase their value and accuracy. Additionally, multiple checks are implemented in and between models to avoid errors and thus possible process perturbations.
The requirements of the human operator are considered by the implementation of an understandable ergonomic common interface. Multiple inputs are avoided, thus work load and source of errors are reduced.

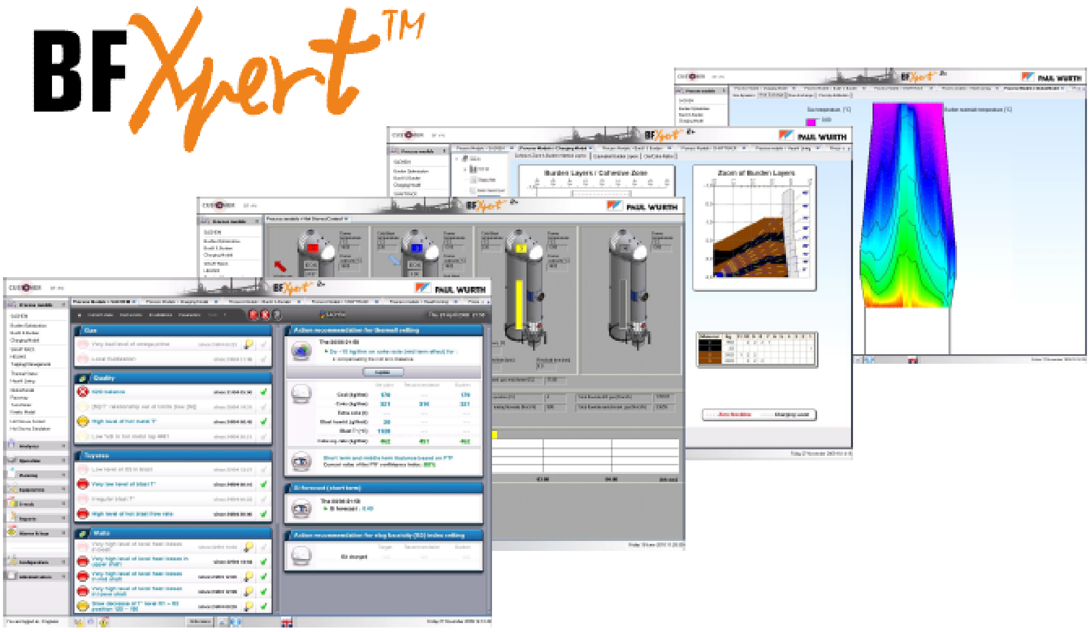

Figure 1: BFXpert™ screenshots.

Real time control models

The real time control models are designed to assist operators by taking over routine tasks. The operator is freed up, thus having more time to concentrate on analyzing the process, reasoning and decision-making.
Control models will ensure continuity and improve safety of the operations while optimizing costs and prolonging the life-cycle of the installations. Safety measures in form of continuous checks are implemented to avoid perturbations.
The Hot Stoves Closed Loop Control Model manages hot stoves heating and change-over. The heating control calculates amongst others the optimum dome set-

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point temperature, the thermal balance of the heating phase and the remaining time on blast. The efficiency of the last cycle is calculated and used as an adaptive parameter inside the model.

The change-over control estimates the remaining time for each stove phase. The system can run in fully automatic mode or in operator mode, in which the results are only displayed and need to be put into action manually [**Erro! Fonte de referência não encontrada.**, **Erro! Fonte de referência não encontrada.**]. **Figure 2** shows a Hot Stoves Closed Loop Control Model screenshot.

In order to simulate different steady-state scenarios using different blast set points and fuel compositions, this control model is linked with the Hot Stove Simulation Model (described in chapter 0).

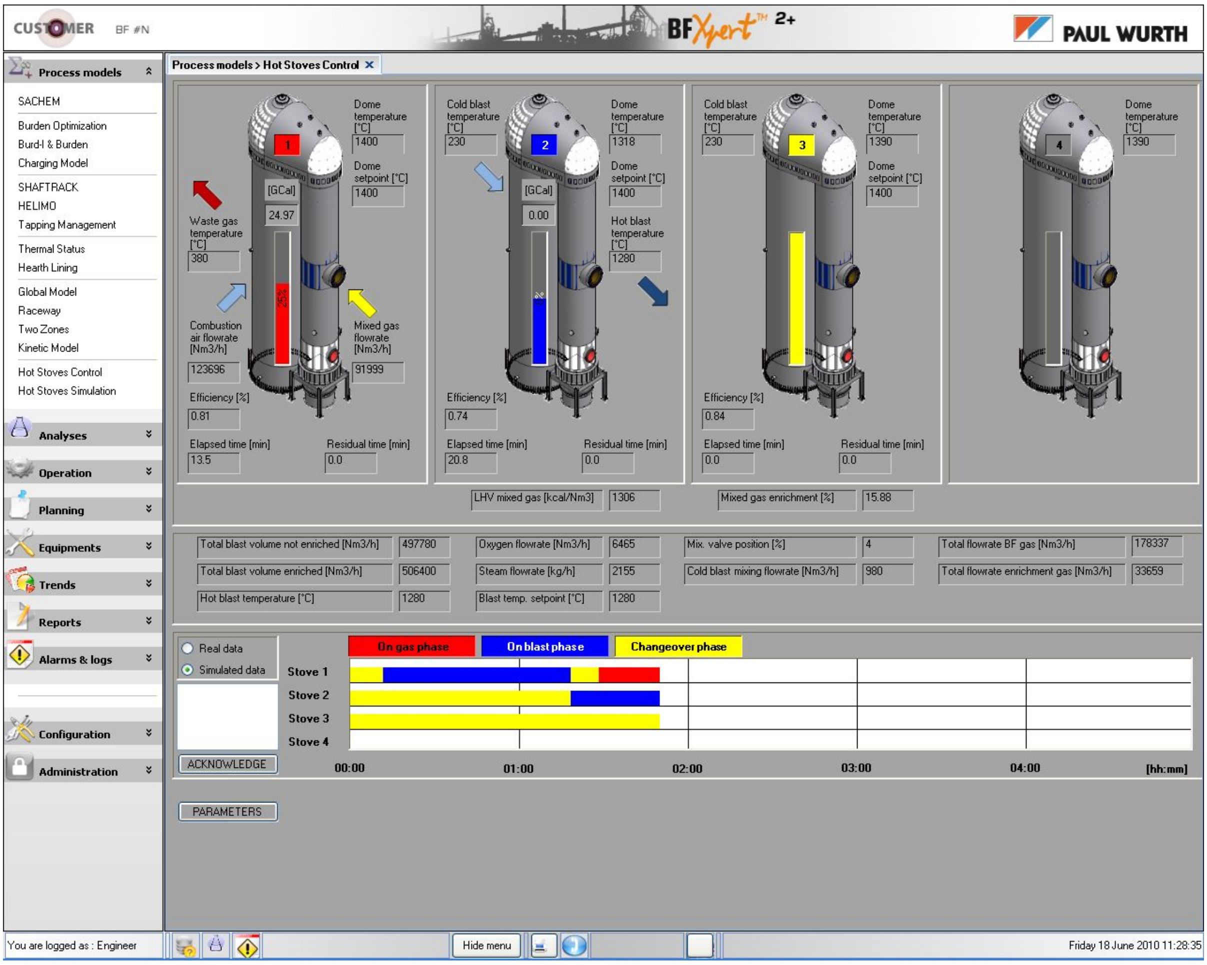

Figure 2: Hot Stoves Closed Loop Control Model screenshot

The BLT® Burdening Interface with the integrated Burden Calculation Model is an innovative 'recipe based' application to handle all charging related steps.

The Burden Calculation is a central imbedded model to ensure, that the targeted burden composition is maintained stable while the raw material chemical compositions and weights change.

In order to overcome complicated recipe updating procedures, a concept of relative recipe definition was developed by Paul Wurth. The main difference is that the weights allocated to batches are expressed in a relative manner, i.e. in percentages of the nominal charge. A batch corresponds to a Bell Less Top (BLT®) Hopper filling. A charge is a set of at least one coke and one ferrous material batch.

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A recipe is defined by:

- A reference basis (coke, ferrous or hot metal basis, coke throat/belly height)
- The number of charges per charging cycle
- The total number of batches
- The raw material types arrangement of each batch on the main conveyor/skip
- The way each batch is discharged by the Bell Less Top into the blast furnace

In between these steps the system performs multiple consistency checks. User input values are checked in order to see, if the values are within the limits of the operation of stock-house and BLT® [**Erro! Fonte de referência não encontrada.**].

If the stock-house control system foresees the possibility to specify the raw material type arrangement on the main conveyor or collecting conveyor to skip; the interface controls the arrangement and visualization of the material types on the conveyor.

Once a recipe has been defined and stored in the database, it can be selected at any time to activate it. The user-friendly recipe definition together with the possibility of saving, filtering and loading as well as editing recipes minimizes time requirements and sources of input errors [**Erro! Fonte de referência não encontrada.**].

The system is capable of working in an automatic mode upon detection of raw material composition changes coming from the integrated Analysis Management functionality (explained in chapter 0). In this case the recipe will not require manual updating. The only figures changing in order to update the recipe are the specific raw material weights to keep the hot metal and slag quality constant.

Additional safety to this procedure is given by the batch composition and BLT setting check. The new weights will be transferred to the interface. Upon request to put the recipe into production, it is checked for potential errors or problems.

Prior to defining a new recipe the optimal burden composition and process conditions can be checked with the Burden Optimization Model and with the Kinetic Model. Both models are explained in chapter 0.

The burdening interface is enhanced by its interaction with the Charging Model calculating the piling-up of the burden in the furnace (chapter 0). When a recipe has been defined, all information regarding batch composition and charging matrix are available and can be transferred to the Charging Model automatically.

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Real time operating guidance expert system SACHEM®

SACHEM is a knowledge-based process control system continuously assisting the operator in a cooperative way in order to operate a blast furnace according to a 'best practice philosophy'. It does not contain the expertise of one specific blast furnace plant, but the current up-to-date blast furnace know-how. It is based on metallurgy and process rules as well as on the human model of analysis and decision making.
The heart of the SACHEM is made up of multiple software processes and a database. The processes are specialized in data acquisition, verification and invalidation as well as self re-validation, model computation, signal analysis, recognition of phenomena, generation of alarms and warnings, action recommendations and elaboration of synthesized information [**Erro! Fonte de referência não encontrada.**]. **Figure 4** shows four representative SACHEM screenshots.

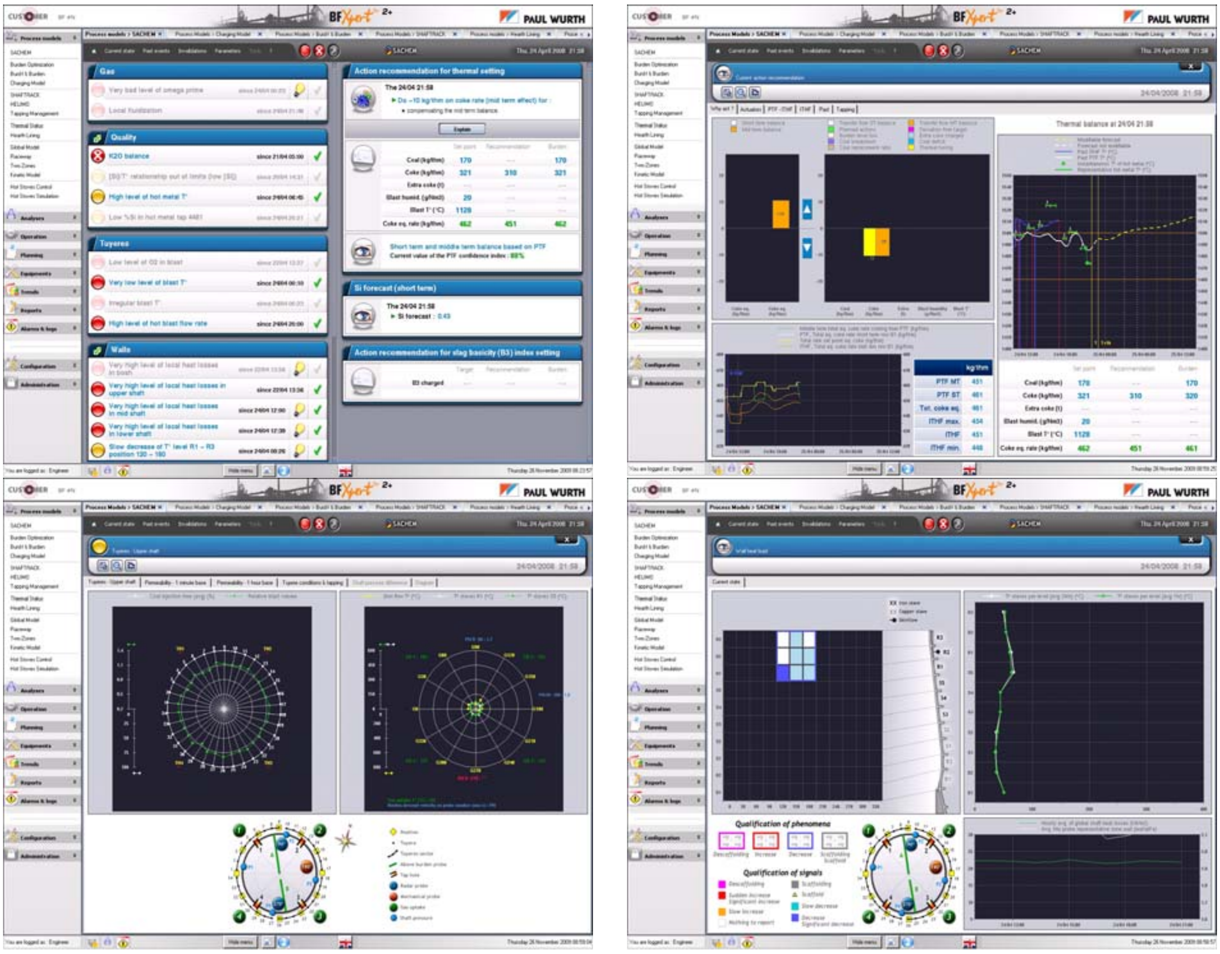

Figure 3: Four representative SACHEM screenshots

After data collection SACHEM organises the data synchronisation, for example data coming from the charging and corresponding data coming from the tapping.
In order to guarantee the best results, SACHEM continuously checks the data consistency. The data quality can be affected by different causes, such as natural physical incertitude, measurement deviation or rupture, etc. The implemented on-line automatic invalidation functionality ensures data consistency.
SACHEM displays an overview of all measured data currently invalid and arranges these invalidations into two categories: critical or non critical invalidation. Those

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invalidations that prevent completely one or more internal models from functioning are considered as critical. Invalidated data (not taken into account) is automatically revalidated and taken into account after repair or replacement of the relevant sensor.
SACHEM is based on the early perception of significant process patterns. These elementary patterns are assembled to identify up to 180 different blast furnace process phenomena. A judgment on the severity of the detected phenomena allows classifying them into warnings or alarms and the necessity to recommend actions [**Erro! Fonte de referência não encontrada.**].
SACHEM displays for every phenomenon a justification for the detection of a phenomenon and a necessary action. Aiming on simplifying the surveillance of the furnace, numerous mechanisms are implemented to avoid a too large quantity of information shown to the operator. The displayed amount of data will stay manageable for the operator at all time.
SACHEM always recommends a gradual action to recover the maximum flexibility (range of action) for the future. The recommendation of actions aims to achieve and maintain the operational process targets (production, temperature, chemistry) and to prevent disruptions (alarming phenomena or harmful behaviour).
The forecast function of hot metal temperature and silicon content allows to be able to act based upon the future evolution of the furnace. The hot metal temperature prediction model runs with two combined loops: one for the short term and one for the medium term reaching up to 12 hours into the future [**Erro! Fonte de referência não encontrada.**].
The recommendations of actions in the field of blast furnace thermal and chemical adjustment are displayed together with explanations and procedures.
Depending on targeted operating set points, the recommendation includes the available actuators like coke rate, injection rate, hot blast temperature and steam addition or a combination of these. Already planned actions are taken into account e.g. shut-down or future increase of fuel injection. The thermal model is adaptable to local thermal control preferences.
The implemented thermal models take into account the dynamic behaviour of the furnace based on actual thermal state and its future prediction. Recommendations concerning the fuel rate adjustment are provided taking into account the current thermal balance and the hot metal temperature forecast. The thermal models are self-adaptive to the current blast furnace behaviour. Their target is to minimize the fuel consumption while keeping the hot metal temperature stable [**Erro! Fonte de referência não encontrada.**].
SACHEM speaks the operator's language; the system delivers the messages and the advice to the operator, depending on the context. The messages will be established commonly together with the operators. On the 'Front Page' the operator will find all important information provided by the detection functions, the recommended actions and information about invalidated data. He always knows which information is new, and which has already been consulted.
To be complete in the assistance offered to the operator; for every detected phenomenon the 'on-site' procedure can be included and opened by a mouse click in a dedicated view. The initial delivery includes a first set of general and qualitative recommendations coming from blast furnace experts.

Real time process models

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After a recipe from the burdening interface has been verified and put into production the single batches charged into the blast furnace are progressively handed over to SHAFTRACK (shaft tracking model). Its interface presents a convenient graphical representation of the charged batches with all relevant information and the corresponding location inside the furnace. The model tracks batches from the furnace top down to the tuyere level in order to visualize their position.
The batches are represented graphically by layers inside the blast furnace inner lines. The model predicts and continually updates the expected time a batch will arrive at the tuyere level. A comparison between the actual fuel rate and the target fuel rate is displayed graphically. In case of high discrepancy, alarms are generated. The connection between batch and fuel rate tracking allows determining the correct timing for fuel rate adaptations and prepared furnace shut-downs.
HELIMO (hearth liquid model) estimates the amount of molten hot metal and slag inside the hearth, based on continuous mass balances of produced and tapped liquid quantities. The necessary input values originate from blast furnace data, from SHAFTRACK and from the Hearth Lining Model.
HELIMO calculates the residual mass of hot metal and slag remaining in the hearth after tapping and its accumulation in time. Based on this information and the hot metal production rate, the model permits a prediction of the time remaining before closing the tap-hole and the time until the next tap.
The model manages all relevant tapping information enabling monitoring and thus providing uniform tapping conditions. Beneath the cast information it supervises and stores data concerning the tap-hole, the instrumentation and the injection mass. This permits HELIMO to diagnose the tapping process and to advice corrective actions.
HELIMO calculates the height of molten hot metal and slag inside the hearth by taking amongst others the hearth wear profile and the coke bed voidage into consideration. Therefore the actual hearth volume calculated by the Hearth Lining Model will improve the accuracy of the remaining hot metal and slag mass as well as the liquids level estimation.
The Global Model is a two dimensional iterative model which calculates internal conditions of the blast furnace in steady state using averaged measured data. The Global Model uses layer geometry, porosity and cohesive zone data obtained by the Charging Model (see chapter 0) as an initial estimation for the gas dynamics sub-model. The gas dynamics module redefines porosity of the burden column by using measurements and resolving Ergun's equation. Calculated results provide the burden layer porosity, pressure and velocity fields of the gas in the shaft. The heat-transfer sub-module calculates the gas and solid temperature fields. The mass exchange sub-module considers the chemical interaction between oxidized iron ore and reducing gas providing insight to the chemical process within the furnace. The oxidizing state of solids and gas, indirect reduction and the RIST operating line are amongst available results. Once individual sub-modules have converged a global iteration loop links all sub-modules which again are re-iterated to a state of convergence. Finally one of the most remarkable results is the position and shape of the cohesive zone in the shaft. The combination of tabular data and visualizations in two dimensional maps and charts provide a deeper understanding of phenomena within the blast furnace.

Monitoring, simulation and optimization models

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The Burden Optimization Model computes the optimum burden composition (iron-bearing materials and fluxes) in order to obtain the requested quality of hot metal and slag to minimize the production costs, taking into account the constraints specified on burden raw materials and on the specified product characteristics. It is a powerful tool to minimize the hot metal costs and carry out planning calculations.
The Kinetic Model calculates heat and mass balances, top gas temperature and heat losses, gas efficiency, gas composition, equilibrium equations for metal-slag repartitions, viscosities and melting temperature as well as pressure drops and velocities inside the blast furnace.
Through the integration in BFXpert, the Kinetic Model can easily be activated with the current data acquired from the database or with input data given by the user. It can be used to evaluate coke rate, blast flow rate and pressure, hot metal and slag analysis, top gas analysis and flow rate, burden materials rate and utility parameters to verify the effectiveness or feasibility of particular operating conditions.
In this model material, energy and momentum balances, expressed in differential form, are used to represent the indirect reduction zone. On the contrary, total balance equations and semi-empirical correlations are used for the smelting zone.
The Hot Stove Simulation Model calculates steady-state scenarios obtainable with a particular stove battery for different blast targets and fuel compositions. Being well imbedded in the common BFXpert platform, this model easily re-uses values kept from the Hot Stoves Control Model to simulate different steady-state scenarios.
The Thermal Status Monitoring provides a synthetic graphical representation of top gas and furnace thermal status in 2-dimensional maps. Missing data is interpolated. The thermal status of the blast furnace and occurring phenomena can efficiently be evaluated by showing the maps as movie strips between two chosen dates. Anomalous conditions are quickly revealed and are traced over time.
The Raceway Model calculates and simulates the conditions in the raceway: adiabatic flame temperatures, gas velocities, impulse, and penetration depth as well as gas composition.
The Hearth Lining Model is an on-line mathematical model to monitor the hearth' thermal status and wear profile. Based on these results proper counter measures can be taken before the hearth lining wear gets critical. **Figure 4** shows a Hearth Lining Model screenshot of a vertical section.
The model continuously monitors the evolution of thermal and erosion profiles and takes into account the build-up of adherent relining material. The hearth wear profile is determined in two calculation steps.
First, a numerical solution for the heat transmission is calculated. Second, there is a self-tuning procedure in which the model parameters are corrected to minimize the deviation between calculated and measured temperatures.
This procedure, applied to a pre-defined set of vertical two-dimensional sections, produces a three-dimensional representation of the hearth, showing the actual and maximal historic wear profile as well as the thermal status.
The result of the three-dimensional wear profile is used to calculate the hearth volume needed in HELIMO (Hearth Liquids Model).

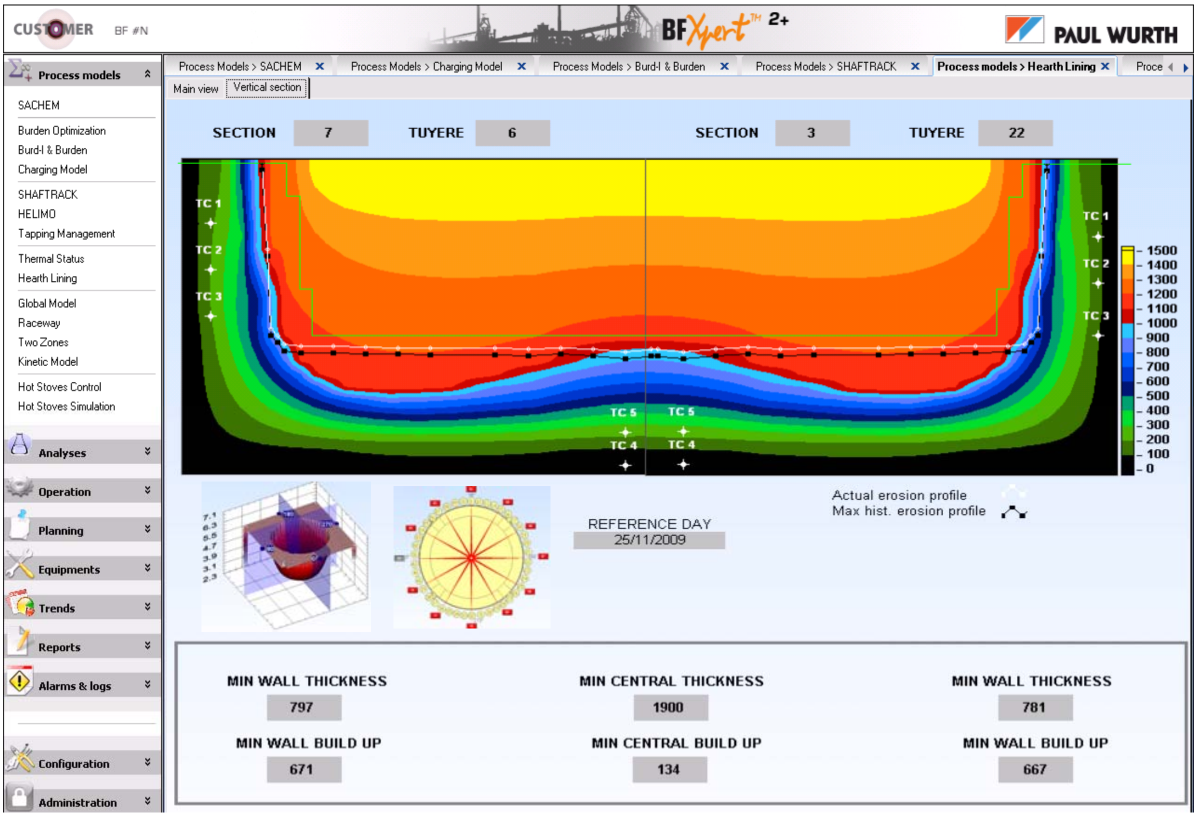

Figure 4: Hearth Lining Model screenshot of a vertical section.

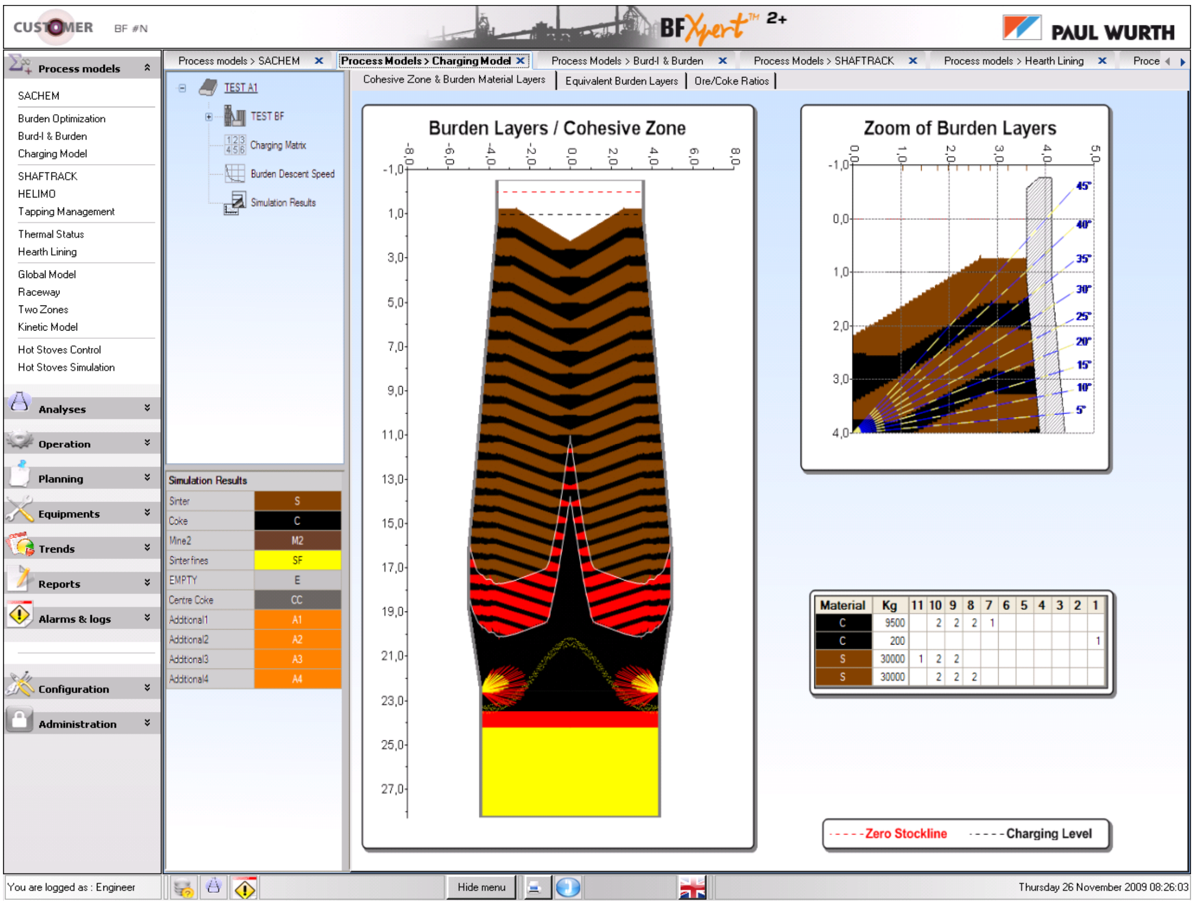

Figure 5: Charging Model screenshot.

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The Charging Model calculates and illustrates probable effects on burden and gas distribution within the furnace based on a charging matrix. A dynamic falling curve mode indicates how layers are constructed within the blast furnace radius. Ore to coke distribution and burden column porosity calculations help to understand burden distribution effects on gas distribution [**Erro! Fonte de referência não encontrada.**].
In order to obtain accurate results the model takes into account diverse characteristics of the Bell Less Top (BLT®) charging systems. Falling curves measurements, specific charging phenomena such as coke push, percolation and grain size segregation are considered. Ultimately the Charging Model provides an estimated shape and position of the cohesive zone.
The results of the Charging Model are used as initial data for the Global Model.
Within the process of burden calculation and distribution the Charging Model can be used to verify a recipe before utilization.
Additionally, as an offline tool, it provides an independent environment for simulating new charging concepts. It also increases efficiency in the routine of adapting a charging cycle to changing furnace conditions.

Configurable system tools and other functionalities

BFXpert includes a common set of configurable system functionalities to assist operators in their daily tasks such as configurable reporting, configurable trending and user friendly formulas graphic editor as well as the analysis management.
The configurable reporting functionality provides site-wide client connections and the ability to create, schedule and web-enable reports. Using well known Microsoft Excel, the authorized user can define his own reports, which can be scheduled, emailed, exported, faxed, stored to disk, printed and published to the web server report portal.
A set of templates for daily, weekly, monthly and yearly reports adapted to process engineers as well as plant manger is already included. These reports can be easily adapted by authorized people to the own preferences without any programming skills. The system integrates data from both real-time and database sources.
The Analyses Management tool supports operators to keep the overview of the variety of analyses. Its functionalities include the display and validation of analyses as well as the application of different statistic rules to prepare the analysis data for its further use in the different models.
The configurable trending functionality allows users to define and store their own preset graphs and to configure the chart styles as well as colours easily. Also it is possible to directly export the displayed data as picture or Excel file.
The Formula Graphic Editor is designed to easily create, modify and delete formulas of process variables and to archive the created variables for trending purposes.
Operational support functions to manage data integration for charges, casts, stoppages and tuyeres replacement are provided to have a consistent set of data.

3 CONCLUSION

BFXpert™ combines the best available process know-how with the most extensive expertise in blast furnace design and iron-making equipment.
Internal data transfer between models minimizes the amount of user inputs. Routine tasks are handled or respectively cross-checked by BFXpert™. The main task is to operate the furnace as stable as possible 24 hours a day and 7 day a week.

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At the same time the ergonomic interface strengthen the interaction between the user and the system as well as the acceptance of the system by the user. The cooperative assistance of BFXpert leads automatically to a training of operators throughout its models, functionalities and the provided explanations. The process awareness of operators is increased.
BFXpert improves the safety through fewer technical incidents lowering the risk of human, environmental and equipment hazards.
The blast furnace campaign life is extended through stable mechanical and thermal loads as well as the monitoring of critical areas enabling preventive actions.
The availability is improved leading to an increased production capacity. The overall energy consumption (blast furnace and hot stoves area) is reduced. The product quality is improved, resulting in improved slag granulation and steel shop operation.
All the enumerated advantages lead to one major benefit: the reduced hot metal cost.

REFERENCES

1 Helleisen, M.; Giroldini F.; Carmichael, I.; Thirion, C.: Optimized use of BLT® and PCI with intelligent supervisor assistance SACHEM®. 5th European coke and iron-making congress. Stockholm, June 12-15, 2005
2 Thirion, C.; Odicino, G.; Fontana, P.: Improving BF operation through SACHEM® (Intelligent Supervision System) and process optimization models, ABM 3rd International Meeting on Ironmaking, São-Luís, Brazil, 2008
3 Fontana, P.: Desenvolvimentos inovadores na automação de processo para o melhoramento das prestações de usinas siderúrgicas; III Seminário de Engenharia - CST, Vitória, Brazil, 1987
4 Tockert, P.; Thirion, C.; Lonardi, E.; Thillen, G.; Goffin, R.; Hausemer, L.: New Developments in Bell-less Top® Charging Technology of Blast Furnaces, AISTech 2009 Proceedings - Volume I 413-421
5 Bermes, P.; Tockert, P.; Simoes, J.P.; Hansen, F.; Hausemer, L.: Advanced BF Process Control using BFXpert™, PRIISM – 2010 Ranchi, India, 2010
6 Thirion, C.; Odicino, G.; Fontana, P.: Improving BF Operation through SACHEM® and process optimization models, International Ironmaking Conference, Jamshedpur, India, 2007
7 Buchwalder, J.; Dobroskok, V. A.; Goffin, R.; Lonardi, E.; Thillen, G.: Contemporary Blast Furnace Top Charging Practices, METEC InSteelCon 2007