BOF design improvements and upgrades

Since its launch in 2011, the converter division of Danieli has revamped/redesigned five converters and is currently working on a further two. Design changes include vessel size and shape, vessel suspension system, vessel shell construction materials, cone water cooling, barrel air cooling, converter temperature monitoring and equipment condition monitoring systems.

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Danieli Corus

Danieli entered the steel converter business in 2011 with the inception of a new, dedicated business unit, Danieli Linz Technology (DLT). Activities ramped up rapidly in this highly demanding and conservative area of steelmaking. Currently, five BOF converters supplied by DLT are operating worldwide with sizes between 80t and 350t. Another two are currently under fabrication (see Table 1).

Since July 2018, Danieli converter technology has been fully integrated into Danieli Corus at IJmuiden (The Netherlands). See also the Danieli article on page 28.

All these BOFs are bespoke but based on best practice, input from end user and other requirements. The designs include fixed bottom, detachable bottom, welded and bolted top cones, with and without knuckle sections, forced draft air cooling and water cooling (see Figure 1).

### Table 1 Reference plants

<table>
<thead>
<tr>
<th>Plant</th>
<th>Tap weight t</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcelorMittal Dobrava Gornicza</td>
<td>350</td>
<td>May 2014</td>
</tr>
<tr>
<td>Aperam Timoteo</td>
<td>80</td>
<td>Dec 2015</td>
</tr>
<tr>
<td>ArcelorMittal Krakow</td>
<td>155</td>
<td>Nov 2016</td>
</tr>
<tr>
<td>ArcelorMittal Krywy Rih</td>
<td>160</td>
<td>Aug 2017</td>
</tr>
<tr>
<td>ArcelorMittal Galati</td>
<td>180</td>
<td>Dec 2017</td>
</tr>
<tr>
<td>ArcelorMittal Temirtau</td>
<td>300</td>
<td>2019</td>
</tr>
<tr>
<td>USIMINAS Ipatinga</td>
<td>180</td>
<td>2020</td>
</tr>
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CONVERTER PROCESS EFFICIENCY
The BOF converter remains one of the most important process units worldwide for producing high quality steel. To facilitate the physical and chemical reactions during blowing the converter has to provide a certain reaction volume, bath depth and reaction surface. The characteristic benchmark is the specific volume (defined as ratio of inner reaction volume to mass of liquid steel \([\text{m}^3/\text{t}]\)) which should be maximised.

Several boundary conditions have to be considered, however, when upgrading or revamping a vessel in an existing steel plant. These include:
- Clearances during charging, tapping and to the off-gas system
- Tilting torques
- Foundation loads

Various design iterations are made during the engineering phase in order to find the right solution for each plant configuration and revamp. A typical example is the 350t BOF revamped for ArcelorMittal Dobrava Gornica (Katowice) in 2014. Figure 2 shows the original and new vessel designs. It can be seen that the new vessel is slightly taller and wider, giving an inner volume increase from 225m³ to 275m³ and an increase in specific volume from 0.64m³/t to 0.79m³/t, but it still fits into the original space.

VESSEL SUSPENSION SYSTEMS
A key design feature of a converter is its suspension system which has to:
- Keep the vessel shell in the correct position at all times
- Withstand all possible conditions which can occur during operations, such as high temperature, water shocks, mechanical impacts, burn-throughs and solidified steel bath
- Be maintenance free. This is the most challenging issue

In principle, suspension systems can be subdivided into...
vertical and horizontal suspension elements, which are characteristic for all modern suspension systems for vessel sizes of more than 50t. The loading of these elements is dependant on the actual tilting angle of the BOF.

For the vertical loads Danieli Corus applies the well-known lamella-type suspension elements (usually eight in number) but with an improved design to provide a better load distribution within the elements which should also increase their operating life. The thermal expansion and long term deformation are compensated by elastic deformation of the lamella elements.

The horizontal loads are typically carried by only two elements, which are, therefore, the most critical. Danieli Corus has developed a new patented element, the so-called DANIELLA element (see Figure 3). There is a centre bracket welded to the vessel shell and two brackets welded to the trunnion ring, with the lamella plates arranged between these. These lamella plates do not have a fixed connection to any bracket but are simply located in the positions shown.

During vessel heating at the start of a campaign as well as during production, the vessel brackets are exposed to a higher heat load than the rest of the assembly. This results in more thermal expansion and is compensated by elastic deformation (bending) of these plates within a provided the clearance to the centre plate (see Figure 4). The long term deformation of the vessel shell (creep) is not hindered at all in this DANIELLA element and does not cause any additional stress or deformation.

This is a simple and very robust structure which does not require special elements like bearings, forgings or castings, leading to simpler repairs (eg, in an emergency case) which can be carried out by the regular maintenance team, and so minimising downtime and costs.

Figure 5 shows the installation of the Danieli suspension system and detail of the Daniella plates.

The advantages can be summarised as:

- Simple and robust design
- No special parts involved (repairs can be done by maintenance staff only)
- Lamella plates are simply inserted between welded-on brackets and held in position by holder plates. Thus, these plates can easily be changed or adjusted eg, in an emergency

CONVERTER LIFE

In the BOF supply market, there is an increasing demand to provide complete system responsibility. This means optimising converter and refractory technologies with the aim of increasing their lifetimes in parallel as a system.

There are two aspects to converter life: campaign life, as measured in number of heats between refractory relines, and overall vessel productive life, as measured in years, and which is influenced primarily by shell distortion. Both directly influence the cost of liquid steel via Opex and Capex, respectively.

To help maximise vessel refractory life, the refractory should be maintained for as long as possible, and hence is at high temperature over a long period. However, for maximum productive life of the vessel shell, its temperature should be as low as possible. These are obviously in contradiction – a condition that worsens as the lining thins during a campaign. Today, campaign lives are measured in thousands, lasting even one to two years, but this requires using slag splashing and rocking at every heat to maintain a certain minimum lining thickness in order to avoid further shell overheating or even burn through.

Modern efficient plants also operate with ever shorter tap-to-tap times so there is less time for shell cooling. Under these conditions vessel life can be reduced to less than 10 years, from a more normal 20 years or more (some converters have been in operation up to even 40 years). Consequently, compromises need to be made.

The possibilities for converter suppliers to increase the lifetime of the vessel shell as such are rather limited. The most reliable technologies can be summarised as:

- Application of high creep resistance material for the vessel shell
- Installation of a water cooling system for the converter top cone
- Installation of an air cooling system for the converter barrel section
- Installation of a temperature monitoring system for the complete vessel shell

Creep resistance Creep resistant steels which can be used for a converter vessel, are more or less limited to the following pressure vessel materials (based on European Standards): 16Mo3, 13CrMo4-4, 10CrMo9-10 and P420MHT. A comparison in terms of stress to reach 1% creep strain for a temperature level of 500°C is shown in
16Mo3 is a very common material, having excellent mechanical properties up to 500°C, reasonable creep resistance, and is moderately easy to weld. The best grades in terms of creep are the Cr-Mo-alloyed steel varieties, 13CrMo4-4 (ASTM A387 Gr.11) and 10CrMo9-10 (ASTM A387 Gr.22). These demonstrate excellent creep resistance but require very careful welding as well as post weld heat treatment (PWHT). This is not an issue for the supplier but has to be taken into consideration for on-site repairs. These materials have been in use for many years in converters in North America and are now being accepted in other parts of the world.

An additional potential steel is P420MHT, a thermo-mechanical rolled grade which does not require PWHT. However, if it is overheated during vessel operations (above 600°C) its mechanical properties can degrade so it is not the preferred material for BOF application by Danieli Corus.

**Top cone water cooling** The top cone is the most exposed part of the BOF in terms of temperature, particularly during tapping and from slopping slag. In some plants the temperature of the top cone is so high that it almost becomes a ‘wear’ part. A possible solution is to use water cooling, as a result of which lifetime can be significantly increased (even doubled). However, because of the extreme conditions and the risk associated with water by eg, contacting liquid steel, leakages must be quickly identified and the cooling system shut off and repaired (eg, during the next shut down or relining period).

**Air cooling of the barrel** The barrel section is of utmost importance because the deformation in this area defines the end of the lifetime of the converter body. For instance, with severe heat distortion the vessel shell can even extend across the trunnion ring gap. Air is a very ineffective cooling media but for the barrel section there is really no alternative available.

Danieli Corus uses forced air cooling of the vessel shell which flows through hundreds (even thousands) of holes in air panels or on the inside of the trunnion ring web plates into the air gap between trunnion ring and converter. These air flows disrupt the natural air flow within the trunnion ring, providing turbulence and a mixing of the hot air with the cooler, and increases the convection factor outside the vessel. Air cooling is more effective at higher shell temperatures.

**Converter temperature monitoring system (Q-TEMP)** Another feature to prolong converter life is monitoring of the vessel shell temperature. Danieli Corus has already installed a converter temperature monitoring system.
system, the so-called Q-TEMP, on an 180t BOF in Ukraine. However, this installation is to be further improved in terms of lifespan of the sensors, which are based on thermo-resistance elements, as well as providing better access.

Based on the combined experience of the Danieli Corus ironmaking team, where similar applications are successfully installed on blast furnaces, and the experience from BOF applications, the next generation – Q-TEMP 2.0 – has been developed and will be applied in a new BOF in Brazil. This system is based on two different measurement methods. In the top half of the vessel (with no direct visual access) thermocouples are arranged directly onto the vessel shell. In the bottom half, which has visual access the temperature is measured by infra-red cameras (see Figure 7).

There are 32 thermocouples arranged in four horizontal rows on the vessel shell. The data is transferred via hard-wired cables through the trunnion ring to the outside of the trunnion pin. From there a WiFi connection is provided for data transfer and further processing. The recorded data are saved on a hard drive and displayed in the main pulpit. (An example of the displayed temperature distribution of a converter vessel is shown in Figure 8.)

Q-TEMP 2.0 has following new features (see Figure 9):

- Use of thermocouples instead of thermo-resistance elements
- All thermocouples can be maintained and exchanged from inside the trunnion ring
- All elements are arranged in such a way that they permanently contact the vessel shell and so can follow all vessel shell deformation
- Not necessary to remove slag shields for maintenance of the protection piping of the elements

STATE OF THE ART

Recently Danieli Corus has been awarded a contract to replace an 180t BOF in Brazil where all the above factors were essential for this order (see Figure 10). The design includes:

- High creep resistance steel for the vessel shell
- Water cooling system for the top cone
- Air cooling system for the barrel section
- Temperature monitoring system for the complete vessel shell

DANIELI CONDITION MONITORING SYSTEMS (DCMS)

In modern challenging steelmaking scenarios, there is a common focus on cost reduction while maintaining high plant availability and reliability. This is somewhat of a contradiction because, on the one hand, maintenance reduces the operation time, but it aims to avoid total failures of components which can create major shut downs
and disable production. Hence, there is an optimum of how much maintenance should be applied. In principle three types of maintenance are possible:

a) **Breakdown or emergency maintenance** Repair or change of components after breakdown. Most risky and can cause major shutdown if spare parts are missing, if repairs are complicated and can be a time-consuming repair, so should be avoided.

b) **Preventive maintenance** Is applied on a regular basis when a machine or components are overhauled at specified time intervals, regardless of the condition of the parts.

c) **Predictive maintenance** The maintenance requirement is determined by continuously analysing the condition of the machine or components in order to predict and schedule the most efficient repair action prior to failure. This is the preferred option.

In principle, the DCMS measures machine vibrations in dedicated locations. The vibration signals are collected through accelerometer sensors installed directly on the machine body. Data sampling and acquisition is managed automatically and is configurable on the server with different modalities.

The vibration data is synchronised to the machine movements in order to relate the vibration signals with the working condition of each piece of equipment. A server collects the data and performs on-line processing, data archiving and post-processing. The vibration values acquired during the machine working condition are compared with the pre-fixed threshold limits for automatic alarm generation and management.

In the BOF this system can be typically applied in the converter tilting drive (bull gear and primary gears) as well as in the main bearings. An overview of the application is shown in Figure 11.

**CONCLUDING REMARKS**

Since its launch in 2011, the converter division of Danieli Corus, with the aim of improving process efficiency and lowering capital and operating costs, has revamped/redesigned five converters and is working on a further two. Design changes include vessel size and shape, vessel suspension system, vessel shell construction materials, cone water cooling, barrel air cooling, converter temperature monitoring and equipment condition monitoring systems.

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