Construction and operation of TISCO Taiyuan 4,350m³ blast furnace No.6

In November 2013, Taiyuan Iron & Steel (Group) Co., Ltd. (TISCO) started the new BF No.6 at their Taiyuan, Shanxi plant. It has a 4,350m³ inner volume, similarly dimensioned to the existing BF No.5, which started in 2006. The furnace is equipped with the Danieli Corus high conductivity integrated lining and cooling concept based on graphite refractories and copper cooling plates. This article presents the technical considerations on which TISCO selected this design, an overview of the project execution and also analyses the first years of operation from the perspective of production and maintenance.

Ironmaking at TISCO Taiyuan

Taiyuan Iron & Steel (Group) Co., Ltd. (TISCO) is one of the major players in the Chinese steel industry. The company operates a plant with an annual capacity of 12Mt steel of which 4.3Mt is stainless. The plant is located in Taiyuan, the largest city of the Shanxi province in North China and their first blast furnace of 1,058m³ inner volume, was commissioned in 1958. Hot metal production grew at the site with an installed base of furnaces with hearth diameters just below 10m until 2006, when the large BF No.5 was commissioned. A few years later, the planning for BF No.6 commenced.

BF 6 Technical Considerations

TISCO blast furnace No.5 was operated at relatively high productivity and at elevated levels of pulverised coal injection (the system was designed for injection rates up to 250kg/tHM). At that time, there was a trend in the global steel industry that required use of more lower-quality raw materials – since the better-quality raw materials were becoming less available – and a more frequent fluctuation in production levels caused by economic circumstances. Such operating conditions increase the loadings on the blast furnace lining: the blast furnace is a high temperature, pressurised counter-current reactor and abrasive raw materials are descending and gradually softening and melting while high temperature gases are ascending through the burden and along the lining. Loadings on the lining are thus thermal, mechanical and chemical.

Furthermore, the blast furnace is a continuous process, but with batch elements, such as charging and tapping. The blast furnace process is sensitive to de-stabilisation due to variations in raw material quality, equipment failures, (unscheduled) shut-downs, burden slips, casting deficiencies and ‘gas-jets’. Therefore, the severe process...
stave coolers are unable to cope with high temperatures and high temperature fluctuations, as this causes material degradation and cracking despite many improvements in coating, cast iron grade and refractory inserts. However, the application of cast iron stave coolers in the upper stack and throat has proven to be very successful as these areas are usually not exposed to high temperatures or temperature fluctuations. But in the bosh, belly and lower/middle stack areas, temperatures and temperature fluctuations increase. For these areas, a modern design is mandatory. In our industry, two designs are promoted: one based on copper stave cooling and the other based on copper plate cooling.

Copper stave coolers have been developed since the 1980s and are currently installed in many plants in high thermal load zones such as the bosh, belly and lower stack. During recent years, many plants have reported failure of copper stave coolers. Figure 1 illustrates a case of stave wear caused by abrasion. Research has demonstrated that the root cause of these failures is usually abrasion by descending burden, particularly coke. This suggests that in these cases, the copper stave coolers were not adequately protected by an accretion. While in many situations, acceptable campaign lengths have been achieved with stave-cooled furnaces, premature failure of staves is encouraging iron producers to consider more durable options.

Another modern bosh, belly and stack design includes machined copper plate coolers and high conductivity graphite (with added silicon carbide in areas where resistance against abrasion/erosion is required). Combinations of copper plate coolers with other types of refractory are also used, but designs based on graphite have shown the best results.

Figure 2 shows the condition of several furnaces equipped with this ‘indestructible bosh’ design during (in most cases) mid-campaign intermediate repairs to eg, the hearth area.

One of the dominant topics in the debate about campaign life capabilities of stave-cooled and plate-cooled designs focuses on the hot face temperature of the lining. The authors do not wish to conclude this debate within the scope of this article, but would like to highlight some of its considerations. Suppliers of copper stave-based designs have stressed the importance of maintaining a hot face lining temperature lower than 100°C to mitigate the risk of softening of the copper cooling members. However, for the creation of an accretion layer that protects the lining, some softening of the descending burden is required; this is impossible at such low temperatures. Designs based on copper plate cooling and high conductivity graphite have a higher maximum allowable hot face temperature (due mainly to the nature of the majority of the materials conditions discussed above are also highly dynamic in nature.

During the basic engineering phase for BF No.6, TISCO recognised that the new furnace should be able to cope with these increasing demands. Campaign lives of more than 20 years (at availabilities of over 95%) can only be achieved if the internal profile of the furnace is maintained during the campaign, as any degradation will immediately have a detrimental effect on process stability, efficiency and campaign life. The global steel industry acknowledges that the choice of lining and cooling design of the blast furnace plays an essential role in this respect.

Historically, blast furnace campaign lives were typically limited to only a few years until modern lining designs were developed in the 1970s. Designs based on cast iron
present, which can cope with temperatures in excess of 1,000°C. With these designs, the combination of high cooling capacity, high conductivity and resistance against erosion/abrasion, ensures the creation of the desired accretion layer and in practice, hot face temperatures in operation are always below 100°C. This allows the operators more freedom to optimise the gas and burden distribution without the risk of compromising the blast furnace lining.

For TISCO, this consideration made the choice of blast furnace cooling and lining technology one of the critical paths in the stage of basic engineering for the new furnace. Based on the experiences of the first years of operation with BF No.5, the decision was taken to investigate domestic as well as foreign experiences in production and operation with larger blast furnaces of several cooling and lining designs.

After the very first basic design was completed, a literature study was executed to summarise global experience. Technology suppliers were contacted for technical discussions and ironmaking experts from the Chinese steel industry and overseas areas were consulted. The results of all these exercises were summarised and quantified for performance with respect to the ironmaking process and maintenance. The integrated cooling and lining design based on copper plate cooling and graphite refractories, as proposed by Danieli Corus, was evaluated as the prevalent option.

The main reasons for TISCO for selecting this design were as follows:

- Proven performance in operations for high productivity, high coal injection rates and long campaigns
- Easier maintenance – plate coolers can be replaced from outside the furnace during a short stop without having to blow the furnace down

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner volume</td>
<td>4,961 m³</td>
<td></td>
</tr>
<tr>
<td>Daily production (average)</td>
<td>10,000 tHM/d</td>
<td></td>
</tr>
<tr>
<td>Daily production (maximum)</td>
<td>12,000 tHM/d</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>350 days/yr</td>
<td></td>
</tr>
<tr>
<td>Annual hot metal production</td>
<td>3.5 MthM/yr</td>
<td></td>
</tr>
<tr>
<td>Hearth diameter</td>
<td>14.2 m</td>
<td></td>
</tr>
<tr>
<td>Number of tuyeres</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Number of tap holes</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Coke rate</td>
<td>320 kg/tHM</td>
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</tr>
<tr>
<td>PCI rate (normal)</td>
<td>200 kg/tHM</td>
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</tr>
<tr>
<td>PCI rate (maximum)</td>
<td>250 kg/tHM</td>
<td></td>
</tr>
<tr>
<td>Hot blast temperature</td>
<td>1,300 °C</td>
<td></td>
</tr>
<tr>
<td>Hot blast volume (dry) without oxygen enrichment</td>
<td>7,000 Nm³/min</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Design parameters, BF No.6
‘Dry contact’ between plate cooler and graphite without the application or mortar/ramming eliminates the risk of gaps that – as with some other designs – lead to loss of cooling efficiency.

Cooling water piping design/pattern is optimised to minimise consequences in case of damaged/leaking cooling plates.

In the summer of 2011, TISCO awarded the contract to Danieli Corus for the design, supply and installation supervision of an integrated cooling and lining system based on machined copper plate coolers, graphite refractories and a heat flux monitoring system for BF No.6. In earlier stages, contracts for a PCI system and copper cooling members for the furnace’s four tapholes had already been awarded to Danieli Corus.

BF NO.6 DESIGN

As a result of the basic engineering as described above, the design specifications for the new furnace were as presented in Table 1.

The design specification for the campaign life of the furnace was for a target of at least 15 years. Given earlier experiences with long campaign lives for this design, the requirement could be agreed upon without hesitation. Many furnaces equipped with this lining and cooling technology are currently beyond their 15th year into an ongoing campaign; indeed, one of these is in its 30th year without any major repairs scheduled for the short term.

The general arrangement of BF No.6 is given in Figure 3. The scope of the high conductivity lining and cooling system, for which the contract was signed with Danieli Corus, is highlighted in colour.

PROJECT EXECUTION

After the contract for the design, supply and installation supervision of the cooling and lining system was signed, the project began immediately in September 2011. The engineering took until May 2012 and during this phase priority was given to longer lead items, such as the copper cooling members and the graphite refractories. Manufacture of these items took from December 2011 until June 2012.

In implementing a successful design, three factors are essential in its execution:

- Quality of engineering
- Quality of the materials
- Quality of the supervision.

To ensure a good quality of materials, the utmost attention is given to the selection, approval and qualification of vendors and the inspection and acceptance of the materials. As an example, copper cooling members are subject to X-Ray
inspection to detect leakages and other defects. Refractory materials are submitted to non-destructive testing, such as basic dimensional checks, but other methods are also applied. First, samples are selected and processed during laboratory tests at selected research centers for refractory materials. Second, samples are selected and cut in situ for the detection of non-superficial defects. An example of such a defect is shown in Figure 4.

After the extensive laboratory testing and at vendors’ premises, many of the materials were submitted to final inspection upon arrival at the TISCO plant. This process took place in August and September 2012 and the installation of the furnace internals started immediately after, to be completed by January 2013.

Installation supervision is essential for the success of the design in operation. Drawing on the experience of more than 100 projects in the design and installation of such cooling and lining systems, Danieli Corus experts are fully equipped for such tasks.

Figure 5 shows an example of the ‘dry contact’ between copper cooling member and graphite refractory material that was an important factor for TISCO in selecting this design.

Installation of piping and balancing of the cooling water system took another few months until July of 2013, whereupon the furnace was put into operation. Figure 6 shows the furnace during the construction phase.

Upon completion (see Figure 7), BF No.6 stood as the new flagship for the TISCO Taiyuan site. The furnace was designed and built, not only in accordance with international standards for process technology and for the longest possible campaign life, but also designed and built to provide operational staff and all others active on site with the safest and cleanest possible working environment.

The operator control room, as shown in Figure 8, is equipped with all modern systems for maximum process control and 24/7 online monitoring capability of the
production process and condition of the essential items, such as raw materials charging, stockline condition and tuyeres. The cast houses have a flush and flat floor for unimpeded logistics and maximum safety for cast house staff (see Figure 9).

OPERATION: PRODUCTION
BF No.6 was commissioned on 7 November, 2013. Production was initiated at a coke rate of around 600kg/thM and the 10,000thM/d production threshold was achieved on day 15 after blow-in and coal injection started on day 10. Stable operations around the 10,000thM/d mark with coal injection levels up to 200kg/thM and coke rates down to 300kg/thM were achieved within the first month of operations, which is considered extremely fast. An overview of these exceptional results achieved during the blow-in and ramp-up period is given in Figure 10.

During the first 300 days these parameters were maintained, as illustrated in Figure 11.

As part of an operational benchmark executed around a year after the initial blow-in, the performance of the furnace was compared with that of five other blast furnaces with a 14m hearth diameter. Three are located in Western Europe, one in North America and one in Asia. All these furnaces are considered to be well operated and, as Figure 12 clearly shows, TISCO BF No.6 compares well for these parameters.

The furnace has now been in operation for three and a half years. The initial results were continued as demonstrated in Figure 13 by the monthly average figures for productivity (calculated against inner volume), coke rate and coal injection rate shown below. Slag rates have been around 300kg/thM consistently and oxygen enrichment levels in the hot blast around 3%.

The peak in coke rate in March 2015 is because of a short stoppage.

One of the notable results achieved during this long period of stable operations (even under crisis conditions) is the high efficiency of the process. Pulverised coal injection has been kept around the 170-180kg/thM level, while gas utilisation $\eta_{CO} = CO_2/(CO+CO_2)$ (ETACO) was between 47% and 49% quite consistently. In December 2015, this parameter crossed the 50% mark (see Figure 14) and has remained at this elevated level since.

OPERATIONS: MAINTENANCE
The furnace is demonstrating exceptional performance with respect to maintenance. Over the course of the first three and a half years of operations no incidents have occurred and only very little maintenance work has been executed.

In 2015, the furnace suffered two leaking cooling plates (out of a total installed number of well over 2,000). These
leakages occurred in rows 16 and 22. Two replacement cooling plates were delivered, passed the pressure tests and were installed during a short maintenance stop on 21 July 2015. The installation and welding were supervised by Danieli Corus and executed according to the submitted procedure for cooling plate replacement. Before final installation, a template is used to check whether the cooling plate fits the slot that has become available after the leaking cooling plate has been pulled from the furnace from the outside. Assessment of the furnace condition indicated that the remaining refractory inside the furnace was sufficient in both locations. During the replacement procedure, TISCO decided to weld an additional cover plate over the existing cover plate in order to eliminate the risk of damage to the shell. The complete replacement procedure for both cooling plates was executed in only a few hours.

*Figure 15* shows the pulling equipment in position outside the furnace as well as one of the new plate coolers in its position during the replacement procedure before final welding.

**CONCLUSIONS**

- The choice of blast furnace cooling and lining design plays an essential role in campaign planning and the operator's possibilities to optimise the process.
- Although some iron producers have achieved good results with stave cooled designs, many are experiencing the drawbacks and limitations of this technology, which can suffer from premature failure.
- Plate-cooled designs with high conductivity graphite refractories (and silicon carbide added in areas exposed to abrasion/erosion) have a proven lifetime capability of over 20 years, with some cases in the 30th year of their ongoing campaign.
- Quality of engineering, quality of materials and quality of installation are essential for the success of a design – compromising either factor compromises the system.
- TISCO Taiyuan BF No.6 is performing well in terms of production (benchmarked against international furnaces of similar size) and maintenance.
- The successful application of copper plate and graphite block technology at TISCO, opened a new field of technology for China, promoting long campaign lives.

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