BF PROCESS TECHNOLOGY ENHANCED BY CHARGING CONTROL, PROCESS MONITORING AND MATHEMATIC MODELS[1]

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Abstract

Today's market conditions impose high flexibility to the blast furnace process (raw materials, production level, fuel injection) while minimizing production cost and maximizing availability as well as life time of the equipment. In addition, increasingly stringent regulations in the areas of environment and governance require careful acquaintance of resources consumption and production of waste or emissions. The Bell Less Top® (BLT®) while introduced more than 40 years ago continues to create great opportunities to improve blast furnace operation. Indeed it starts "at the top" in one of the most critical stages of the process through controlled and precise burden distribution. Its success is underscored by implementation on furnaces of various sizes and a worldwide market presence of more than 60 %. Blast furnaces equipped with TMT probes and measuring devices acquire a precise representation of the process. Process data can be advantageously used as input for mathematical models and expert systems of Paul Wurth BFXpert™. In turn, BFXpert facilitates prediction of future process states, advises potential optimizations, reduces information overload for key decision makers and minimizes costly and risky trials. Attempting to leverage all this potential creates a need for a complete solution capable of ensuring the symbiosis of all innovations. This paper demonstrates how charging and measurement systems coupled with data analysis and mathematical modelling, become an integral tool in the cost efficient and stable hot metal production.

Keywords: BF top charging; Process; Charging model; Expert system.

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1 INTRODUCTION

The process of operating a blast furnace today must be flexible. This is induced, in part, by simultaneous issues of varying raw material quality, minimized coke rates, and increased injection fuel rates, all while being required to ensure maximum availability. In addition, increasingly stringent regulations in the areas of environment and governance require careful planning to address consumption of resources, and production of waste or emissions.

The Bell Less Top® (BLT®) system while introduced more than 40 years ago, continues today, to create great opportunities to continuously improve BF iron production. Indeed it starts “at the top” in one of the most critical stages of the process through controlled and precise burden distribution. Its success is underscored by implementation on furnaces of various sizes worldwide. The BLT has a market presence responsible for more than 60% of blast furnace hot metal production.

Currently, a blast furnace equipped with TMT probes and measuring devices is capable of acquiring a precise representation of the iron making process. Process data can be advantageously used as input for mathematical models and expert systems of the Paul Wurth level-2 system BFXpert™. In turn, BFXpert facilitates prediction of future process states, advises potential optimizations, reduces information overload for key decision makers, and minimizes costly and risky trials.

Attempting to leverage all this potential creates a need for a complete solution capable of ensuring the symbiosis of all innovations. This paper will demonstrate how charging, and measurement systems coupled with data analysis and mathematical odeling, become an integral tool in the efficient and stable production of hot metal.

2 EVOLUTION OF THE BELL LESS TOP AND IMPACT ON THE CHARGING PROCESS

The first Parallel Hopper Bell Less Top in North America was installed at Essar Steel Algoma (formerly Algoma Steel) in 1975. This type of BLT quickly became the standard configuration for new blast furnaces throughout the 1970’s and 1980’s. During this time, components of these systems went through continuous improvement cycles. The results of these improvements are the GEN2 Three Hopper and Two Hopper BLTs. In 2007, the first Two Hopper BLT was implemented at Severstal NA in the USA. Design features combine the flexibility of multiple hoppers with the advantage of a Central Feed Single-Hopper BLT. This ensures perfect centering of material as it exits the hopper. In order to achieve similar material flow to the Single-Hopper system, the outlet openings of the hoppers have been moved towards the centerline of the blast furnace. This creates improved circular burden rings regardless of the hopper used. The modified hopper shape and arrangement, leads to a material discharge which is close to a plug flow, resulting in less grain size segregation and more uniform granulometry.(1)

In regard to blast furnace size and production level, several constraints related to cost and technology have been addressed by new Paul Wurth solutions; including the Central Feed BLT with a single material hopper, and the MINI and MIDI Bell Less Tops in the year 2000 which were developed for small to medium sized blast furnaces. The first North American Compact Central Feed BLT was installed in 1997 at USS Great Lakes.

From a process perspective the Three Hopper Bell Less Top provides greatest flexibility. The increased charging capacity resulting in longer effective furnace charging time also ensures a higher catch-up rate. More complex charging cycles and patterns (small batches, more chute revolutions) can be executed. This is especially useful when dealing with variable material quality such as different sinter fractions. In the event that one hopper is out of service it is possible to maintain nominal production rates with the remaining hoppers. With respect to BF operation, it is commonly understood that regardless of running with a two or three hopper BLT, only optimum charging patterns will ensure high process efficiency.(2)

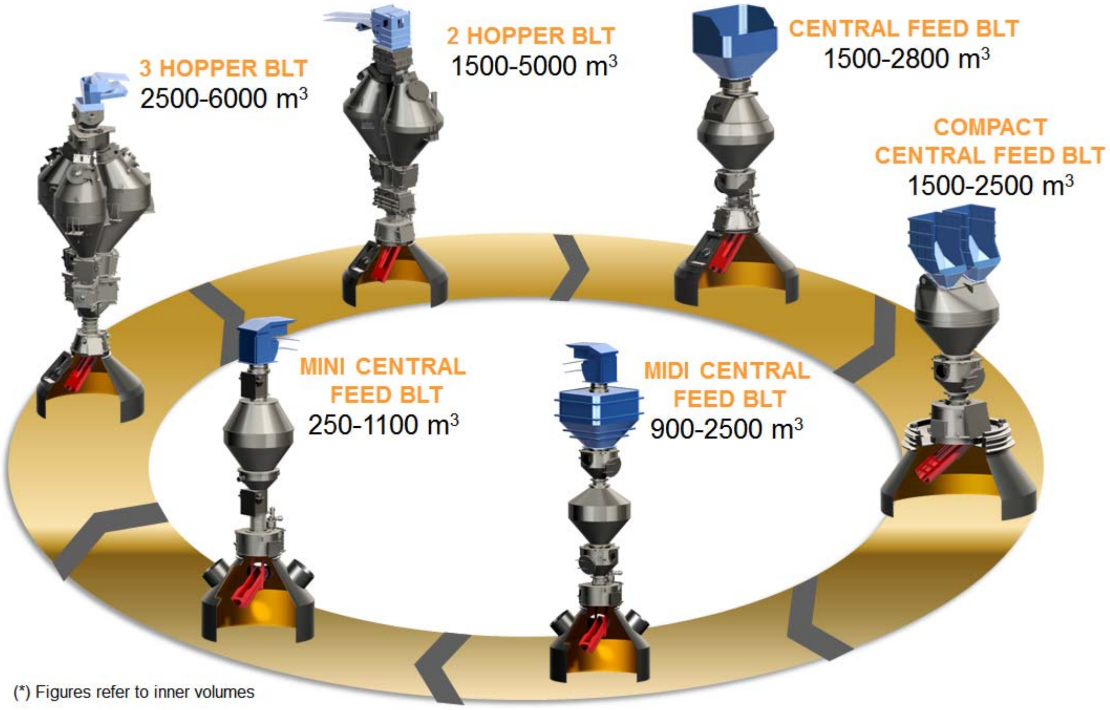


Figure 1: Paul Wurth Bell Less Top family.

More recently the development of the G3 chute transmission gearbox has extended process capabilities with its higher rotation speed of up to 12 rpm instead of the conventional 8 rpm and its high performance pressurized cooling circuit. In addition its enclosed-body chute allows for most precise burdening and accurate center coke charging. A new distribution chute with a closed cover at its end has also been developed for conventional chute transmission gearboxes.

3 PROCESS OPTIMIZATION BEST PRACTICES

Key process characteristics such as shaft permeability, gas utilization and burden descent can be primarily controlled by the charging system. Prior to the recent decade, days were sometimes required to find the optimum charging pattern for a given BF operation point. Often conditions changed more quickly than there was time available for optimization. Limited feedback from the blast furnace made it difficult to take full advantage of the Bell Less Top. Obtaining an ideal charging pattern included mandatory phases of trial and error tests with changes based on theoretical concepts.

To make full use of the equipment, Paul Wurth provides integrated solutions for charging, measuring and automation. Based on this, the following paragraphs describe how the charging and BF process can be efficiently adapted in a short period of time making use of the latest process models and measurement probes.

The process models are part of BFXpert™, the Paul Wurth blast furnace level-2 system. It consists of a modular set of integrated powerful on-line and off-line models on a common platform including SACHEM® expert system as well as BFXpert RULES and other tools. BFXpert covers all areas of blast furnace ironmaking such as charging, blast and injection, tapping and supervision.

It provides diagnostics as well as recommendations to assist blast furnace managers, process engineers and operators in their daily tasks to safely achieve the target production at optimized cost as well as ensuring a longer campaign life.(3)

The Paul Wurth BFXpert Burdening Interface model also known as BURD-I, integrates several important steps required for charging. First, a mass balance tool aids technicians with calculations required to determine raw material and flux rates for a given burden composition, while accounting for slag basicity, MgO target and coke/ferrous base targets. Next, the stockhouse matrix is set; in which the filling sequence of the main conveyor or skips is defined, choosing the appropriate stockhouse material bins, with integrated checks that limit the risk of error. A third critical step results in creation of the Bell Less Top matrix, directly impacting the charging pattern.(4) A coupling between BURD-I and the Charging Model permits an easy assessment of the resultant matrix and its effect on the charging pattern. This integration greatly reduces the number of iterative steps required to find an optimum charging matrix. The Charging Model provides visualization of burden layer pile-up, coke push effect, ore to coke ratio calculations across the BF radius, and an estimation of the cohesive zone.

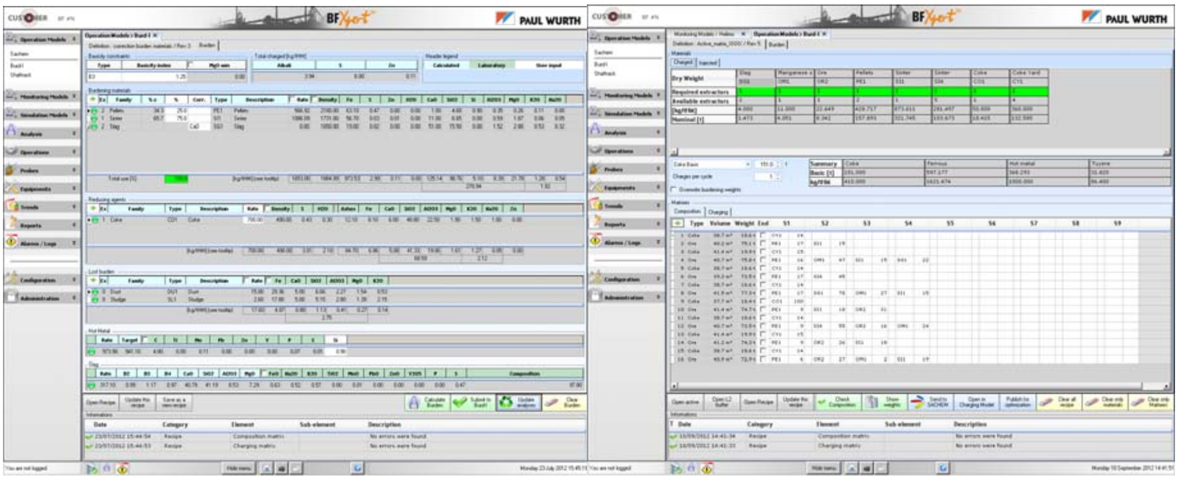
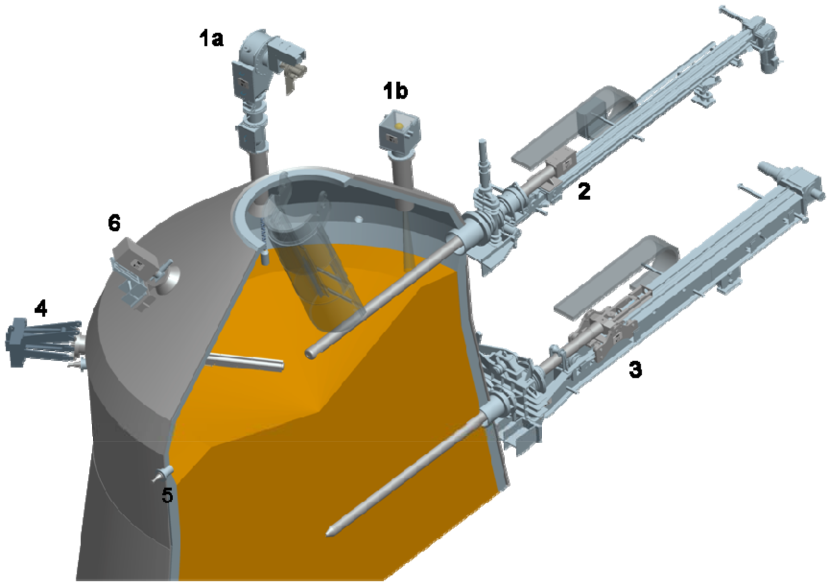


Figure 2: Burdening Interface (BURD-I) – Integrated mass balance, stockhouse & BLT matrices definition.

In order to support the reliability and establish accuracy of mathematical models, direct feedback from the blast furnace is absolutely critical. This can only be possible with input from measurement probes and other sensors. Integration of the probes data in BFXpert makes this information available within the plant network.

An excerpt of the wide range of probes TMT can supply for the blast furnace is given in Figure 3.



1 **Mechanical and radar stockline detectors**

2 **Movable Above-burden Probes**
Temperature and gas measurement, Profilemeter

3 **Movable Below-burden Probes**
In-burden Probe, Scanning Probe

4 **Fixed Above-burden Probes** (Temperature and gas measurement, Impact Probe)

5 **SOMA**
Above-burden temperature measurement

6 **Furnoscope**
Top cone visualization

Figure 3. TMT Probes overview.

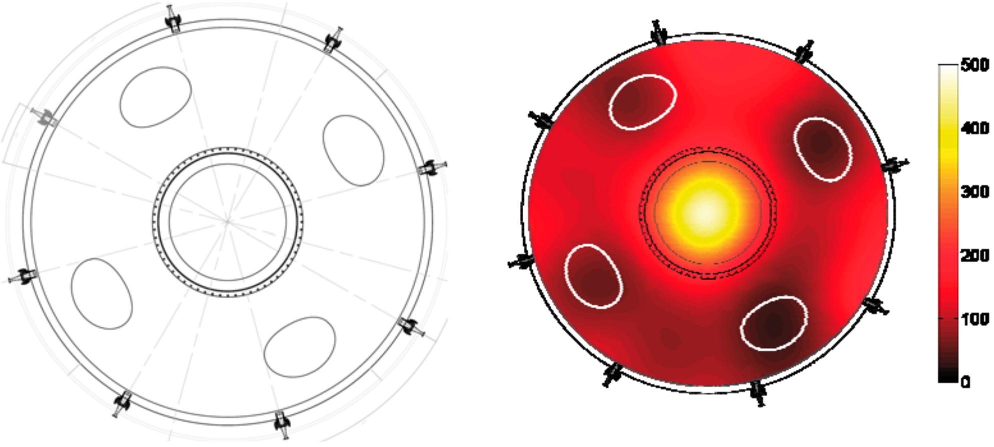
The most commonly used probes are combined Above-burden Probes capable of measuring gas temperature, and composition, across the radius. Since the temperature profile is directly related to gas distribution, and to a certain extent the softening isotherm of the cohesive zone, it provides a good representation of the inner state of the furnace. In addition, data representing the CO_2 / CO distribution ratio provides perspective related to reducing gas utilization, indicating which regions may be in states of depletion or excess. It is well understood in the blast furnace community, that in normal conditions, an ideal temperature profile presents a well-defined peak in the center with low temperatures at mid-radius and a slight temperature increase at the wall. Certain conditions such as scaffolds or excessive heat load at the walls require alteration of the temperature profile and gas distribution.

Probe1	T1	T2	T3	T4	T5	T6	T7
Temperature	61.6	69.3	68.2	68.47	77.55	119.62	244.2

Probe2	T1	T2	T3	T4	T5	T6	T7
Temperature	58.58	61.88	63.8	65.45	84.15	191.12	366.3

Figure 4. Above-burden Probe and graphical representation in BFXpert.

The SOMA acoustic top gas temperature measurement system by TMT is an alternative to classic above burden temperature measurement. One of the most beneficial features of the probe is the fact that it does not interfere with burden distribution. This characteristic also has the advantage of reducing the maintenance costs associated with traditional probes. The SOMA system has a unique ability to measure the complete top gas temperature distribution across the blast furnace section with a full two dimensional view. Using acoustic methods to measure top gas temperatures eliminates the effects of radiation and conduction experienced when using thermocouples.(5)



(a) (b)

Figure 5: SOMA system.

Figure 5a illustrates the blast furnace geometry indicating the position of the SOMA transceivers and the uptakes. In the Figure 5b the SOMA 2D top gas temperature measurement clearly recognizes the 4 cold zones below the blast furnace uptakes as well as the position of the gas channel. This perfectly illustrates the ability and precision of the SOMA system.

In addition to temperature sensing Above-burden Probes, a Profilemeter introduced within the top cone allows measurement of the burden profile by means of a radar scanning system. Burden layer geometry and thickness can be reconstructed, resulting in the ability for users to determine characteristics such as angles of repose and the relative shape of the profile (whether it’s a “V”, “M” or flat). The key benefit of this information is that it provides the ability to qualitatively assess the extent of material movement and segregation on stockline level. A flat surface can reduce the rolling of pellets and grain size segregation. A “V” shape will contribute to the segregation of coarse particles towards the center and increase coke push effect.

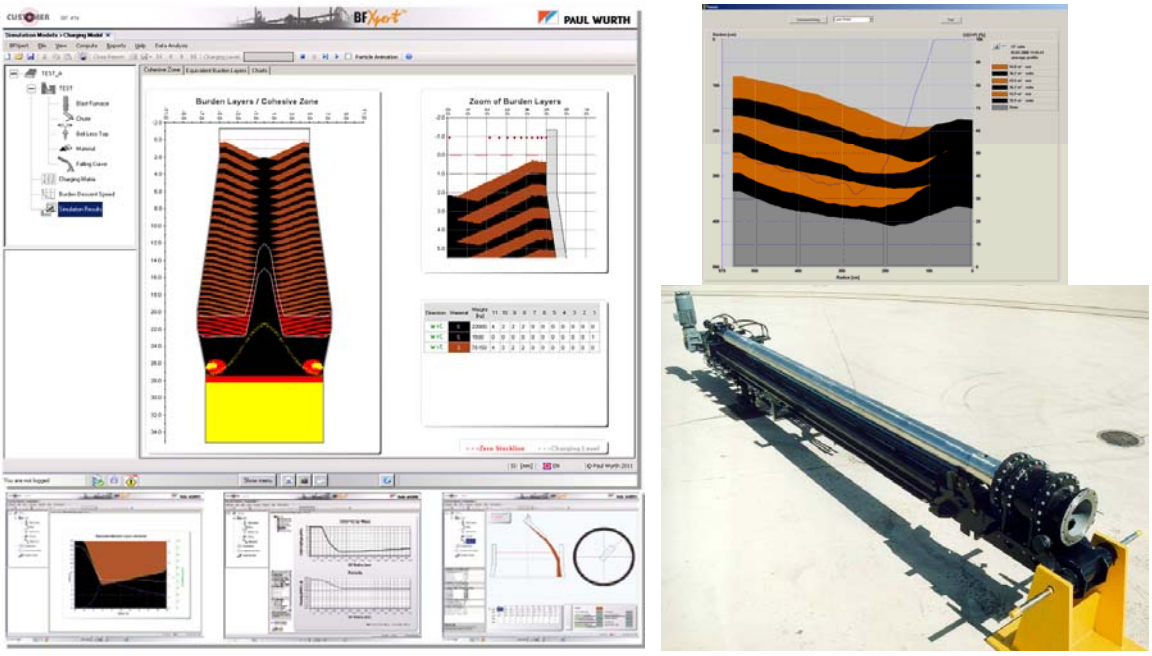
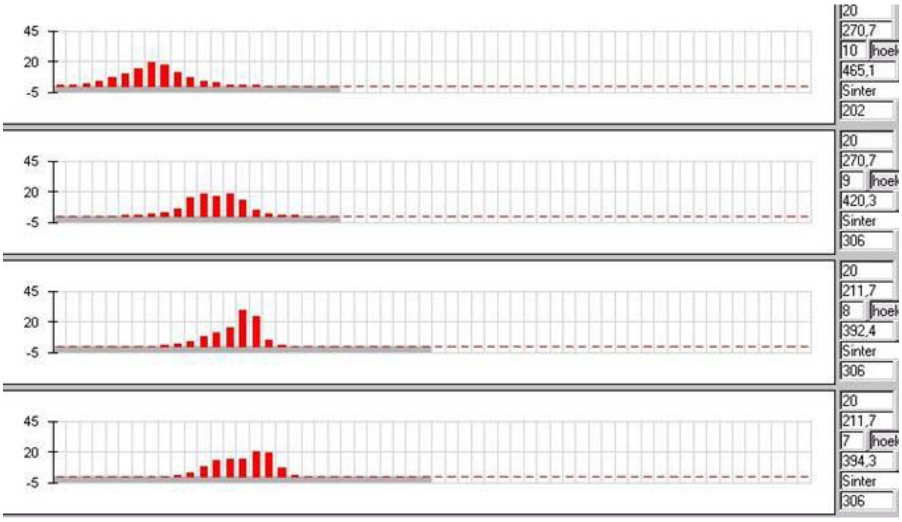


Figure 6. Charging Model & Profilemeter layers pile-up.

Another probe particularly useful for evaluating blast furnace charging is the impact probe. It can be applied to the assessment of material trajectories with the additional benefit of contributing to the calibration of the Charging Model. It is equipped with impact-sensors that measure the amplitude, distribution, and the center of impact of the material stream on the upper edge of the probe. A measuring sequence verifies the impact points of individual material trajectories for various distribution chute angles. Resultant impact positions can then be used in the Charging Model for proper tuning of the falling curves.



20
270,7
10 hoek
465,1
Sinter
202

20
270,7
9 hoek
420,3
Sinter
306

20
211,7
8 hoek
392,4
Sinter
306

20
211,7
7 hoek
394,3
Sinter
306

Figure 7. Results of an impact probe showing the distribution and center of the burden impact.

Further down the furnace shaft, two additional probes can be utilized; the Scanning and In-Burden probes. The operating principal of the Scanning Probe is based on the measurement of electrical resistance differentials between coke and iron bearing burden material layers. The Scanning Probe directly measures the C/C+O-ratio. It is the ultimate tool to verify the charging strategy and the burden distribution model. This is important in developing an understanding of the deformation and mixing of burden layers as subsequent materials are discharged. This tool also provides insight to the effect of coke push.(6)

One of the most important probes on blast furnaces is the In-Burden probe. This probe measures the temperature, gas composition and pressure along the shaft radius inside the burden approximately 5 m below the maximum stockline level. To a certain extent results are potentially more accurate when compared to the Above-burden Probe. This is based on the fact that the distance between the stockline surface and the Above-burden Probes creates the potential for the gas to adopt a radial velocity component as a result of turbulence created by uptake extraction, which in-turn induces some gas mixing.

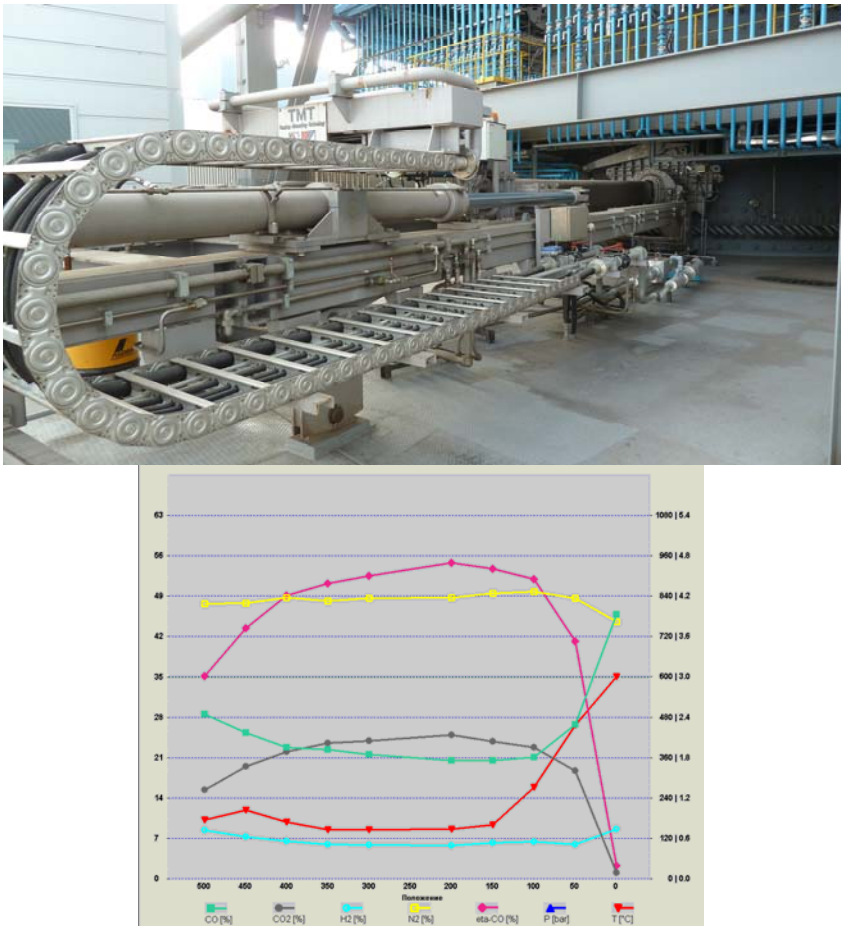


Figure 8. In-Burden probe and results.

The blast furnace operator guided by expert system and the further models in BFXpert remains the key actor in the process of understanding what kind of charging pattern is required in a given situation. Analyzing the results of the various probes and comparing their results with model details would be one method which enhances understanding of the BF process. As an example a side by side comparison or superposition of the scanned Profilemeter layers and temperature profile enable the ability to identify potential discrepancies.(7)

Other probes from TMT with relation to evaluation of blast furnace charging and material/ gas distribution are the Furnoscope and the multi-point-vertical probe.(8)

The furnoscope provides a real time view into the top cone of the blast furnace. It provides operators with an infrared image to monitor burden surface conditions, gas distribution, and movement of charging equipment inside the blast furnace. Process irregularities, such as channeling or slipping become visible directly.

The multi-point-vertical probe is the ultimate tool to receive detailed information about blast furnace shaft operation. It consists of a horizontal beam with multiple gas sampling points and thermocouples to provide information at several measurement points while at the same time the probe is descending with the burden in the furnace shaft.

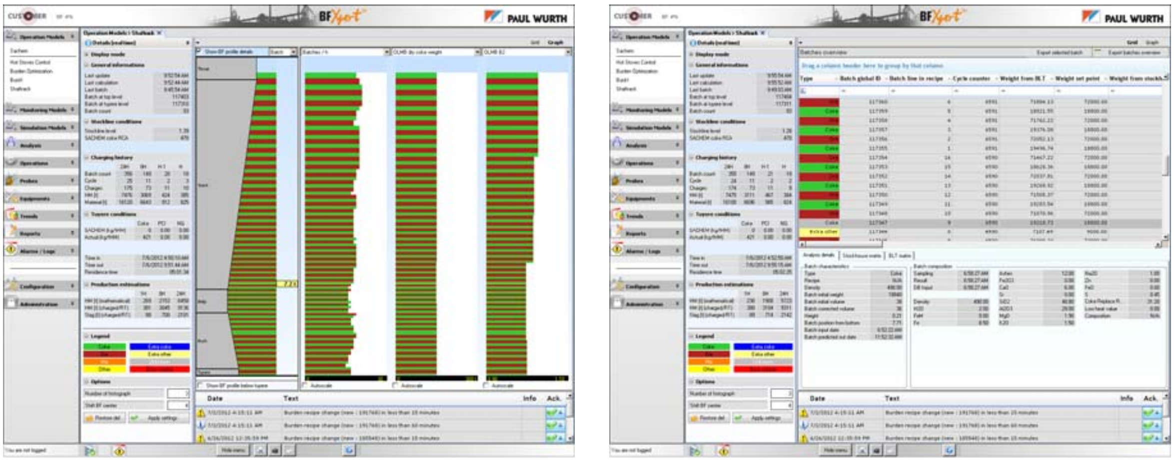


Figure 9: Shaftrack Model screenshots.

The aspect of planning in any process is critical. Tracing the descent of burden materials is important to enable the planning of events such as coke-rate changes in conjunction with auxiliary fuel rate changes, or the preparation of extra coke for a BF stop. The BFXpert model SHAFTRACK, enables traceability of batches down the shaft and provides the ability to determine “when” batches will arrive at the tuyere level.

The applicability of this model is demonstrated in the case of a coke-rate decrease. When this occurs, the timing of auxiliary fuel injection is critical. If auxiliary fuel injection rate increases too soon, the total fuel excess will result in hot metal temperature and silicon increase. Conversely, if auxiliary fuel injection rate increases too late, the hot metal temperature will drop. The information provided by SHAFTRACK enables operators to react to the transitory states of the BF process in a timely and effective manner.

In addition to the blast furnace models with a direct relation to blast furnace charging, BFXpert includes models for various areas of blast furnace operation, such as hearth liquids and casthouse management, closed-loop hot stoves operation, expert system support for operators, automation of procedures, evaluation and simulation of blast furnace operational set-points.

The benefits obtained by the use of BFXpert are the following:

- Routine tasks are handled or respectively cross-checked
- Continuous training and increased process awareness of operators
- Improved of operation stability 24 hours a day and 7 day a week
- Early detection of process phenomena or plant anomalies enabling preventive actions
- Improved safety through fewer incidents lowering the risk of human, environmental and equipment hazards
- Increased plant availability, thus increased production capacity

- Improved product quality, thus improved slag granulation and steel shop operation
- Reduced overall energy consumption (blast furnace and hot stoves area)
- Extended campaign life through the monitoring of critical areas enabling preventive actions

4 CONCLUSION

Recent years have indicated that successful BF operation is dependent on several key factors: reliable and predictable equipment, process data recording and analysis, collective know-how, and the ability to simulate aspects of the process and equipment using the latest in software models as provided by BFXpert.

Operators can now benefit from the opportunity to explore sophisticated charging practices and the possibility to optimize utilization of the Bell Less Top with tools available in the Paul Wurth Level 2 BFXpert system. Understanding the criticality of managing burden distribution, and through this, gas and heat production, incidents such as high heat loading on the walls or drainage problems in the hearth can be readily avoided. The result is stable BF operation with longer equipment lifetime and ultimately an increase in availability of the blast furnace plant with minimal fuel consumption. These factors contribute to safer operation, overall savings and a smaller environmental footprint.

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