BOF Process Optimization and Technology Improvements at Ternium Brazil

Intensive process and technology improvements related to the basic oxygen furnace converter — the key process to increase steel plant productivity and stability — have been performed at Ternium Brazil. This paper details the road map for process developments and investments in equipment technology, as well as the results achieved. The main topics of this development are the process control and optimization systems, slag forming model, oxygen blowing pattern, end-of-blow point control and slag carryover control. The outcomes of this development are improvements in the reblow rate, end-of-blow oxidation, direct tapping, slag carryover, slopping ratio, metallic yield and lining life.

The Ternium Brazil (BR) 5-mtpy steelmaking complex started up in 2010 from a greenfield site in Rio de Janeiro, Brazil. The steelmaking plant (SMP), Fig. 1, with an average heat size of 340 tons, is composed of two hot metal desulfurization (HMD) plants, two basic oxygen furnace (BOF-TBM) converters, two ladle treatment stirring (LTS) stations, one aluminum heating facility (AHF), two RH vacuum degassers and two continuous casting machines (CCMs) with two strands of 14 segments each.

Facing a significant challenge to accomplish the nominal capacity of production, a 5-mtpy project started in 2015 to define the short-, medium- and long-term strategies for the SMP. A dynamic logistics simulation model (ARENA software) had been developed, and evaluation of current plant status and sensitivity...
analysis were performed. Bottlenecks could be identified, new operational targets were unfolded for the short and medium term, and the board of the company defined capital investments for the long term.

This paper describes the road map to de-bottleneck the BOF process through a comprehensive technical understanding, considering the individual meltshop characteristics, resulting in improved process quality, control and stability.

Steelmaking Process Bottlenecks

Steel production process, in essence, involves the making, shaping and moving of steel. When crane interference conditions are coupled with typical day-to-day disruptions caused by process variations, random equipment failures, and upstream and downstream disturbances, system robustness may not be sufficient to meet plant expectations. Simulation is a powerful tool for ensuring that plant designs, upgrades and changes are capable of achieving targeted capacities and efficiencies. Unlike spreadsheet models or linear programs, a dynamic simulation model quantifies lost production capacity due to process upsets, logistical interferences, cycle time variations, random equipment failures, buffer constraints, asynchronous production, queuing, etc. The dynamic and constraint-based nature of the simulation analysis enables a realistic assessment of the type of production performance that can be expected, allowing the best operating strategies and plant configurations to be developed prior to actual operation or before changes to existing systems are implemented, and consequently improving global optimization of the production system.1

The outcome of this simulation was a necessity to increase the availability through improvements in the BOF charge-to-tap (CTT) times by 8.0% and to achieve a 33% increase in BOF lining performance, aiming to reduce one relining for both BOFs a year. After establishing a reduction in CTT time by 8.0%, evaluation through all BOF process steps was necessary, according to Fig. 2. The main topics to be evaluated were regarding the oxygen blowing phase and the time between the end-of-blow (EOB) and tapping start (TS). Reduction of tapping time by increasing the tapping hole diameter was not an option due to quality issues and the compromise between service times and frequency.

Reducing the unexpected blowing interruption was an important aspect to improving the oxygen blowing average time. Seven percent of the heats were being interrupted due to maintenance and operational reasons. An intensive investigation regarding blowing and material addition patterns was made necessary.2

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EOB-TS time delays were mainly related to process reasons; 68% of total delay times according to Fig. 3a. Looking inside the process delays (Fig. 3b), 76% were related to problems achieving the target EOB phosphorus (P), 19% temperature (T) and 2% carbon (C). The focus for the first stage was to improve the dephosphorization (DeP) capacity to reduce the EOB-TS time. Improving blowing endpoint was necessary to improve T and C problems. Nevertheless, an accurate endpoint definition also has a high connection to DeP. A reduction of 9.5% was the new target for the EOB-TS time.

Challenges for P removal from steel are coming from both sides at Ternium BR. According to Fig. 4, phosphorus content in the hot metal supplied to the SMP was increased by 10%. On the other hand, at the same time, steel products with higher phosphorus restrictions have been continuously required, which results in a more challenging operational condition.

Another critical consideration is regarding the EOB aim temperature at Ternium BR. The plant is not equipped with a ladle furnace, which means high BOF EOB temperature. The average EOB temperature is around 1,685°C. Many high-alloyed grades with P lower than 0.010% are tapped up to 1,720°C, which means a more difficult DeP process for the BOF. According to Cappel et al. (2015) it is understandable that operations equipped with ladle furnaces have a competitive advantage compared to other plants.

**Dephosphorization Development**

Dephosphorization reactions are a combination of dephosphorization capacity of slag defined as P-partition, slag volume, kinetics during oxygen blowing phase and post-stirring just after the EOB phase. P-partition \( L_p \) is the capacity to retain phosphorus in form of stable \( P_2O_5 \) in the slag phase in contact with the molten steel (see Eq. 1).

\[
L_p = \frac{\% P}{\% P_{initial}}
\]

(Eq. 1)

Phosphorus removal efficiency \( \% DeP \), Eq. 2, involves the P-partition, slag mass and dephosphorization kinetics. This work is based on a theoretical and empirical approach to achieve the maximum \%DeP removal efficiency. The theoretical part involves the study of slag dissolution, slag saturation and blowing pattern optimization, and the empirical approach involves the application of machine-learning techniques for definition of optimal conditions based on a “learning from historical data” approach.

\[
\% DeP = \left( \frac{\% P_{initial} - \% P_{endblow}}{\% P_{initial}} \right) \times 100
\]

(Eq. 2)
Learning DeP From Historical Data — The target dephosphorization in the BOF process is defined by the difference of input phosphorus, coming from hot metal, and aim phosphorus output according to each steel grade quality. To achieve the maximum phosphorus removal, %DeP efficiency, obtaining a higher P-partition is necessary. Nevertheless, according to Fig. 5a, for a similar P-partition level it is possible to achieve different %DeP efficiency.

According to Fig. 5b, P-partition is reduced approximately four times when the temperature rises from 1,640°C to 1,740°C.

Recent developments in machine learning are making its use for process engineering more feasible. Tree-based estimators and forest of trees data structures can be used to compute feature importance. The relative rank of a feature (variable) used as a decision node in a tree can be used to assess the relative importance of that feature concerning the predictability of the target variable. Fig. 6 exhibits the evaluation of feature importance through an extreme three-regression model to estimate P-partition as a function of operational variables.

Blowing end temperature is by far the most important feature regarding the P-partition, followed by the oxidation degree represented by %FeO in the slag and the electrochemical measurement of oxygen activity in the molten steel, in accordance with the various previous P-partition literature presented by Kumar and Chattopadhyay, 2014. CaO rate is also an important feature as expected in the theoretical approach. The present work focuses on the three main features in order to maximize the BOF dephosphorization process.

Maximizing the efficiency of dephosphorization in a scenario of high EOB temperature is certainly the main challenge in the BOF operations at Ternium Brazil, since the EOB temperature is a process restriction calculated from the temperature losses in the teeming ladle from tapping to casting. The heating up at Ternium Brazil is performed by aluminothermy, which must be minimized due to the impact in the quality, cost and productivity of the SMP. Phosphorus removal efficiency higher than 91.6% is required to produce steel grades with 0.010% of P at the end of blow if one considers a hot metal with 0.120%P as input. To fulfill this challenge without reblow, in a single-blowing operation, a precise BOF process engineering is necessary to optimize all variables involving slag chemical composition, slag mass, blowing pattern (top and bottom), addition pattern, precise blowing end definition, etc. Achieving phosphorus removal efficiency higher than 90% for temperatures above
1,700°C in a single-blowing process is a considerable challenge according to historical data (Fig. 7a).

Improved %DeP efficiency is achieved with higher CaO rate for slags with similar P-partition (Fig. 7b). To increase the CaO rate, it is necessary to consider the CaO saturation in the slag. Otherwise, slag viscosity becomes higher, resulting in lower dephosphorization kinetics. Iron oxide (FeT) in slag works as a fluidizing substance allowing higher CaO dissolution rate and also increasing the dephosphorization efficiency due to higher oxygen activity in the slag phase.

Greater dephosphorization efficiency was achieved for higher FeT contents in the slag (Fig. 8a). Nevertheless, higher oxidized slags have a negative impact on lining life and must be optimized in a range to keep the slag liquid at the blowing end to maximize the dephosphorization efficiency. The control of FeT content in the slag is a combination of blowing end definition, blowing pattern and bottom stirring efficiency. In the present work, the blowing end is controlled by offgas analysis, providing a good accuracy to control the FeT in the slag for a specific blowing condition.

Since the FeT content in the slag must be limited in a restricted range to provide its dephosphorization benefits without damaging the refractory and reducing the BOF campaign, another key element is the adjustment of slag volume when the hot metal %Si content is low. Since the FeT content in the slag is limited, CaO rate also has a limit related to the CaO saturation in the slag. The way the algorithm solves this problem is by adding sources of silicon to make it possible to increase the CaO rate, keeping the target slag closer to lime saturation. In other words, for a defined FeT content in the slag, there is a maximum slag basicity allowed to keep the slag below the saturation index at the blowing end (see Fig. 8b). If basicity reaches a saturation index of one, and the target %DeP efficiency was still not achieved, the addition of an external source of silicon is made necessary to compensate further addition of CaO to keep the saturation in its maximum value. The blowing end temperature is also considered in the slag forming model to adjust the saturation index proposed by Schürmann and Kolm (1985).12

According to Fig. 9a, at higher levels of MgO rate, the reactivity of the slag and DeP efficiency are reduced due to the precipitation of solid MgO. When it starts, viscosity increases with a negative impact on DeP efficiency due to the reaction surface reduction between the metal and slag phase. Slags enhanced with MgO help to increase slag viscosity and to improve their sticking and melting properties. At Ternium BR, BOF refractory wear control is performed through slags enriched with MgO by the addition of dolomitic lime over the main oxygen blow or raw dolomitic lime for slag splashing correction.

Looking for the best compromise between refractory wear control and DeP efficiency, MgO content slightly higher than saturation needs to be the target. A dynamic MgO calculation based on a complex MgO saturation index proposed by Schürmann and Kolm (1986)13 is also considered.

According to Cappel et al. (2015)3 the P2O5 is not stable at steelmaking temperatures and its activity must be reduced by liquid CaO. They also proposed to increase slag volume through the addition of lime and silica flux in cases where the required...

**Figure 8**

![Graphs](image)

*Influence of iron oxide (FeT) content in %DeP efficiency for different P-partition (a) and influence of FeT content in the slag CaO saturation (b).*
dephosphorization slag volume is higher than the maximum slag volume at lime saturation. Other essential conclusions of this work were regarding the dephosphorization slag reaction control based on a kinetic phenomenon rather than a chemical one. They also mentioned that industrial processes are far away from the thermodynamic equilibrium and the individual BOF process characteristics are always an integral element of dephosphorization slag modeling.

Aiming for a reliable understanding of these individual BOF characteristics, development of BOF additives dissolution model was done, and cold simulations have been developed to understand the mixing and blowing conditions better.

Additive Dissolution Model Development — A cyclic model for additive dissolution in the BOF process was developed at Ternium BR. Important mechanisms to describe additive dissolution were developed, such as: oxidation mechanism for hot metal components, slag viscosity, density calculation, and turbulent mass transfer coefficient for solid particles in the BOF process connecting mixing energy input and diffusivity (an indirect way to check the lime reactivity). A complete mathematical description of CaO and MgO saturation in complex steelmaking slags dependent on slag temperature and composition \((\text{FeO-Fe}_2\text{O}_3-\text{CaO-SiO}_2-\text{P}_2\text{O}_5-\text{MgO-MnO-Al}_2\text{O}_3)\)

was established as well.\(^{14}\)

Aiming to support a better BOF process control and assist an operational decision before changing any parameters, performing sensitivity analysis provided valuable information about dissolution evolution over the BOF oxygen blowing period, which affects the refining reactions and also the slag physical properties. Critical operational parameters could be simulated to check their effects on slag formation, charged particle size, lime reactivity, blowing pattern strategy (top and bottom blowing stirring), as well as addition pattern philosophies. A typical curve of metal and slag chemical content evolutions over the main blow period is shown in Fig. 10. These curves are the results of the simulation in each time step.\(^{14}\)

As shown in Fig. 11a, the increase in bottom gas flowrate gives a higher mass transfer rate over the main oxygen blowing process, resulting in lower

### Figure 9

DeP removal efficiency according to lime and MgO rate: DeP full range (left) and DeP for higher removal efficiency (right).

![Figure 9](image)

### Figure 10

Typical metal (a) and slag behavior (b) over BOF main blow process.

![Figure 10](image)
undissolved additive quantities at the end of the process. Even at the beginning of the blow, highly dissolved additives are already evident. Fast slag formation is necessary for a stable BOF process. Otherwise, the process becomes very unstable and costly, e.g., converter lining close to finishing the campaign and operating with low bottom stirring efficiency.

At the beginning of the blow, even in the main decarburization period, MgO saturation is higher than the actual MgO content calculated. At the end of the blow, when the bath temperature is rising very fast, diluted MgO of the slag must be higher than the MgO saturation level (Fig. 11b). An important point to observe is that the MgO content is more elevated than the calculated MgO saturation level, probably due to the precipitation of solid MgO.

This effect can be explained by the dolomitic lime dissolution mechanism proposed by Umakoshi et al. (1984)\textsuperscript{15} for lower FeO content (<20%) dissolution rate of dolomitic lime is controlled by the dissolution of CaO through a boundary layer. On the other hand, MgO is rate limiting when FeO content in the slag is higher than 20%. They also observed that $2\text{CaO} \cdot \text{SiO}_2$ film layer disappears under forced convection conditions and the formation of magnesiowüstite is hardly affected by the intensity of stirring, which can be proven by Fig. 11b.

Development of blowing and addition patterns in the BOF process is a complex task for metallurgists. All operational issues, mechanical limitations, as well as metallurgical results should be evaluated to find a suitable result for the whole process. In order to support this decision, four different addition patterns were simulated according to Table 1.

As a result of this simulation, additive dissolution in the slag is faster for earlier additions of lime and dolomitic lime over the main blowing period (Fig. 12a). As shown, the BOF converter process has heterogeneous mixing characteristics. In the beginning, solid particles exist in a transient regime with regard to their particle sizes and velocities. As the particle size decreases, dissolution becomes faster in the turbulent regime.

When the addition of additives occurs in the latter stages of the blowing process, the characteristics of slag fluidity changes (Fig. 12b) and impairs the fast slag formation (Fig. 12a). There is also a low dolomitic lime dissolution rate. This later addition would contribute to an unsuitable slag for the BOF process and may contribute to a slag attack on the refractory lining and an inappropriate DeP process.
Based on these simulations, raw material specification was improved. New blowing strategies were defined for each step of the oxygen blowing phase, and special attention was given in the slag forming phase (early stage of the blow) where iron (Fe\textsubscript{3}) and silica (SiO\textsubscript{2}) contents are quite high (Fig. 10b), resulting in a very fast dissolution.

The raw material handling system for each BOF contains 10 daily silos for blowing additions. Material batches are loaded in six weighing bunkers. The material prepared in the weighing bunker is then charged via vibrating feeder directly into the BOF. Vibrating feeders have their adjustable feeding rate controlled by a programmable logic controller. The existing raw material handling system was optimized. Charging of additive materials through weighing bunkers was prioritized to accomplish enhanced additive addition just after the blowing start.

**Other Developments**

**Blowing Pattern Development** — In order to evaluate the bath homogenization and mass transfer coefficients, a cold physical model similar to Ternium BR’s 340-ton converter was developed at LaSiP in the frame of a technical cooperation project between Universidade Federal de Minas Gerais and Ternium BR. Significant results could be transferred to industrial practices. Lance flowrate is predominant in determining the bath homogenization compared to the other parameters. For a higher lance flowrate, the jet reaches a longer range along the acrylic, which allows for a clash between the jet and the bubble lance from the external radius, causing a reduction in the size of the decarburization area and penetration. Superior lance flowrates are responsible for a higher mass movement, which favors the kinetics of the reactions. Larger values of the mass transfer coefficients correspond to the experiments with the largest decarburization area, which validates the theory that larger impacted areas allow for a higher occurrence of chemical reactions.

It was also possible to check different bottom blowing patterns and configurations. This indicates good metallurgical results using minimum flowrate for specific periods, which may reduce the operational costs through inert gas consumption savings and, consequently, the lining wear.

A “stepless” oxygen lance was developed, looking to optimize the slag forming phase. Regular lance height steps used for slag phase were changed to a slope. The inclination is defined according to the content of Si in hot metal, resulting in a very smooth lance movement and slag formation as well.

Plenty of blowing interruptions due to operational reasons were related to strong slopping. Uncontrolled high pressure on the primary dedusting system was
related to a high rate of iron ore pellet additions (up to 10% of total metallic charge). A concept of single blowing pattern for the main decarburization period was defined for the control stability, and a constant oxygen flowrate of 90% compared to the former blowing pattern design was defined. This setpoint of oxygen flow is not changed even while the iron ore pellets are added. Iron ore addition is done until 70% of the oxygen blow, despite the low/high quantity of iron ore. The average blowing time did not change considerably, even with the oxygen flowrate reduction through the lance. Actually, the global input of oxygen increased when compared to the former lance flowrate.\(^2\)

**Blowing Endpoint Improvements** — An accurate blowing end detection is a key factor for controlling the bath oxidation level and the blowing end temperature. Ternium Brazil is equipped with automatic blowing end based on offgas on-line analysis. The improvements in blowing end detection were performed in four aspects:

- Improve the accuracy of offgas analysis system by increasing the frequency of filter maintenance, calibration and inspection.
- Simplify blowing end carbon by focusing on bath oxidation for a pre-defined slag to achieve the target DeP efficiency.
- Increase the data acquisition ratio by improvements in network design.
- Simplify blowing pattern and offgas system after main decarburization period; improvements regarding hot metal ladle thermal losses.\(^2\)

**Direct Tapping Model** — Industrial process data were used to train three artificial neural network (ANN) regression models for phosphorus predication at the BOF blowing end. Data from two complete lining campaigns were used to capture the short- and long-term influences related to DeP process. The three ANN models have been trained using the available operational data at different moments after blowing end. The first ANN is trained with heat data available just after the blowing end event, the second additionally uses the oxygen activity measured by the electrochemical cell, and the third uses the in-blow chemical analysis result. The decision-making algorithm is designed to maximize the direct tapping practice taking into consideration the associated risks. Normally the tapping is authorized when the risk of out of range is smaller than 1%.\(^2\)

**Steelmaking Plant Process Integration, Maintenance Improvements and Investments** — Other significant developments to support the phosphorus issue were regarding reducing slag carryover on the BOF tapping phase. Investment in a new and reliable slag detection system was made. Due to the higher confidence in this new system, the existing slag stopper could start to use the signal to abort the steel tapping and tilt the BOF automatically.\(^2\) In other words, it means lower phosphorus pickup after tapping.

Important developments regarding the lining wear were made by the refractory team. The main actions focused on brick quality adjustments for the lower cone region, where there was an excess of wear below the trunnions; brick quality improvements in the area of tapping cylinder; adjustment of the upper cone panel size; and better sealing between the bottom and lower cones. Slag splashing practice start-up and commissioning were in 2014.

Regarding the oxygen blowing lance, in early 2016 an investment in a device for mechanical lance skull cleaning was made. In parallel, the development
of Slagless® technology has been performed. This mechanical cleaning device has high effectiveness to clean the higher side of the oxygen lance and Slagless technology performs better on the lower side of the oxygen lance. When both technologies were associated, the necessity to remove the oxygen lance for skull cleaning was minimal. Continuous improvements in the Laval calculation have been performed.23

Significant process improvements and investments took place to de-bottleneck upstream and downstream facilities. The main essential points are the best practices to optimize setup times at the hot metal desulfurization plant, secondary facilities and CCM. Included were steel plant thermal balance optimization,24 best practices in teeming ladle cycle and downstream cranes, investment to increase the hot metal buffer between blast furnace and steel plant, investment in wire feed injection on RH plant and later start-up of new RH plant,25 and investment in two extra segments for the CCM.

Last but not least, there are significant equipment reliability engineering developments to be mentioned on the maintenance side: improvements on the boiler and dedusting system through the application of Inconel alloys (well suited for service in extreme environments subjected to pressure and heat) over the internal system; implementation of frequency inverters for the pump system; investment in maintenance technologies to keep high availability of liquid metal cranes and converter tilting system (bearings monitored through shock pulse method (SPM)); as well as the implementation of maintenance best practices.

The road map for process developments and investments in equipment technology to achieve the operational targets is shown in Fig. 14.

Results

Intensive process and technology improvements related to the BOF converter have been performed in recent years at Ternium Brazil. Significant results related to process quality and process stability associated with costs savings and improved productivity have been realized.

Metallurgical Results — A new slag forming model was implemented, and higher metallurgical process quality associated with significant costs savings were achieved. The main result was a 40% reduction of global reblow rate (Fig. 15a). Phosphorus reblow rate was reduced by 55% (Fig. 15b); this result was associated with intense slag forming costs savings (34%) (Fig. 16).

It is important to observe two different steps of phosphorus reblow rate in Fig. 15b; the first stage of improvements (FY15/16) can be associated with the implementation of new slag forming philosophy and end of blow definition point optimization. In the second stage of improvements (FY16/17), a newer slag forming philosophy focused on cost savings was implemented in 2016 (Fig. 16). Therefore, the second stage of reblow reduction may suggest a better strategy for addition and blowing patterns, which is connected with the actions to reduce the slopping ratio (Fig. 19a) as well.

![Figure 15](image-url)

**BOF global reblow rate (a) and BOF reblow rate due P reason (values related to baseline) (b).**

![Figure 16](image-url)

**BOF slag forming costs at Ternium Brazil (values related to baseline).**
According to a novel study regarding blowing patterns strategy and their results on dephosphorization process, a better dephosphorization degree was observed for a blowing pattern with constant oxygen flowrate, which is in accordance with one of the actions to reduce the slopping ratio.

The new slag detection system commissioning brings more reliability to reduce the slag carryover on the BOF tapping phase; best practices were also implemented. On average, the phosphorus pickup was reduced by 30% for a specific grade (Fig. 17a). Another significant benefit to be considered is regarding the reduction in 85% of heats out of range due to slag carryover (Fig. 17b).

Reblow reduction was associated with improvements in key metallurgical parameters for the BOF process. Despite the reblow rate reduction, slag oxidation levels were also reduced. A significant reduction in slag FeT was performed (Fig. 18a) as well as a greater Mn yield rate (Fig. 18b). At Ternium BR there is no practice to add Mn-based materials in the BOF process.

Improvements on these parameters are responsible for enhancing the steel plant metallic yield, alloying savings and delivering better conditions for upgrading BOF lining performance. A direct benefit of slag FeT to be estimated is regarding the contribution to the increase in production: in one year of production, this better metallic yield is responsible for delivering almost one extra day of production.

Slopping rate is a relevant indicator to verify the overall BOF process quality and stability. A reduction of 80% (Fig. 19a) was observed even for challenging additions of iron ore pellets.

Another important point to support better process stability is the reduction of oxygen lance exchange for skull cleaning service (Fig. 19b). A result of a single lance running for up to 300 heats was faced. This lower necessity to change oxygen lance had a positive effect on the BOF process; changes in the blowing process are soft and indistinguishable, which brings more stability for process modeling.

**Lining Results** — The challenging target to improve BOF lining performance was accomplished and lining...
Life was improved up to 50% (Fig. 20a). This result is a combination of all efforts: better metallurgical results, lower EOB-TS times, refractory engineering optimization, slag splashing technology investment in 2014 and all operational best practices.

Another significant result was the reduction of %MgO content in slag by 18% (Fig. 20b). Despite the MgO content reduction, lining performance was improved by 50%, and it is a piece of genuine evidence about the better slag balance and process stability.

**Figure 19**

Slopping event control (a) and lance cleaning rate (b).

**Figure 20**

BOF lining performance (a) and MgO content reduction (according to baseline) (b).

**Figure 21**

Charge-to-tap performance (a) and EOB/TS time improvements according to baseline (b).
It is also important to remark that excess MgO does not help the dephosphorization process and may bring process instabilities, and this process instability contributes to worse lining performance. Therefore, the advantages of slags enriched with MgO to control lining wear are achieved when there is a good compromise between the target MgO and process stability.

**Productivity** — As expected, improved process optimization, quality and control make the BOF process more reliable. Charge-to-tap times could be reduced by 5.5% (Fig. 21a). Nevertheless, after the introduction of external scrap in 2017, new challenges have been faced to achieve the target CTT reduction (e.g., delays between scrap charge and blowing start times, tramp elements control, new challenges for stable blowing process). On the other hand, a stable reduction of 10% in the EOB/TS times has been achieved (Fig. 21b). As an outgrowth of enhanced BOF lining performance, a reduction of two relinings per year was reached (Fig. 22), an improvement of 40% compared to baseline. This means one relining less per BOF; in other words, approximately 10 days of extra production for each BOF. Reduction of relining days by 20% due to an investment in a new relining machine is expected, and commissioning was planned for 2019.

Higher process stability and quality have been the main drivers for improved BOF productivity. Maximum daily production has been increased year by year. Comparing the baseline (2014) to 2018, the maximum number of heats tapped in one day was increased from 46 to 51 (Fig. 23a), which represents an enhancement of 11%. In a single-vessel operation, the maximum number of heats was increased from 39 to 45 (10%) (Fig. 23a).

Total of 17.4 kt molten steel tapped in one day was achieved for two-vessel operation mode. Nevertheless, for one-vessel operation mode, when upstream and downstream facilities are not a bottleneck, and lack of hot metal is not a problem, 14.6 kt molten steel tapped in one day is observed (e.g., relining and maintenance days).

Steelmaking plant production has increased year by year. Comparing the baseline (FY14/15) and last fiscal year, production increased from 4.0 to 4.6 mtpy (Fig. 23b). Nominal output of 5.0 mtpy is planned to start in 2021, and investments have been made to debottleneck either SMP or other facilities over the site.

**Conclusions**

Higher process efficiency considering the individual SMP characteristics has been performed. BOF process complexity was reduced through a comprehensive metallurgical technical understanding and process integration; the process becomes more stable and reliable with lower deviations.

Top management promoted the innovation of process engineering philosophy through the development of “out of the box” engineering thinking involving shopping floor team in many steps. The effect was many paradigm shifts.
Definition of the short-, medium- and long-term targets for the plant was essential to keep the interdisciplinary and multi-cultural teams working to develop sustainable solutions without abrupt changes in the main scope.

The challenge to tap more heats with higher added-value steel associated with lower costs and production time, respecting safety in harmony with the environment, has been fulfilled, and it should be a continuous challenge to keep sustainable operations.

Acknowledgments

The authors thank Ternium Brazil and Titus Schaar (chief operating officer) for all investments and efforts to make this project viable. Acknowledgments also go to Heber Gomes (process coordinator), Evanildo Bernabe (steel plant operations manager) and all operational shop floor, refractory, automation, maintenance, contract, and purchasing teams for supporting this project. The authors also want to thank development partners such as technology, raw materials, and equipment suppliers and university institutes (LaSiP-Universidade Federal de Minas Gerais, Montauniversität Leoben, UFF and Universidade Federal de Ouro Preto). Special acknowledgment goes to Tilo Schulz and Axel Boeke for their outstanding cooperation on the frames of OneSteel former project.

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