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21ST CENTURY LINING DESIGN FOR BLAST FURNACES[1]

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Abstract

Blast furnaces are cooled by stave and/or plate coolers to protect the furnace shell. Choices for either system are usually based on objectives related to working volume or durability. In modern blast furnace iron making operations, process stability and hence a plant's performance is greatly influenced by the furnace's internal profile. The purpose of this article is to present a process–based comparison of lining systems. Based on the documented knowledge of the blast furnace iron making process from zone to zone, field observations (i.e. post mortem and interim findings at shut down furnaces) are analyzed to compare successes and failures of lining and cooling systems. Several findings were analyzed, which provided insight into how and why designs have been successful or have failed under various circumstances (i.e. productivity, raw materials, etc.) Critical factors for maximized process stability and campaign length from hearth to throat are presented.

Keywords: Blast furnace; Bosh and stack; Refractory; Cooling; Lining; Campaign life.

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INTRODUCTION

21st Century blast furnace design requirements should focus on low cost hot metal production. This requires the right balance between capital expenses (CAPEX) and operational expenses (OPEX). Low–cost hot metal production can be achieved by:

- low coke rate (< 300 kg/THM);
- high fuel injection rate (PCI > 200 kg/THM);
- high oxygen rate (> 30%);
- high productivity (> 3.0 THM/m^3WV/d);
- stable operations and high availability (>95%).

The blast furnace must also be able to cope with various raw material compositions of sinter, pellets and lump ore and achieve a 20 year campaign life. It is of paramount importance that the profile of the bosh, belly and stack is maintained during the entire campaign as any degradation will immediately have a negative influence on low–cost hot metal production requirements[1]. Hence, bosh, belly and stack designs must be robust and strong.

PROCESS CONDITIONS

The blast furnace is a high–temperature, pressurized counter–current reactor. Abrasive raw materials are descending and gradually softening due to (s)melting whilst high temperature gases are ascending through the burden but also along the lining. The tuyere level flame temperature is > 2000℃ and the blast furnace operational pressure is 2 – 4 Bar(g). This can result in high thermal loadings to the lining.

The blast furnace process is semi–continuous since charging and tapping are a batch operations and hot blast and fuel injection are continuous. This combination results in dynamic process conditions.

Average process conditions are well–understood and reported in industry. Designers, however, must also have a good understanding of the dynamic process conditions' fluctuations since these impose significantly higher thermal and mechanical loadings to the lining. Dynamic upset process conditions can also – for example – be a result of equipment failures, malfunctioning top sprays, (unscheduled) shut–downs, burden slips, casting deficiencies and 'gas–jets'.

Local, incidental upset process conditions can result in loadings that are ten times higher compared to average conditions. An example is illustrated in Figure 1: this dynamic temperature development has often been reported to reflect 'loss of solidified protection layer' and rapid solidification of a new protection layer due to high–efficiency cooling system. We believe, however, that it is more likely that this reflects the consequences of a high–temperature 'gas–jet' impinging on the lining.

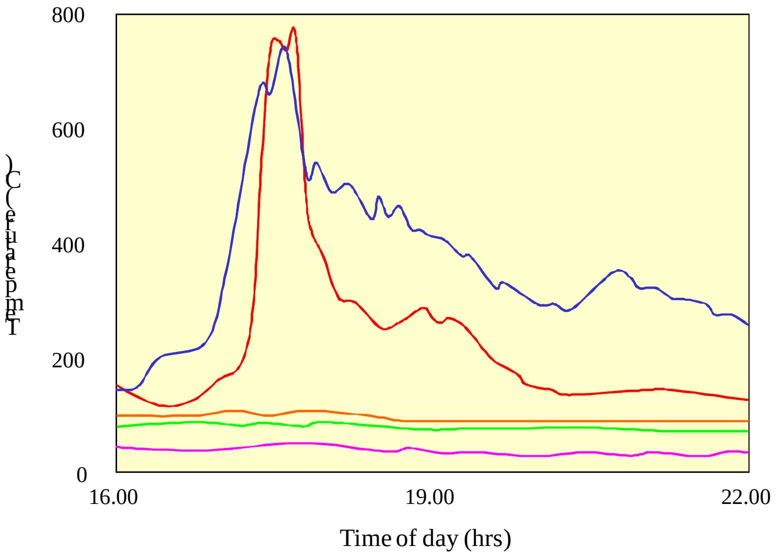

Figure 1: (Lower) Stack temperature measurements.

Process conditions have been monitored at many plants and temperature fluctuations have often been observed exceeding > 100°C / minute. Table 1 summarizes actual 'fatigue limits' of various lining material grades and actual temperature fluctuations for 3 different raw material compositions. It is clear that only high–conductive, ductile lining material such as copper and (semi–)graphite will survive (irregular) high productivity, particularly with high pellet operations.

Table 1: Temperature fluctuations

Material Fatigue Limits	**°C/min**	**°F/min**
Graphite	500	900
Semi Graphite	250	450
Silicon Carbide	50	90
Cast Iron	50	90
85% Al_2O_3	5	9
45% Al_2O_3	5	9
Chrome Corundum	4	7
Observed Temperature Fluctuations		
Sinter Burden > 90%	50	90
Mixed Burden 50%/50%	150	270
Pellet Burden > 70%	180	320

Lining designs are often an 'assembly' of metal cooling members and refractory components. The design and engineering of the cooling system and refractory components may have been executed by different companies and consequentially may not match each other. For example, the application of low conductivity ceramics and high density plate coolers systems introduces opposing philosophies with regards to thermal fatigue.

It is our philosophy to evaluate the 'integrated lining design' as one system: this system includes mechanical (shell and cooling members), refractory and process engineering (cooling system) components. Customized systems can be developed to meet specific blast furnace requirements and loading conditions. Maximum peak heat load capabilities of typical bosh and stack lining designs are summarized in Table 2.

Table 2: Maximum peak heat load capabilities

Cooling	**Refractories**	**Maximum Peak Heat Load Capability (W/m²)**
Dense Pattern Plate Coolers	Graphite	500.000
Copper Stave Coolers	SiC/Gunnite	500.000
Medium to low Dense Pattern Plate Coolers	Graphite	320.000
Dense Pattern Plate Coolers	SiC bricks	180.000
Third Generation Cast Iron Stave Coolers	SiC/Castable	170.000
Dense Pattern Plate Coolers	Alumina/Chamotte	110.000
First Generation Cast Iron Stave Coolers	Alumina/Chamotte	110.000
Wide Pattern Plate Coolers	Alumina/Chamotte	35.000

It is noticed that the blast furnace bosh and stack design imposes conflicting requirements:

- minimize fuel consumption / minimize heat loss – minimum cooling
- minimize shell temperatures – maximum cooling

The heat load is a consequence of specific process conditions and lining design. History has proven that high–efficiency designs using high–conductivity materials are required to secure low shell temperatures and long a campaign life based on the premise that lining protection is achieved by a solidified layer in the bosh, belly and lower stack. However, it is observed that copper stave cooler designs have a limited ‘anchoring’ functionality and this could result in exposure of the copper stave coolers to the abrasive and erosive descend burden and ascend of gases. Copper has a limited resistance against abrasion and erosion and wear of the copper ribs will catalyze further loss of anchoring functionality.

The ‘Hoogovens’ bosh design comprises a dense pattern of machined copper plate coolers and (semi–)graphite and a 20+ year campaign has been achieved in 2006[2]. The ‘Hoogovens’ bosh design is the optimum solution to secure a stable bosh profile and to allow high productivity levels. This first bosh design was installed at Hoogovens IJmuiden in the early ‘70’s and performed very well. Figure 5 shows the bosh of Hoogovens IJmuiden Blast Furnace No. 4 after 8 years of operations. The bosh of Corus IJmuiden Blast Furnace No. 6 has been commissioned in 1986 and is operating at very high productivity levels for many years. One of the principal advantages of a high conductive plate cooler design relates to the ‘solidified layer adhesion’ capability and this is also clearly observed in Figure 2.

Figure 2: Protection by solidified layer.

ADVANCED BOSH, BELLY AND STACK DESIGNS

Two design philosophies have survived into the 21st century and share a similar engineering philosophy based on the 'thermal solution'. Reference is made to Figure 3 illustrating advanced copper plate cooler and copper stave cooler design. Both designs include cast iron stave coolers in the upper stack.

The ‘Hoogovens’ copper plate cooler design includes high–conductive graphite refractory in the bosh, belly, lower and middle stack. This graphite provides thermal protection to the embedded SiC refractory courses. The SiC provides protection against abrasion and erosion and this design provides a synthesis of thermal and mechanical components.

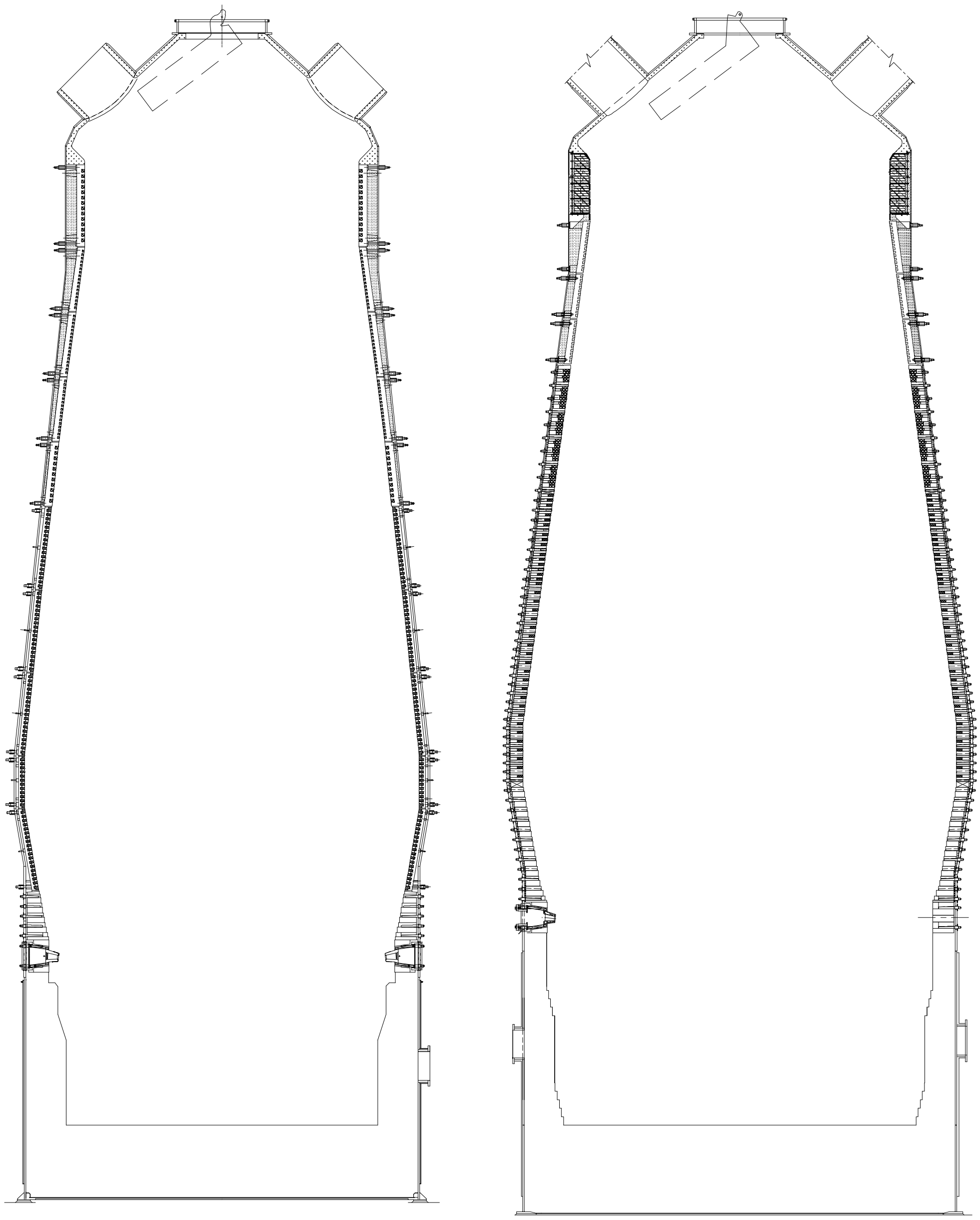

Figure 3: Advanced bosh, belly and stack designs.

Copper stave coolers also have a high cooling–efficiency but cannot survive all process conditions. Exposing conventional copper stave coolers to fluctuating high–temperature process condition can result in leaking cooling channels due to expansion issues (cracking) and abrasion/erosion. This has been observed at various plants on different continents and prohibits low–cost hot metal production.
Additional refractory protection is required such as graphite and SiC inserts vis–à–vis the plate cooler design. This off–sets, however, typical copper stave cooler advantages proclaimed in industry such as reduced CAPEX and increased working volume. Furthermore, stave cooler designs require long shut–downs if repairs are required.
In addition, copper plate coolers are always required in the (lower) bosh to permit high coal injection rates and to protect tuyere–coolers. This area is exposed to a variety of loadings (Figure 4):

- Heat (Raceway Gases and Impinging Metal and Slag)

- Erosion and Abrasion (Solids, Gases and Liquids)
- Oxidation (Water Leakages, FeO)
- Alkali's, Zinc, Lead

These loadings depend on the raw materials and blast furnace operations. The loadings should preferably be quantified. Otherwise, it is recommended to qualify the loadings and investigate the (historical) performance and track records of other bosh designs.

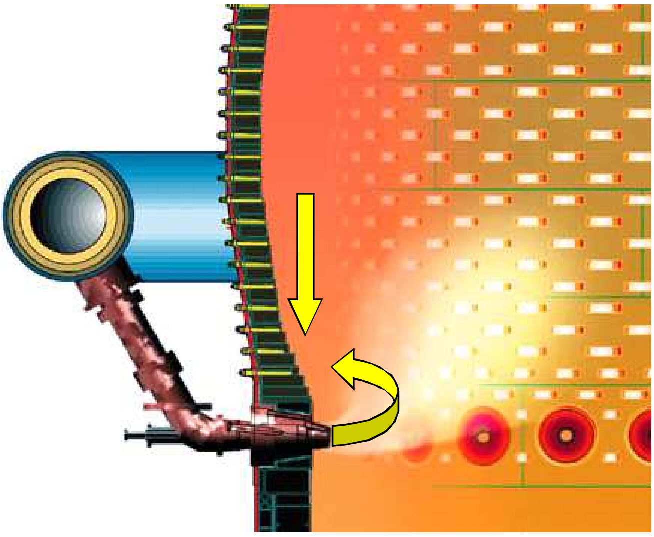

Figure 4: Bosh loadings.

The loadings depend on the temperature level and may occur within a limited temperature range or above a certain threshold level. A simple rule states that the loadings converge to zero at lower temperature levels. Vice versa, loadings are increased when temperature levels are increased. Stable and moderate process temperatures at the interface between the burden and gas and lining will thus minimize lining corrosion and degradation. Some critical threshold temperatures for lining corrosion mechanisms are summarized in Table 3.

Table 3: Critical threshold temperature levels for Chemical Attack / Corrosion

	ºC	**ºF**
CO Disintegration	480 – 850	900–1560
Alkali– and Zinc Attack	800 – 950	1470–1740
Oxidation by O_2	> 400	>750
Oxidation by CO_2 and H_2O	> 700	>1300

PERFORMANCE MONITORING

Advanced instrumentation permits continuous and accurate process and equipment control. We have also attended many post–mortem analyses and provided FMEA consulting and engineering services.

'Hoogovens' bosh, belly and stack design have proven to be robust and stable and permits multi–campaign low–cost hot metal production[3][4]. We have also noticed that many 'myths' have been developed around copper stave cooler designs and specific operational pre–cautions are often required to prevent premature failures.

Figure 5: 'Hoogovens' bosh design.

These observations are supported by extensive lab analysis and multi–physics models. Our models also indicate that copper stave cooler designs are more sensitive to dynamic process conditions and providing ultra–efficient copper stave cooling systems could de–stabilize operations.

In this respect, it can be said that the dense plate cooler design de–couples the process from the limitations of equipment. This then provides a sound equipment basis from which the long–term improvement in process stability and fuel rate can be realized.

CONCLUDING SUMMARY

- Advanced bosh, belly and stack designs combine (lower) bosh plate coolers and upper stack cast iron stave coolers;
- Bosh plate coolers are required to decouple process and equipment – a robust bosh permits operators to achieve high productivity, low coke, high fuel injection and oxygen rates;
- The 'Hoogovens' lining design has proven (multi–campaign) lifetime > 20 years at high productivity and high fuel injection rates contributing to low–cost hot metal production.

BIBLIOGRAPHY

1 Ichida M.; Takao M.; Morizane Y.; Nakayama T.; Anan K.; Kakiuchi K.; Yamada I.; "Inner Profile and Burden Descent Behavior in the Blast Furnace"; Nippon Steel Technical Report No. 94, July 2006.

2 den Exter, P.; Molenaar, R.; Tijhuis, G.; Toxopeus, H.; "Corus IJmuiden BF No. 6 Ends Successful 16–year Campaign"; ISSTech 2003.

3 Lingiardi, O.; Musante, R.; Velo, E.; Ametreno, R.; Zubimendi, J.; Gómez, O.; de Nicola, H.; "Ternium–Siderar Blast Furnace # 2: End of Campaign", AISTech2007

4 Bakker, T.; Bol, L.; Molenaar, R.; "The 2006 Reline of Corus IJmuiden Blast Furnace No. 7"; AISTech2007.