



MODERN BLAST FURNACE IRONMAKING TECHNOLOGY¹

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Abstract

Modern blast furnace ironmaking technology must comply with increasing environmental permitting and legislation and the blast furnace industry is simultaneously facing unreliable raw materials quality as well as high and volatile raw material prices due to high global demand. These challenges may be overcome by minimizing coke and energy consumption. This includes high pulverized coal injection, efficient gas cleaning and hot blast system technologies and a long campaign life blast furnace design. These technologies are discussed in the paper.

Key words: Blast furnace ironmaking.

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INTRODUCTION

More than 1500 Mt hot metal has been produced in 2011 and approximately 2/3rd has been made by integrated steel plants. New blast furnace plants are currently mainly developed in India and South-East Asia parallel to the consolidation, modernization and expansion in China, which effectively started around the year 2000: Chinese steel production currently amounts to approximately 60% and contributes significantly to high demand for ferrous raw materials and coking coal.

The majority of Chinese hot metal production is produced by blast furnaces as high natural gas prices do not favor alternative ironmaking technologies. Regional scarcity of scrap limits the introduction of the electric arc furnace on a large scale.

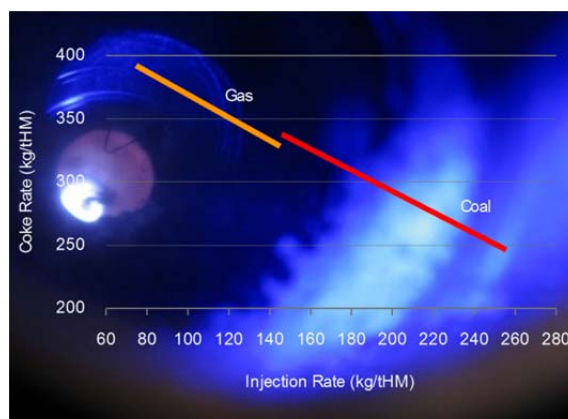
Blast furnace ironmaking demonstrates to remain competitive to alternative ironmaking technologies unless regional gas prices favor direct reduction plants, for example in the Middle-East. Currently US gas prices also enable competitive direct reduction technology for new plants. New blast furnace projects in South-America are being developed, but face challenges and delays.

New blast furnaces must comply with demands from modern societies, which is materialized by strict environmental legislation and environmental permitting. New blast furnaces are therefore equipped with advanced technologies to reduce energy consumption and simultaneously maximize the availability to contribute to low cost hot metal. Many existing blast furnace plants in other regions are continuously modernized during interim shut-downs and relines to comply with similar challenges.

PULVERIZED COAL INJECTION

The significant increase in global demand for raw materials has contributed to high raw materials costs which may amount to over 80% of the total cost of hot metal. This includes coke: modern blast furnace ironmaking must therefore focus on the reduction of coke consumption. This can be achieved by fuel (gas, oil, coal) injection at the tuyeres.

Fuel injection – particularly gas - results in a reduction of the raceway adiabatic flame temperature (RAFT).



Gas injection could be an economical method to (partially) reduce the coke consumption, but is typically limited to approximately 150 kg per tonne hot metal due to the resultant RAFT reduction. High pulverized coal injection (PCI) enables a coke reduction of 200 - 250 kg per tonne hot metal.



High PCI rates do require rather good raw materials and low slag volumes, but also provide an opportunity for high oxygen enrichment, which results in higher productivity levels of an existing blast furnace. Oxygen enrichment also raises the calorific value of the top gas, which could provide down-stream advantages in power generation and combustion in the hot blast system.

Consequences of PCI and effects on the blast furnace process as well as process targets and associated process control options are listed in the table.

Increase of PCI	Effect on Blast Furnace	Process Targets	Process Control Options
<ul style="list-style-type: none"> • Decrease Flame Temperature • Increase Ore / Coke Ratio • Change Slag Composition • Increase Impurities (S, P) 	<ul style="list-style-type: none"> • Increase Gas per Tonne Hot Metal • Increase Top Temperature • Decrease Burden Descent • Increase Burden Resistance • Changing Gas Distribution: <ul style="list-style-type: none"> – Heat Loss – Productivity – Fuel Rate • Changes in Hot Metal Quality 	<ul style="list-style-type: none"> • Stable Productivity • Minimum Fuel Rate • Stable Burden Descent • Stable Hot Metal Quality 	<ul style="list-style-type: none"> • Increasing Oxygen Enrichment • Changing Burden Distribution • Improving Burden Quality • Changing Burden Composition • Optimize Coal Selection • Improve Coal Combustion Efficiency

High coal injection rates do require 100% availability of the system, which must therefore be simple and safe and have a minimum amount of moving parts (valves). This provides other advantages such as low maintenance costs. Individual control valves are not required since the circumferential distribution of the hot blast is dynamic and asymmetric. Dilute phase coal injection based on physical principles has resulted in the world's highest injection and lowest coke rates.

BLAST FURNACE

The transition to high PCI rates changes blast furnace process equilibrium conditions and do require blast furnace process optimization which is usually achieved by trial-and-error. There are no standard operating procedures for high coal injection operations and customized optimization is required. This optimization includes for example changing burden distribution. Modern blast furnaces are equipped with chute-type charging units as well as advanced instrumentation such as radar profilometers and acoustic gas temperature measurements to assist in pursuing stable operations at low coke rates.

The blast furnace will be exposed to the risk of erratic operating conditions during transition towards high PCI rates. This could result in local, incidental high heat load to the blast furnace lining. High PCI rates also influence the ore to coke ratio in the blast furnace. This could cause higher burden loadings to the blast furnace lining particularly at the interface of lower stack to belly and belly to bosh.

Copper stave coolers have been introduced in the 1980's to cope with traditional failures of cast iron stave cooler or ceramic linings in the lower stack. Occasional copper stave cooler failures have been reported due to engineering and manufacturing errors, which caused cracks in the supply and return pipes and leaking welds. These errors can be prevented by using appropriate support and expansion provisions and qualified manufacturing and quality control procedures.



More importantly, over the past ten years it has been noticed that copper stove coolers also have inherent problems such as sensitivity to erosion, particularly in the bosh. Erosion rates of 10 mm per month have been observed, which could result in catastrophic leakages within a few months particularly if ultra-thin copper stove coolers are used.

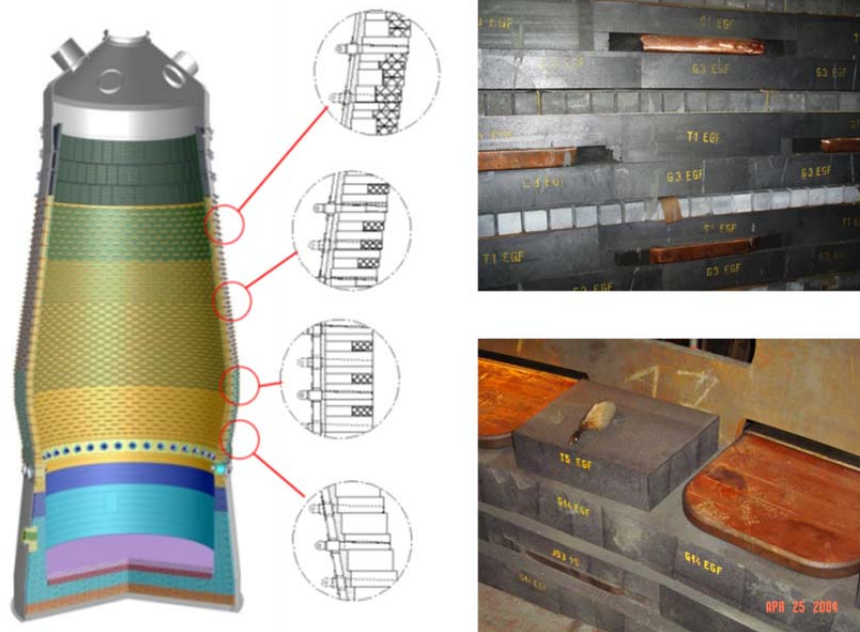
This erosion contradicts the classical theory which suggests that high conductivity lining designs enable protection by an accretion of solid slag, metal, coke and ore.

An extensive research programme has been executed including experiments and computer modeling such as:

- Friction abrasion experiments
- Impact erosion experiments and erosion CFD modeling
- Burden descent modeling
- Diffusion of Fe into copper
- Transient FEA thermo-mechanical modeling
- Corrosion by Sulphur and Halogens

This research program has indicated that erosion is caused by descending coke. This is a result of the lack of anchoring functionality of the copper stove coolers, which causes local sliding of coke at the lining.

A modern Hoogovens lining design minimizes sliding effects in the bosh and the equilibrium lining profile enables the creation of a stable accretion, which protects against erosion. The belly and lower stack include a combination of graphite and silicon carbide refractory and machined copper plate coolers, which enables the creation of an accretion, but also provides sufficient erosion resistance if the accretion may not be present. 25 Year campaign lives can be achieved at high PCI and productivity levels.

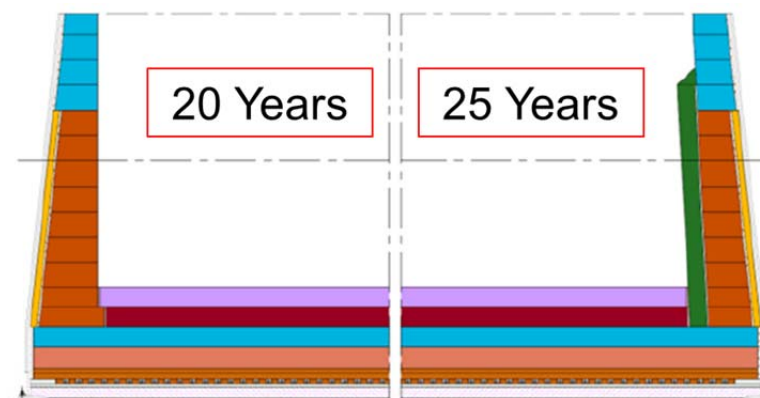


The bottom and hearth performance is currently the limiting factor at many existing plants. The condition of the bottom and hearth usually determines the timing of relines. This is amongst others due to the fact that the blast furnace working volume and production were increased during previous relines, whilst increases of the hearth were limited due to cast-house and foundation constraints. The hearth 'productivity' will then effectively increase, whilst the hearth volume is also reduced at low coke rate due to a reduction of the permeability of the hearth.

A modern hearth design includes a large volume to reduce liquid velocities. Lower liquid velocities reduce erosion and result in lower lining temperatures. A large volume is achieved by using a conical shell and a 'thin' refractory lining design. 'Thin' lining designs also result in lower hot face temperatures, lower stress levels and lower expansion, which favour a long campaign life.

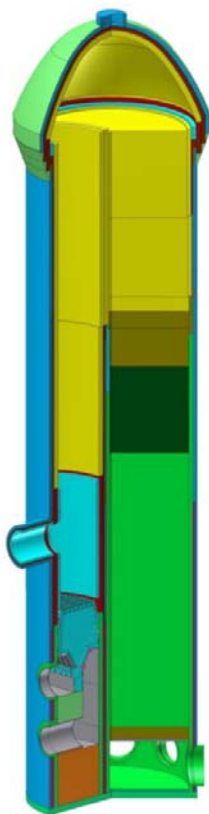
Efficient hearth shell cooling may be achieved by spray, jacket or stave cooling. It is important to limit water temperature fluctuations as this causes havoc to the campaign life due to dissimilar expansion and contraction of the steel and refractory lining.

The hearth includes micropore semi-graphite to minimize effects of erosion, oxidation and dissolution. A ceramic cup could be considered as an option and may extend the campaign life, but reduces the hearth volume.





HOT BLAST SYSTEM



Modern hot blast systems provide continuous on-line hot blast temperatures of 1250°C. High hot blast temperatures are necessary to reduce the total carbon consumption rate and contribute to low cost hot metal. The risk of intercrystalline stress corrosion doesn't enable higher hot blast temperatures to-date using conventional regenerative hot blast stoves. Investigations into alternative recuperative heaters and pressurized combustion are made to evaluate the feasibility of these technologies and increase future hot blast temperatures.

Three different hot blast stove designs are currently used in our industry. These include internal, external and dome burner designs. External burner designs require the largest foot-print and highest capital investment cost. Also, the dome is sensitive to higher stresses due to asymmetric (thermal) vertical expansion of the combustion and checker shaft. Dome burner designs footprint's are comparable to internal designs and the total cost are also comparable. However, the dome burner introduces a risk of cracking of the dome refractory due to the exposure to the high-intensity dome combustion and cyclic conditions. Also asymmetric expansion of the hot blast stove and vertical hot blast main could cause higher stresses in critical areas.

Modern hot blast stoves meet today's requirements:

- Low investment cost
- High efficiency 85%
- Long campaign life 30+ years
- Low emissions

Hoogovens hot blast stoves include advanced expansion provisions in the refractory design to reduce stress levels. The inverted catenary shape dome design is independently supported by the steel shell and has demonstrated campaign life of 40 years. Internal coating of the shell minimizes corrosion and contributes to a long lifetime. The partition wall between the combustion and checker shaft has demonstrated to be gastight during the entire campaign, which is achieved by advanced expansion provisions and gastight seals.

Modern ceramic burner designs results in optimum mixing of gas and air and minimum CO-emissions. The combustion shaft includes an additional refractory lining to protect against the cyclic high-intensity combustion conditions.

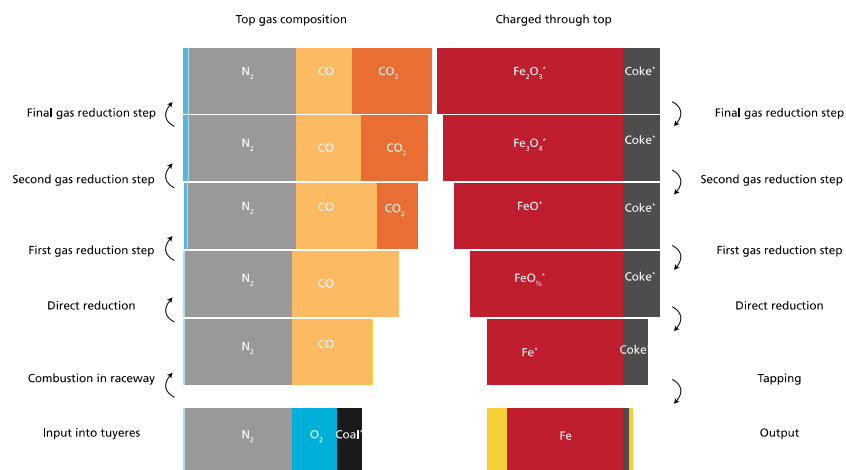
High-efficiency checkers are available, which result in lower costs of the hot blast stove. 30 mm flue holes minimize the risk of long-term contamination and cracking of the checkers. Also this results in lower pressure differential compared to smaller flue hole diameter checker designs.



A high efficiency can be achieved using external waste heat recovery: this energy can be most efficiently used to preheat external combustion gas and/or air. This could eliminate enrichment gas requirements and lower operating costs. Most systems to-date are provided with external waste heat recovery systems.

GAS CLEANING

The blast furnace produces significant amounts of gas – as is illustrated in the figure below, more tonnes of gas are produced than tonnes of hot metal. Blast Furnace gas has a pressure around 2 Bar(g) and temperature around 150°C. The ‘raw gas’ is contaminated by moisture and dust. The gas temperature must be reduced and the dust and moisture removed before the blast furnace gas can be efficiently used for down-stream combustion in the hot blast stoves or power plant turbines. A modern blast furnace is therefore provided with a gas cleaning plant.





Modern gas cleaning plant includes five principal components:

- 1) Cyclone Dust-Catcher
- 2) Scrubber
- 3) Demister
- 4) Top Gas Recovery Turbine
- 5) Effluent Treatment Plant.

85% of the dust can be removed by centrifugal forces in the cyclone dust-catcher. The remaining 15% of small dust particles can only be removed with a scrubber, which is installed at more than 100 blast furnace plants. This scrubber includes a recirculating water system: the small dust particles are dissolved in water and this water is cleaned in the effluent treatment plant. The sludge is usually contaminated by Zinc and can't be recycled at the sinter plant.

The 'clean' blast furnace gas doesn't include dust anymore, but the remaining moisture must be removed and this can be accomplished by the demister. The top gas recovery turbine (TRT) is used to recover part of the 'mechanical' energy.



Higher TRT efficiencies can be achieved with a dry gas cleaning plant. Another advantage is provided by the fact that water consumption is further reduced. Conventional bag-filter dry gas cleaning plants do have a rather large footprint and are rather sensitive to upset blast furnace process conditions causing high or low top gas temperatures. Additional heaters and burners are therefore required to warrant blast furnace gas temperatures within the operating limits of the bag-filter system, but complicate the gas cleaning plant.

Another example of dry gas cleaning technology includes so-called Electro-Static Precipitator (ESP) technology, which is usually installed at power plants and recently more often at steel plant converters. Our analysis indicates that this is the most efficient system and enables lowest operating and investment costs.

CONCLUSIONS

- Blast furnace ironmaking is competitive to electric arc furnace and alternative ironmaking technologies, especially for large scale production of high deformability steel; this competitive edge is sometimes compensated for by local scrap abundance or very low gas prices;
- Blast furnace ironmaking main challenges relate to the global high demand for raw materials and associated high costs as well as increasing environmental legislation and permitting challenges;
- Modern blast furnace ironmaking technology must target low coke operations, which can only be achieved by high pulverized coal injection and is further complicated by fluctuating raw material qualities.



- Besides suitable equipment, high levels of pulverized coal injection further requires a solid understanding of modern blast furnace ironmaking fundamentals with the operating personnel.
- The transition towards high pulverized coal injection rates expose the blast furnace to the risk of – temporarily – erratic process conditions and increase heat load and burden load to the blast furnace lining.
- Copper stove coolers are sensitive to erosion and could constrain low coke operations: instead Hoogovens design with copper plate coolers, graphite and silicon carbide have demonstrated to be able to cope with all raw materials and low coke rates.
- Modern hot blast systems include external waste heat recovery to enable preheating of combustion gas and air: enrichment gas could then be minimized or eliminated. Internal burner designs expose the system to minimum stress levels and warrant a long campaign life. Appropriate refractory expansion provisions and gastight seals result in ultra-low emissions comparable to external and dome burner systems.
- Modern gas cleaning plants include static cyclone dustcatchers and wet scrubbers. Alternative dry gas cleaning technologies using bagfilters are currently deployed primarily in Asia and Russia, but are more sensitive to upset blast furnace process conditions unless ancillary heaters and coolers are used. Instead electrostatic precipitator gas cleaning technologies could be considered.