

Blast furnace modern design – modular construction

This article summarises the results of a comparison of two modern blast furnace designs. These designs include similar hearth, upper stack and throat armour technologies, but differ on the lining selection for bosh, belly and stack. The first design includes copper plate coolers, graphite and silicon carbide. The second design includes copper stave coolers.

Results of a partial reline modular construction case study are described for the first design. This demonstrates the feasibility of reducing the shut-down duration for a partial bosh, belly and stack reline to 40 days. A complete reline can be realised within 70 days. This is comparable to the shut-down duration for the second design using copper stave coolers.

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Modern blast furnace designs – using copper plate coolers, graphite and silicon carbide or using copper stave coolers – have been used by the industry since the 1970s and 1980s, respectively. The main objectives of these designs have been a longer campaign life and higher availability. Currently 15-20 years are commonly required for new plants and at partial or full relines. Low coke rate operations and high productivity levels introduce more challenging operations. Lower quality of raw materials results in increases in the amount of fines and slag volume, which reduces gas permeability and increase the risk of liquids flooding. Burden and gas distribution are fundamental and critical for low cost hot metal operations.

Shut-down durations for (partial) relines are also more critical today due to the fact that most plants are operating fewer blast furnaces than in the past. Lost production during these relines must be minimised and modular construction reline technology has been demonstrated at many plants using designs with copper and cast iron stave coolers since the 1990s.

Catastrophic abrasion failures of copper stave coolers have been reported by many plants in the past 10 years and this compromises the availability, productivity and campaign life of these plants. The performance of copper plate coolers, graphite and silicon carbide has been outstanding at all plants using the original 'Hoogovens' design. Reline durations using this Hoogovens design technology have always been longer due to the fact that installation of refractory could only be realised after installation of the shell, whereas copper stave coolers can be pre-assembled to the shell. This relative disadvantage has recently been eliminated by the development of modular reline construction technology incorporating pre-assembled Hoogovens technology. This can be realised

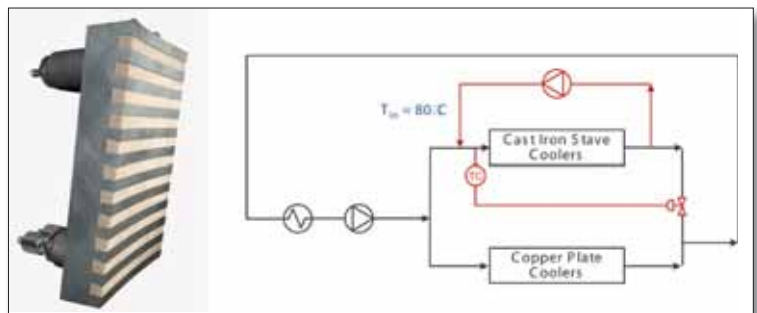


Fig 1 Throat armour and upper stack cast iron stave cooler and cooling system

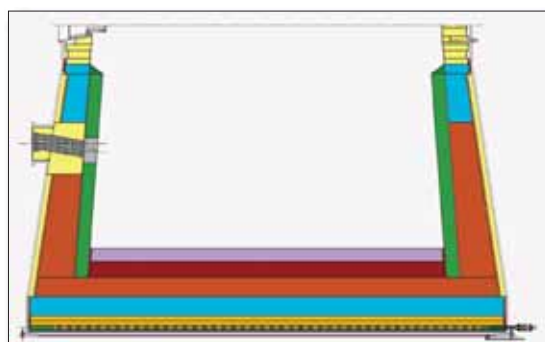
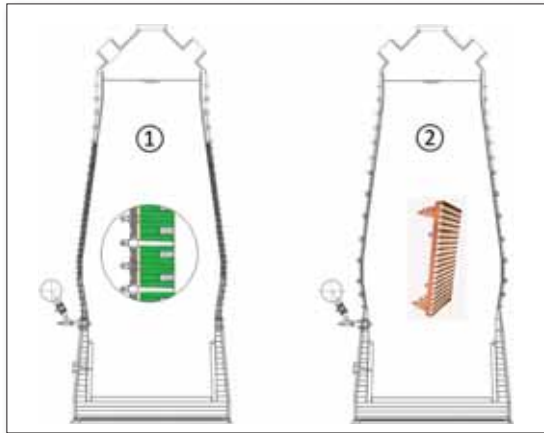


Fig 2 Bottom and hearth

by modern heavy transport and lifting systems with digital control and a temporary re-enforcement system for the shell modules including copper plate coolers and refractory lining.

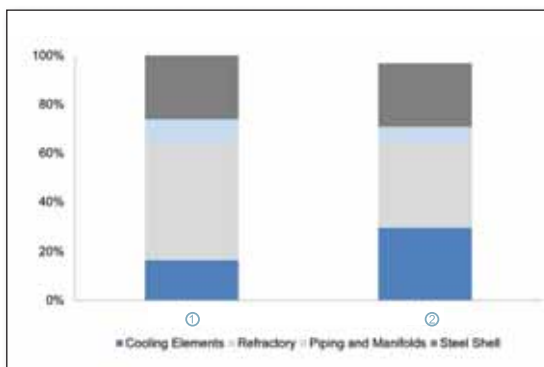
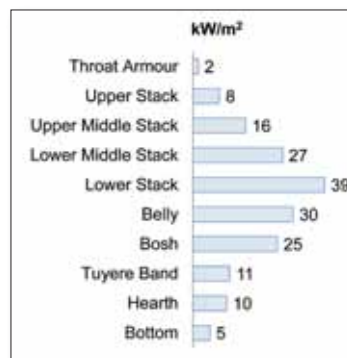
MODERN BLAST FURNACE DESIGN

Modern blast furnace designs include cast iron stave coolers in the upper stack and throat armour. A typical cast iron stave cooler and its associated cooling system are ▶



Ⓐ Fig 3 Modern blast furnace design:
 ① Copper plate coolers, graphite and silicon carbide
 ② Copper stave coolers

Ⓐ Fig 4 Heat load diagram



Ⓐ Fig 5 Relative weights



Ⓐ Fig 6 Performance design ①

	①	②
Flow rate [m/hr]	4,491	3,703
ΔP [kPa]	585	780
ΔT [°C]	6.2	7.4
Pump energy consumption [kW]	886	974
Heat exchanger [MW]	63.5	63.5

Ⓐ Table 1 Piping and cooling system

illustrated in *Figure 1*. Typical properties of the cast iron stave coolers include:

- Ⓐ Expansion bellow compensators for minimum stresses
- Ⓐ Curved profile for optimum burden descent
- Ⓐ Silicon carbide inserts for maximum abrasion resistance

The cooling system includes a recirculating and temperature control system to maximise the drying effect of the upper stack and efficiency of the blast furnace.

A modern hearth design is illustrated in *Figure 2* and includes high conductivity (ultra-) micropore carbon, graphite and hearth shell jacket cooling. Alternatively, hearth shell cooling can be realised using cast iron and copper stave coolers.

Although the blast furnace hearth, upper stack and throat are critical areas, the choice of technology for the bosh, belly and the lower and middle stack also enables campaign length and campaign security to be increased. Also, there has been a strong relation between the choice of technology for these areas and the required shut-down duration for (partial) relines. Two modern designs using upper stack and throat armour cast iron stave coolers and the abovementioned hearth are illustrated in *Figure 3*.

The left design reflects Hoogovens technology using copper plate coolers, graphite and silicon carbide. The right design reflects typical copper stave coolers. A case study has been executed to compare technical data for these two designs for a large blast furnace with a hearth diameter of 14m, 40 tuyeres and a daily production of 10,000tHM.

The theoretical heat load diagram is illustrated in *Figure 4* and is independent of the lining design. This diagram illustrates daily average values.

Technical parameters of cooling systems for the two designs are summarised in *Table 1*. The higher flow rate for the first design is a result of the specific routing layout which has been optimised for leak searching procedures and it is offset by the lower ΔT and ΔP . The heat exchanger capacity is comparable to and independent of the lining design.

The weights of the reactor designs are summarised in *Figure 5* and are comparable. The main difference is the ratio between refractory and cooling elements.

The performance of Hoogovens technology is unquestioned and a typical example is reflected in *Figure 6* after a 15-year campaign at high productivity and high PCI; this campaign is now in its 25th year and similar cases are reported at other plants.

Despite the fact that many plants with copper stave coolers are operating according to expectations, it has become increasingly clear that catastrophic abrasion could occur, necessitating frequent maintenance shut-downs, campaign extension repairs and premature (partial) relines while compromising productivity and low coke rate operations. An example of copper stave abrasion is shown in *Figure 7*.

Significant research has been executed during the past 10 years to understand the reasons for the abrasion failures. Various copper stave cooler design improvements are claimed to eliminate this risk, but have not yet been demonstrated in real practice. Many solutions that have been suggested are based on adjusting the blast furnace process to protect the stave lining. This fuels the debate about interdependency between process and reactor lining for both blast furnace designs. Although this debate is beyond the scope of this article, the authors have found no cases so far where operators were confronted by limitations imposed by the lining design based on copper plate coolers and high conductivity refractories.

BLAST FURNACE MODULAR CONSTRUCTION

A particular advantage of copper and cast iron stave coolers is associated with the fact that they can be pre-assembled to the shell, reducing the reline duration using modular construction technology. This technology has been used since the 1990s after advanced heavy transport and lifting technologies emerged in other industries in the 1970s. These technologies include self-propelled modular transporters, skidding, jacking and strand-jack systems as illustrated in *Figure 8*. The transport and lifting systems are compact and can result in significant reductions in reline shut-down time. Replacement of entire blast furnace reactors have already been accomplished.

The duration of a traditional blast furnace reline is in general more than 120 days, but can be reduced to less than 70 days using modular construction technology. Prerequisites for modular construction include space at and around the blast furnace and sufficient strength of the tower and/or casthouse structure for temporary support of blast furnace modules.

An auxiliary foldable and movable platform is required for flexibility of activities inside the reactor. A foldable design is illustrated in *Figure 9*: the diameter of the platform can be modified to suit the different diameters of the blast furnace bosh, belly and stack.

Modular construction technology has been used frequently in our industry for (integral) relines using copper and cast



Fig 7 Performance option 2



Fig 8 Lifting and transport systems

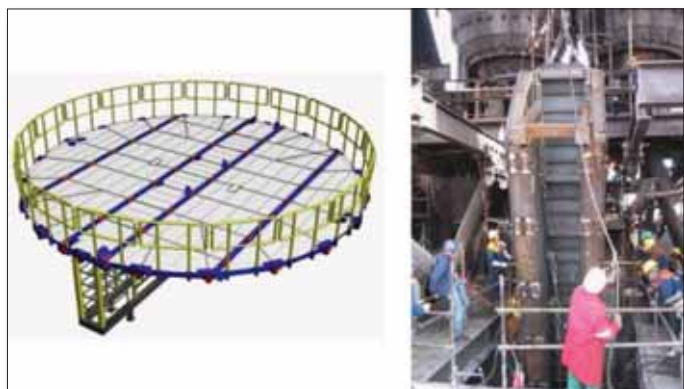


Fig 9 Foldable and movable platform

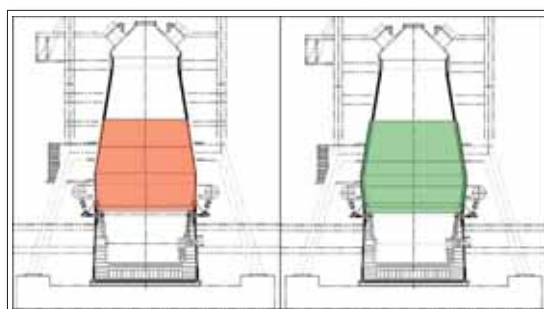


Fig 10 Partial reline battery limits

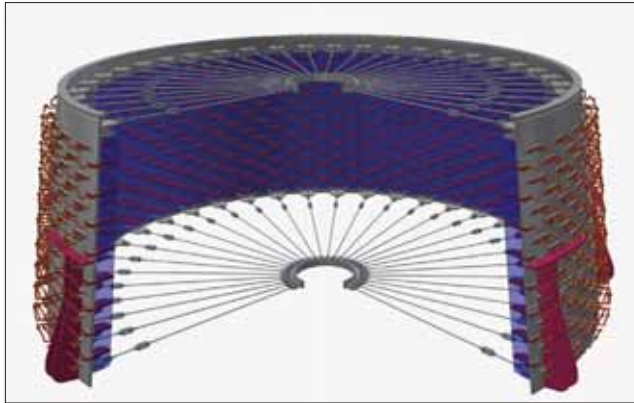


Fig 11 Module design

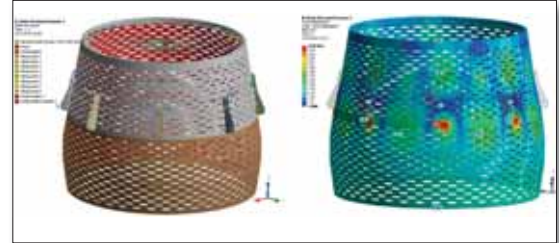


Fig 12 Shell stress and strain model

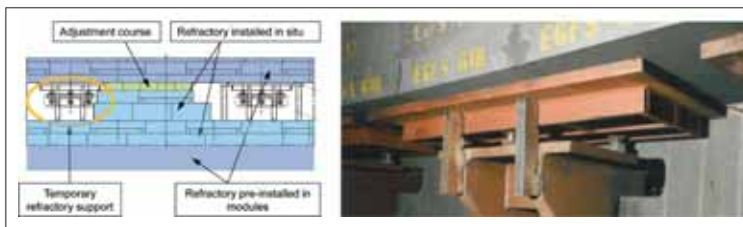


Fig 13 Refractory interface

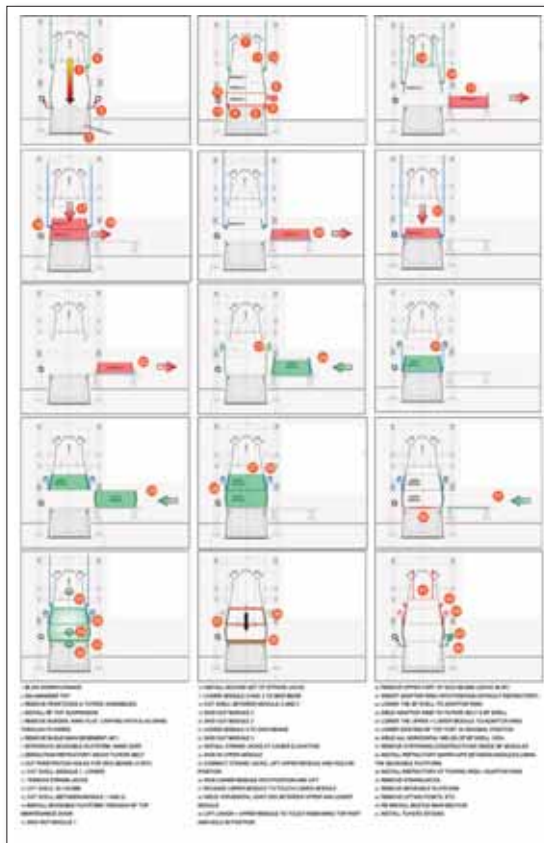


Fig 14 Reline modular construction

iron stave coolers, as these can be pre-assembled in the shell without risk of damage, for instance to the refractory lining. Either the refractories are not installed or they are an integrated part of the staves. A comparable technology has now been developed for a (partial) reline using Hoogovens technology within an engineering consultancy project.

The scope of this partial reline project is illustrated in Figure 10 and includes the replacement of the bosh, belly and stack copper stave coolers and shell (left, red area) by a new shell, copper plate coolers, graphite and silicon carbide (right, green area). The copper stave coolers have been failing to the point that shell deformation and cracking has been occurring within less than five years after commissioning. The hearth and upper stack does not require relining and hence a partial reline – replacing the copper staves by copper plate coolers, graphite and silicon carbide – with a minimum shut-down time has been explored.

A typical module design for the lower stack is illustrated in Figure 11 and includes pre-assembled copper plate coolers, graphite and silicon carbide refractory, external interconnecting piping and temporary re-enforcement structures.

Deformations of the module are less than 2.5mm during transport, lifting and installation as has been demonstrated by stress-strain models (see Figure 12). This can only be realised by modern heavy construction systems with digital control of cylinders to ensure equal distribution of forces introduced by the transport equipment.

These modules with a pre-assembled lining are comparable to 'conventional' modules with copper or cast iron stave coolers. The interface between two modules using pre-assembled refractory lining is critical, but in-situ installation has already been demonstrated frequently during conventional relines whereas installation is accomplished simultaneously at different levels. Typical examples are illustrated in Figure 13.

A detailed dismantling and installation procedure is illustrated in Figure 14. Refer to the sequence below the figures to determine sequence of operations. Pre-reline activities include casthouse activities to provide sufficient space for transport of the modules and also installation of skidding, jacking and strand-jack systems. Pre-assembly

of the modules should be realised close to the plant to minimise transport movements. Temporary and local re-enforcement of the tower structure may be required. Furthermore, provisions for modifications to the cooling system can already be installed.

Salamander tapping is necessary after blow-down to secure safe working conditions during the (partial) reline. Additionally, salamander tapping will enhance cooling down and blow-in of the furnace. Remote drilling (see *Figure 15*) secures safe working conditions. A capping layer using slag sand is deposited on top of the remaining burden after removal of the tuyere stocks, or gunning could be used. This capping layer effectively seals the hearth to eliminate oxygen entrance and risk of carbon oxidation. Furthermore, it eliminates the risk of CO gas in the blast furnace, although an additional venting systems is always required.

Actual dismantling can be executed after installation of the movable platform and installation of the top suspension system. Due to space constraints for this specific plant, three dismantling modules are required. Two large new modules and one small adaptor ring are installed after dismantling has been realised. The maximum weight of each of the large new modules is ~600 tonnes. Before lifting into final position, the first and second large modules are partially welded together to secure fast-track installation of the third module. Marry-up of the refractory interfaces is accomplished after welding has been completed.

The external cooling system can be revised in parallel with the modular construction approach. An independent cooling system could be installed, but it is normally more economical to tie-in the new cooling system to the existing system (see *Figure 16*).

Total shut-down for this partial reline for a large blast furnace can be realised within 40 days. The main activities are summarised in the shut-down schedule of *Figure 17*. Within this time schedule it is also possible to replace the tapholes with a conventional external taphole repair procedure. Blow-in is accelerated using oxy-fuel recovery lances, which are most effective if a controlled blow-down has been realised. A comparable schedule for an integral reline – including replacement of the entire reactor – would amount to less than 70 days.

CONCLUSIONS

- Modern blast furnace designs include: state-of-the-art bottom and hearth refractory grades, including high conductive micropore semi-graphite (ultra micropore carbon), external hearth shell jacket cooling and bottom water cooling
- Bosh, belly and stack designs including machined copper plate coolers, graphite and silicon carbide refractory, have demonstrated long campaign life and high availability



Fig 15 Remote salamander tapping

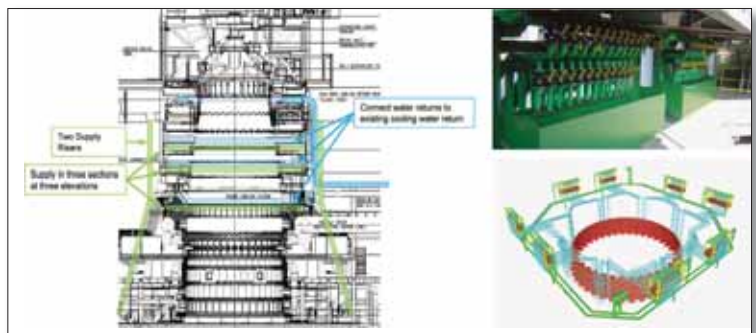


Fig 16 Piping and cooling system

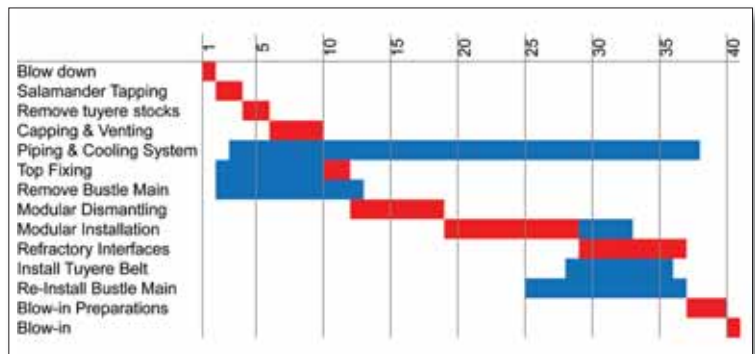


Fig 17 Shut-down schedule

- Modular construction technology has been demonstrated frequently during blast furnace relines using copper and cast iron stave coolers and has been recently developed for Hoogovens technology
- The technology secures a shut-down time for a partial reline of 40 days and a complete reline of 70 days. **MS**

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