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MODERN MINI AND COMPACT BLAST FURNACES: OPERATIONS–BASED DESIGN CONSIDERATIONS*

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Abstract

Whereas only a handful of decades ago, typical blast furnace working volumes were below 1000 m³, such furnaces are currently designated compact or even mini blast furnaces. For certain business cases, however, small furnace sizes remain an attractive option. Decades ago, this size blast furnace would have produced a maximum of 0.3 Mtpa with its 600 m³ working volume over a campaign of up to four years. The current state of technology and operational know–how will allow a similarly sized furnace to produce over 0.7 Mtpa while achieving the multiple decade campaigns that have become familiar to steel producers in full sized operations. This level of productivity, but especially the reliability and supply security associated with mature technology, allows for integration into minimills or taking a first step towards a full scale BF–BOF integrated mill. Steel producers considering such scenarios, which are typically attractive for emerging economies, are confronted with fundamental decisions, one of which is for the technological basis for the compact or mini blast furnace to be included in the plant. This article addresses some of these decisions from an operations–based perspective. A small number of case studies is included.
Keywords: Blast furnace; Process; Performance; Campaign life.

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1 INTRODUCTION

Whereas only a handful of decades ago, typical blast furnace working volumes were below 1000 m³, such furnaces are designated “mini blast furnaces” in the current age of unprecedented volumes. With POSCO Gwangyang No.1 (6095 m³ inner volume) currently being the world’s largest blast furnace, this perspective is perfectly understandable.
For many scenarios, however, the furnace sizes of yesteryear remain an attractive option. Decades ago, the typically sized mini blast furnace of today would have produced a maximum of 0.3 Mtpa with its 600 m³ working volume over a campaign of up to four years. The current state of technology and operational know–how will allow a similarly sized furnace to produce over 0.7 Mtpa while achieving the “endless” campaigns that have become familiar to steel producers in full sized operations.
This level of productivity, but especially the reliability and supply security associated with mature technology, allows perfectly for integration into minimills or taking a first step towards full scale BF–BOF integrated mill.
Scenarios like these are obviously perfectly embraced by the global industry. Steel producers considering such scenarios are confronted with fundamental decisions, one of which is for the technological basis for the mini blast furnace to be included in the plant. In many cases, the furnace proper will be a refractory lined shell with external spray cooling. However, this option is only advised against for working volumes above 400 m³. In the range of working volumes between 400 and 1000 m³, many of the same considerations that apply to larger size classes will hold.

2 OPERATIONAL BASIS

Describe succinctly the equipment and procedures used, as the literature and the statistical methods and the corresponding literature, as the case demands.

3 RESULTS AND DISCUSSION

Regardless of global or local economic circumstances, targets for ironmaking operations have been similar throughout history and in all locations. Any operator is always asked to contribute to achieving the lowest cost operations for the site while also maximizing profit. In blast furnace ironmaking, this translates into the following:

- The lowest possible coke rate at elevated auxiliary fuel injection
- Maximum, sustainable production matching downstream demand
- Operating on the cheapest raw materials

At its essence, the blast furnace is not a high–tech piece of equipment with the ability to operate on the “automatic pilot”. It is a counter–current mass and heat exchanger, in which at least dozens of chemical reactions take place, only very few of which can be controlled directly. In addition, the fact that several inputs, such as raw material quality, are not stable, further complicates this aspect.

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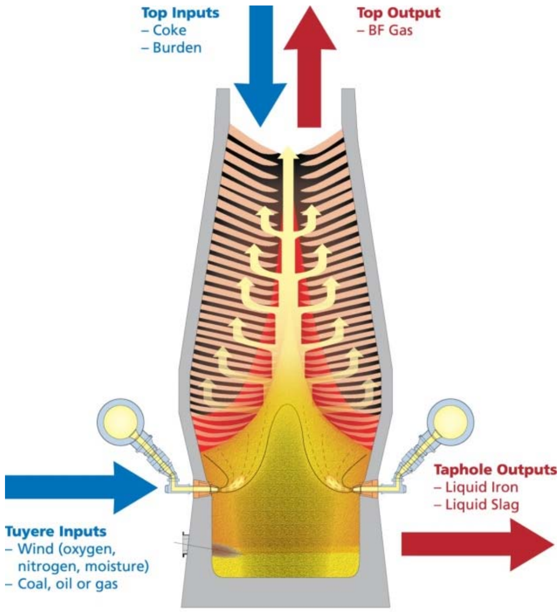

Figure 1. The Blast Furnace as a Counter–Current Mass and Heat Exchanger.

Given this nature, no two blast furnaces are the same, not even if they are of the same design and operated at the same site. It is up to the operator to get grip on the processes taking place inside the furnace, to develop a fundamental understanding of these processes and to go initiate and manage optimization processes that help ironmaking operations meet the mentioned targets. Although some general rules may be applicable to blast furnace operations world–wide, achieving performance beyond industry standard is a process that may take years and requires persistence as well as commitment from anyone involved, including plant management.

Clearly, aiming for maximized process output while feeding it lower quality raw materials and reducing energy input is essentially driving the process towards it limits. With the coke layers providing the furnace with the required permeability, furnace pressure drop will require close monitoring when reducing the coke rate and the process will experience increasing risk of irregular burden descent and other undesirable upsets. Gas flow will need to be kept under control as much as possible, since gas jets along the furnace wall will cause unwanted heat losses, consuming heat that would otherwise be available for heating the burden.

To accommodate the requirements imposed by the operational targets as well as maximum process stability within the (tightened) operational envelope, the operator develops setpoints for the process. These setpoints largely focus on the inputs and outputs that have most influence on process performance and stability. The following needs to be developed:

- Burden distribution strategies
- Fundamental understanding of tuyere inputs (fuel, oxygen, moisture) including operational rules of thumb
- Casting practices

In addition, raw material qualities allow for substantial optimization of the process, but obtaining the best raw materials within tightening budget may be impossible, especially for smaller scale players.

Whenever stable and controlled operations are achieved, a new performance target or operating point may be defined, along with a well–defined plan to achieve the step change towards that target. If (and only if) the step change is successful and

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operations prove stable, further optimization of the operating point may be achieved with minor adjustments and a next step may be defined.

4 BASIC PROCESS CONTROL EQUIPMENT AND TOOLS

The described, stepwise optimization process can only be effected if the operator has sufficient tools for process monitoring and control. Full size, modern blast furnaces may be equipped with substantial instrumentation and the traditional mini blast furnace with only a strict minimum. From the operator’s perspective, there is a basic set of instrumentation required for monitoring how the process responds to operational changes and enabling process optimization:

- Heat flux measurement for monitoring a.o. cooling losses
- Above burden probes for monitoring a.o. gas utilization
- Top cameras for monitoring a.o. burden charging
- A Level 2 system for interpretation of measurements and operator advisory

The basic set of control equipment may be limited to good and reliable casthouse equipment for full control of taphole operation and liquid removal, as well as the right top charging system. As an alternative to the traditional double bell top, many designs have been developed. Since most of these are perfectly capable of depositing raw materials on the stockline in the location desired by the operator, reliability should be the main objective when selecting the right device for the right situation.

5 LIMITS IMPOSED BY EQUIPMENT

Unfortunately, some equipment demonstrates more interdependencies with the process than the owner may want to acknowledge. During the incremental, step–wise optimization process described above, the process may respond undesirably where in many cases, this response is finally caused by limitations of the equipment. Taking a next step or even optimizing the new operating point is impossible and the operator needs to shift back to the earlier operating point that was deemed suboptimal.

Typical process parameters that indicate process–equipment interdependencies limiting the operator are as follows:

- Increased and/or highly fluctuating cooling losses
- Accelerated lining wear/erosion (indicated by wear rods or thermocouples)
- Elevated hot face lining temperatures or cooling member temperatures

As acknowledged widely within the blast furnace ironmaking industry, growing an accretion layer of solidified burden materials (or “skull”) is the key to process optimization as well as long campaign life. This layer (an example is shown inFigure 2) provides protection against abrasion and insulation that drastically reduces heat losses. For further reading on cooling losses and the associated process consequences and financial penalties, the authors refer to Vaynshteyn [1].

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Figure 2. Part of accretion layer remaining after blow–down of blast furnace (1991).

Debate on standard practices for growing an accretion layer remains ongoing and the current consensus is that there is no such standard practice. There may be general rules that provide results in many situations, but as usual in blast furnace ironmaking, the chances of success relate to operator experience and expertise.
While the smoother surface of a stave–cooled blast furnace lining favors stable burden descent, it offers limited anchoring capability for the much desired accretion layer. This observation is supported by the campaign lives achieved with the current generations of both systems. Typical achievements are reflected by best in class performances. A European, copper stave–cooled furnace operating on 100% pellets and moderately high productivity (2.5 $tHM/m^3WV.d$) is relined in 2015 after being taken into operation in 2000. The blast furnaces at the IJmuiden steel plant are plate–cooled and were put into operation in 1986 and 1991 respectively, with the critical bosh areas found in good condition (as illustrated by Figure 3) during their 2003 and 2006 maintenance projects. In both cases, refractory material from the tuyere zone up was left in place and campaigns continued with productivities for the smaller blast furnace around 3.6 $tHM/m^3WV.d$ (peaking at 4.0 $tHM/m^3WV.d$) and for the larger around 2.75 $tHM/m^3WV.d$.

Figure 3. IJmuiden No. 7 bosh condition after 15 years in operation.

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Note that at the IJmuiden furnaces, operational practices were developed towards benchmark level during these campaigns, without seriously affecting furnace condition. Process circumstances included record levels of coke consumption and pulverized coal injection, high productivity, extreme heat loads during the development of burdening strategies and in more recent years, strongly deteriorating raw material qualities. This process has demonstrated the absence of any limiting interdependencies between process and equipment with this blast furnace design. This is supported by experiences at JSPL in India and Ternium Siderar in Argentina. As Castagnola [2] clearly points out, a good preparation of the material charged in the wall area is very important and when copper staves are operated in “naked” condition, they can fail by hot face abrasion. This failure mechanism is also reported relatively widely in the industry albeit not in the public domain. It demonstrates, however, a strong interdependency between equipment and process with stave–cooled furnaces. Cegna [3] discusses process conditions before and after converting a blast furnace from plate cooling to stave cooling, concluding that while copper staves have been successfully used in some facilities, they have shown significant limitations in some others. It also concludes that copper staves demonstrate excessive heat removal at the furnace wall. This not only introduces a coke penalty, but more importantly reduces metallurgical activity in the furnace periphery, ultimately limiting the furnace’s efficiency.
The experienced blast furnace operator has only very limited interested in blast furnace lining design. The operator’s main focus is on the process and optimizing it. Blast furnace lining design only becomes relevant when it imposes limitations on the process and hence on the operator. Any such design, in limiting the operator, limits the plant’s ability to achieve maximum profitability through operating at minimum coke rate and high auxiliary fuel injection rates, high productivity and on cheaper raw materials.

6 APPLYING TO MINI/COMPACT BLAST FURNACES

Given the higher proportion of the burden that is in contact with or in the proximity of the furnace wall in smaller furnaces, the effect of excessive heat removal is increasingly undesirable with such furnaces. Also, since compact and mini blast furnaces are now typically integrated into minimills or smaller/growing integrated BF–BOF sites, reliability of hot metal supply to downstream facilities has become more and more important. Campaign life capability and equipment security are vital and the furnace’s ability to allow the operator to optimize the process regardless of equipment design is essential in this respect.
As mentioned earlier, smaller sized blast furnaces have been typical for the industry in the past and proven technology has been applied in many situations that support the case for equipping today’s mini blast furnaces with this mature equipment in order to meet today’s operational and financial targets for smaller plants. A small number of these furnaces will be presented below.

6.1 Southern Europe, 621 m³ Working Volume

In 1985, the Danieli Corus (then ESTS) high conductivity copper plate–cooled design was applied to the critical tuyere zone and bosh/belly area of a 621 m³ working volume blast furnace in southern Europe. The furnace profile and scope of work is indicated in **Erro! Fonte de referência não encontrada.**.

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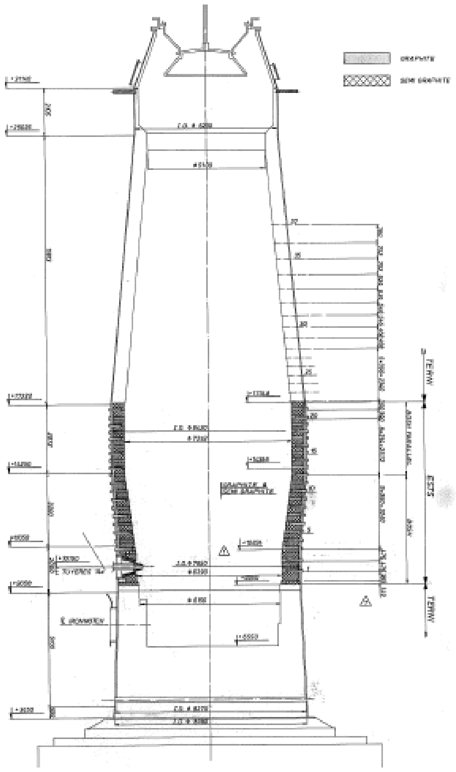

Figure 4. Blast furnace general arrangement.

The furnace was put into operation in 1986 and was only finally decommissioned in 2009. Although production was interrupted over that 23 year period, no intermediate reline activities have been required. When the furnace was taken out of operation in 2006, the lining proved to be in good condition as shown in Figure 5.

Figure 5. Furnace internal condition in 2006.

6.2 Latin America, 631 m³ Working Volume

After a repair in 2001/2002, a 631 m³ working volume blast furnace was taken into operation by a stainless steel producer in Latin America. Problems in the bosh occurred only two months after blow–in. High heat loads and hot spots were observed in the bosh and belly area followed by a breakout six months after start–up. The furnace underwent temporary repairs to get back into production while at the end

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of year 2003, the engineering and procurement for a more permanent repair started. Up until the permanent repair could be executed, the furnace continued operating with maximum attention on protecting the bosh, utilizing a ‘special charge’ that promoted a stable accretion to form. Although effective, this limited the productivity of the furnace. The furnace was stopped for a reline by Danieli Corus in 2005. The scope included the top layer of the hearth wall, tuyere belt, bosh and belly. Some repair work was also carried out in the taphole area when damage was identified during the shutdown. The bosh and belly were converted to the high conductivity plate–cooled design promoted by Danieli Corus. An additional row of plate coolers was installed just above the tuyere coolers.

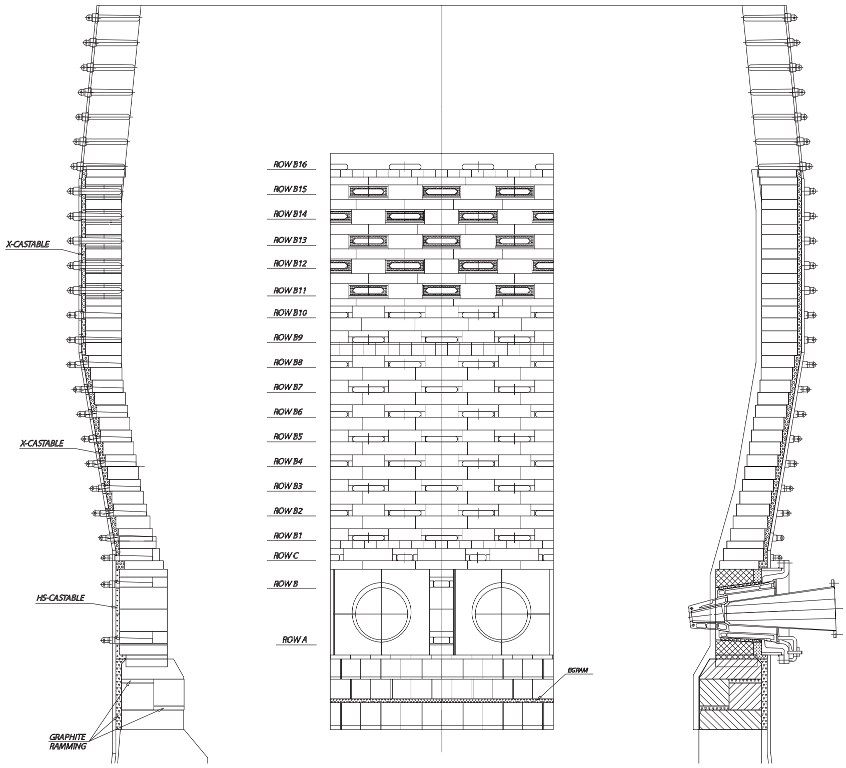

Figure 6. Final design, general arrangement and furnace lines.

Since the furnace was blown in, ten years have passed, whereas the client’s original requirement was for a seven year campaign extension. The furnace lining and cooling is in very good shape, despite having been exposed to severe process conditions caused by e.g. switching between metallurgical coke and charcoal as a reducing agent. The furnace will continue its normal operation and the operators confirm the furnace’s ability to allow for process optimization without being limited by the furnace design.

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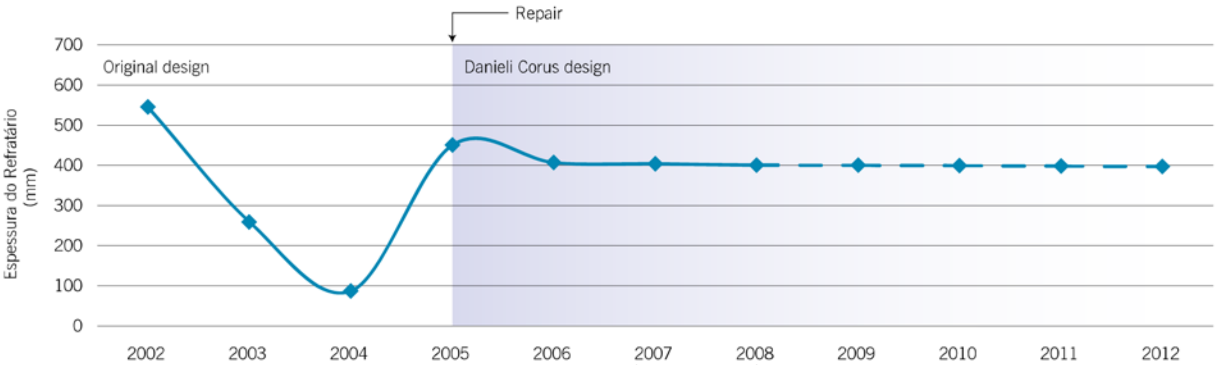

Figure 7. Lining thickness before and after conversion.

For more information about this furnace and the conversion project, we refer to Kaptein [4].

7 CONCLUSION

- In the operation of mini blast furnaces, the same basic rule applies as in full scale production: a stepwise approach with constant optimization is required to reach productivity and coke rate targets
- Copper stave designs can fail early due to erosion and will give limitations on process to try and prevent erosion
- A horizontal copper plate design combined with high conductivity refractories imposes no limitation on the process or operator, also when operating at high productivity, with high auxiliary fuel injection rates and on lower and/or varying raw material qualities
- The operator should be able to focus on the process without being limited by equipment

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