Bulletin — 2025 — pp. 12—22

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Application of IBOS Technology for Metal Yield Optimisation in Secondary Refining Ladles for Brazilian Customers

The Improved Bottom Optimised Solution (IBOS) technology, patented by RHI Magnesita, was developed with the goal of maximising metal yield in secondary refining ladles by reducing the volume of residual steel at the end of the tapping process. This contributes to more efficient resource utilisation and cost savings. The IBOS system features a specially designed ladle bottom composed entirely of high-performance precast refractory modules. For the Brazilian market, a locally produced low-cement alumina-based castable was formulated to withstand severe thermal and mechanical demands. Following material validation, a customised bottom geometry was designed for each customer using computational fluid dynamics simulations, ensuring that every implementation was tailored to site-specific conditions. Full-bottom industrial trials were successfully carried out at two major Brazilian steelmakers. IBOS technology has proven to be a robust solution for increasing metal yield, shortening installation time, and reducing the carbon footprint of steelmaking operations.

Introduction

In the steelmaking industry, metal yield is a critical performance indicator directly linked to operational efficiency, cost competitiveness, and sustainability targets. During the final stage of ladle tapping in the secondary refining process, drainage is often compromised by vortex formation and drain sink phenomena. These effects cause slag to become entrained in the liquid steel stream (i.e., slag carryover). As soon as slag is detected—either visually or by sensor systems—the ladle gate must be closed immediately to prevent contamination of the tundish and mould. This early shutdown leaves a significant volume of steel inside the ladle. The consequences include metal yield loss, reduced productivity, increased steel slab costs, and considerable process waste.

In recent years, the use of precast blocks designed to replace conventional brick-based ladle bottoms has gained traction among major steel producers. Compared to traditional installation methods, this approach offers several advantages: Improved operational consistency, simplified and faster installation, and a reduced carbon footprint. At RHI Magnesita, this evolution was taken a step further with the development of the Improved Bottom Optimised Solution (IBOS)—a patented system that integrates a specially designed inclined ladle bottom composed entirely of high-performance precast modules.

Beyond ease of installation and environmental benefits, IBOS is designed to maximise metallic yield by reducing steel retention at the end of ladle tapping. Each implementation is customised using computational fluid dynamics (CFD) to match the customer's specific operating conditions. The system has been successfully introduced in the Brazilian market, supported by local production capabilities to ensure rapid and reliable delivery.

IBOS Technology

The IBOS technology represents a significant advancement in steel ladle bottom design, aimed at maximising metal yield at the end of tapping. The core of the solution lies in its redefined bottom geometry, which incorporates inclined planes and recessed areas to guide the steel flow more efficiently and delay the onset of vortex and drain sink formation—key phenomena that lead to premature slag carryover and residual steel retention.

Unlike conventional flat-bottom configurations, IBOS uses a sculpted surface composed of steps and slopes that create controlled flow paths toward the taphole. This surface is constructed using large precast refractory blocks and can be applied to both the working and permanent linings (Figure 1). Each IBOS bottom is tailored to the customer's

Figure 1.

Examples of the IBOS technology in (a) safety and (b) working linings.

(a)

(b)

operational parameters, taking into account ladle size, slide gate position, purging systems, and steel grades. Figure 2 illustrates the CFD simulated difference in residual steel at the end of tapping for a standard flat-bottom ladle and an IBOS-configured ladle.

A previously described study [1] used CFD simulations to evaluate the influence of bottom geometry on steel drainage. Four configurations were modelled: Flat, flat with a recessed box around the well block, inclined, and inclined with a recessed box around the well block. Among them, the inclined bottom with a recessed box—adopted as the foundation of the IBOS concept—proved most effective in reducing residual steel at the point of slag carryover. Figure 3 presents the residual steel levels obtained for each geometry. The inclined bottom with a recessed box (IBOS design) achieved a reduction of up to 70% in comparison to the flat-bottom baseline, demonstrating its superior drainage performance and yield optimisation potential.

Beyond yield improvement, IBOS offers additional process benefits. The inclined design reduces turbulence near the well block, protecting the filler sand and supporting full slide gate opening. Its modular structure allows for seamless integration with brick-lined zones using transition ramps. The result is a reliable, repeatable, and easy-to-install system that enhances steel recovery, improves operational safety, and reduces maintenance-related failures. By combining tailored engineering, optimised fluid dynamics, and fast precast installation, IBOS has established itself as a high-impact solution for steelmakers pursuing efficiency, sustainability, and process reliability.

Precast Engineering: Advanced Castable Formulated in Brazil

Implementation of the IBOS system in the Brazilian market required the development of a high-performance refractory castable produced locally. The goal was to significantly reduce lead times associated with importing precast blocks, while providing a technically reliable solution tailored to the operational demands of national steel plants.

To this end, an ultra-low cement vibrated castable was formulated using a hydraulic-ceramic bonding system with sintered alumina, spinel-forming additives, and metallic

Figure 3.

Residual steel in the ladle for various ladle bottom designs, based on CFD simulations [1].

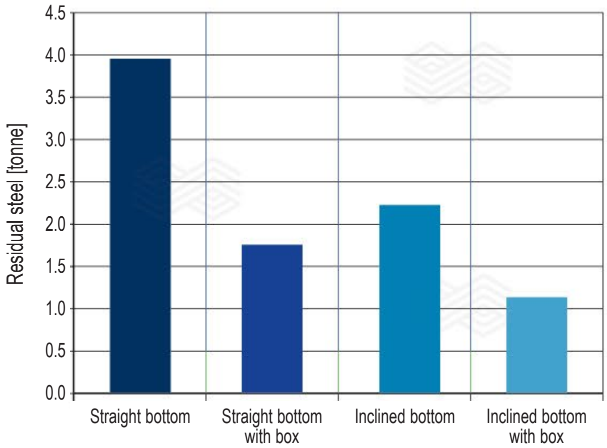
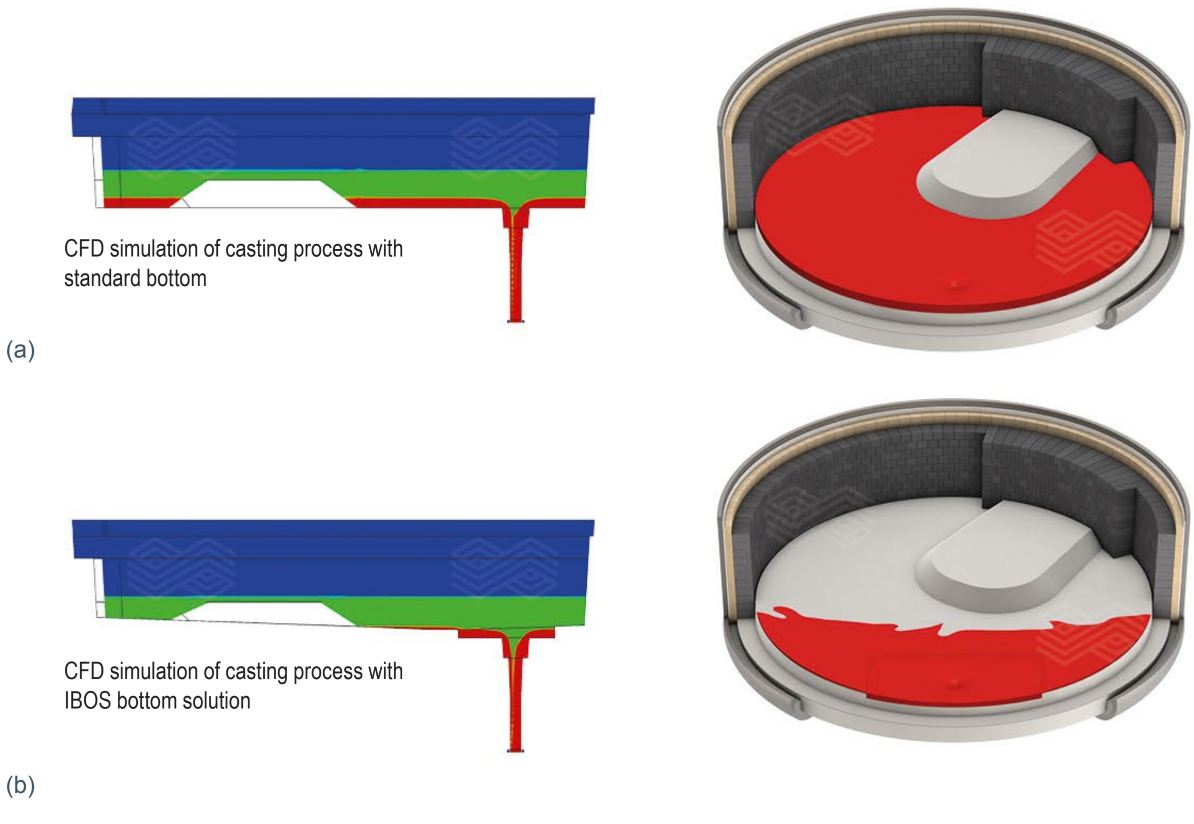


Figure 2.

CFD simulation of the residual steel (red) at the end of tapping for (a) standard and (b) IBOS ladle bottom designs.



fibres, referred to in this article as Brand A (3rd formulation). The combination of raw materials and additives was optimised to ensure high resistance to slag corrosion, liquid steel infiltration, and thermomechanical shock. The main properties of the material are summarised in Table I.

Corrosion resistance was evaluated in a rotary kiln at 1650 °C for 2 hours using a representative ladle slag from actual industrial operations. The developed castable showed an average wear rate of 1.87 ± 0.21 mm/hour, compared to 3.5 ± 0.87 mm/hour for a reference alumina-spinel castable tested under the same conditions.

Impact resistance was assessed using a standardised test carried out internally at RHI Magnesita's research centre in Contagem (Brazil). Test specimens were preheated to 1650 °C for 2 hours and then subjected to repeated impact cycles using a steel ball of defined mass dropped from a specified height. The observed performance was considered satisfactory in terms of crack resistance and structural stability.

The manufacturing process for the blocks includes producing the dry premix, wet mixing, vibrated casting, curing in the mould, demoulding, air curing, and final drying in a furnace.

Table I.

Chemical and physical properties of the Brand A castable developed for use in precast block applications.

Properties	Brand A (3rd formulation)
Al_2O_3 [%]	93.0
Fe_2O_3 [%]	0.1
SiO_2 [%]	0.8
CaO [%]	0.3
MgO [%]	5.0
Bulk density [g/cm³]	3.15
Apparent porosity [vol%]	12.0
Cold crushing strength [N/mm²]	80.0
Linear dimensional variation at 1500 °C [%]	+1.4

Initial validation of the castable formulation was conducted at a national industrial facility, referred to in this article as Plant A, over five ladle campaigns using precast blocks installed in the impact zone of the ladle bottom (dimensions: 1500 × 608 × 400 mm). The operational characteristics of the site are summarised in Table II.

In test 1, the 1st castable formulation showed low performance, with the campaign ending after 57 heats. During operation, visual inspections and a postmortem analysis at RHI Magnesita's research centre identified the main failure mechanisms as slag corrosion, slag infiltration, and spalling. Based on these findings, adjustments were made to the formulation.

In tests 2 and 3, using the 2nd formulation, performance improved significantly, reaching 166 and 175 heats, respectively. However, wear in the impact area remained the limiting factor. The predominant mechanisms were still slag infiltration and thermal spalling, prompting further modifications.

In tests 4 and 5, the 3rd formulation performed consistently. The ladles reached 182 and 180 heats, respectively, and were withdrawn from service due to scheduled rotation rather than wear, confirming the formulation's industrial suitability. Full results from these five campaigns are presented in Table III.

Table II.

Operational parameters of Plant A. Abbreviations include basic oxygen furnace (BOF), RH degasser (RH), and injection refining up temperature (IRUT).

Operational parameters	Plant A
Annual steel production [million tonnes]	7.2
Average ladle life [heats]	179
Ladle capacity [tonnes]	315
Average ladle utilisation [heats/day]	4.5
Primary refining route	BOF
Secondary refining route	RH, IRUT

Table III.

Test results with precast blocks in the impact area of the ladle bottom at Plant A.

Test	Castable formulation	Date	End life [heats[	Wear rate [mm/heat]	Potential (heats)
1	1st	May 2022	57	5.44	59
2	2nd	Dec 2022	166	1.93	166
3	2nd	Jul 2023	175	1.83	175
4	3rd	May 2024	182	1.47	217
5	3rd	Aug 2024	180	1.75	183

Figure 4 presents three photographic records representative of the operational performance of the precast block at Plant A. Figure 3a shows installation of the block in the impact area of the ladle bottom, while Figure 3b depicts the block after 31.5 hours of heating, having reached a final temperature of 1000 °C. In Figure 3c the block can be seen after 150 heats, demonstrating structural stability and no visible signs of damage.

Figure 5 shows the residual refractory thickness in the bottom region over the service life of the ladle in tests 4 and 5. Measurements were taken in hot conditions using laser scanning. The observed wear trend closely aligned with the operational conditions at Plant A, validating the 3rd castable formulation for the precast block and confirming that the campaign ended above the minimum residual safety thickness.

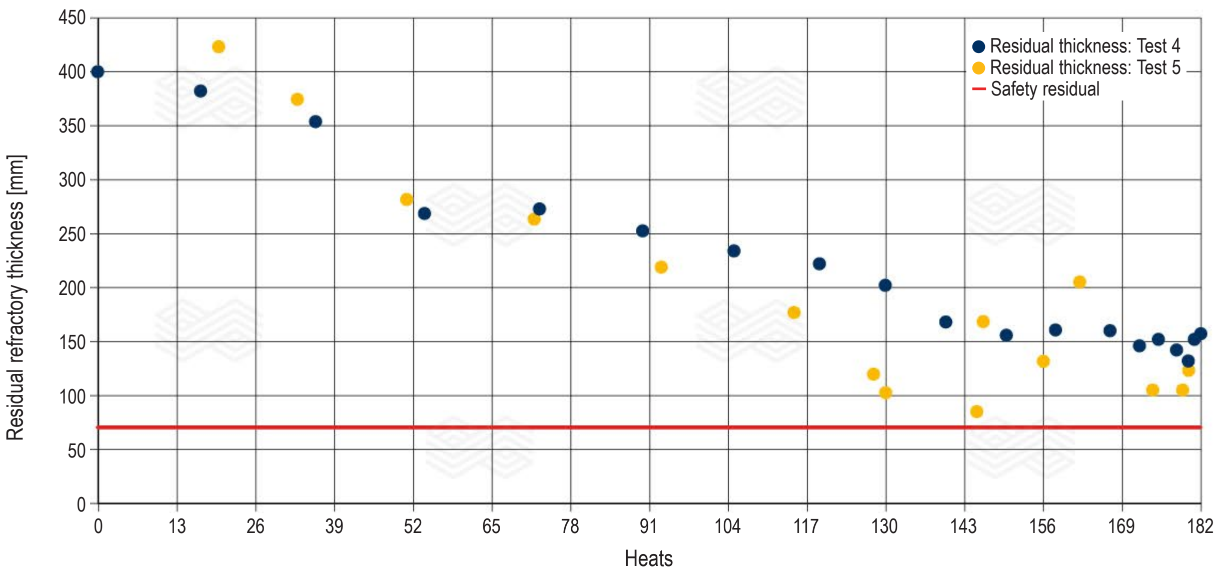
Figure 4.

Photographs of the precast block after: (a) installation, (b) post-heating condition, and (c) post-operation inspection after 150 heats at Plant A.

(a) (b) (c)

Figure 5.

Residual refractory thickness in the ladle bottom during operation in tests 4 and 5.



Postmortem analysis of samples taken from the block installed in the impact zone provided valuable insights into the wear mechanisms and structural stability of the material throughout the campaign. The micrographs reveal marked differences between the cold and hot faces of the refractory castable. On the cold face, a typical microstructure of the designed material was observed, with alumina sources and spinel formation clearly present within the ceramic matrix (Figure 6a). In contrast, the hot face showed significant slag and iron infiltration, which promoted densification of the microstructure and may have been the main factor contributing to refractory wear during the operational cycle (Figure 6b).

Custom Design via CFD: Tailoring Performance to Each Plant

Performance of the IBOS system is directly related to the efficiency of liquid steel drainage during the final stage of ladle tapping. To maximise metallic yield and ensure operational stability, the ladle bottom geometry must be tailored to the specific process conditions of each plant.

In this context, CFD has proven to be an essential tool for the development of customised IBOS designs.

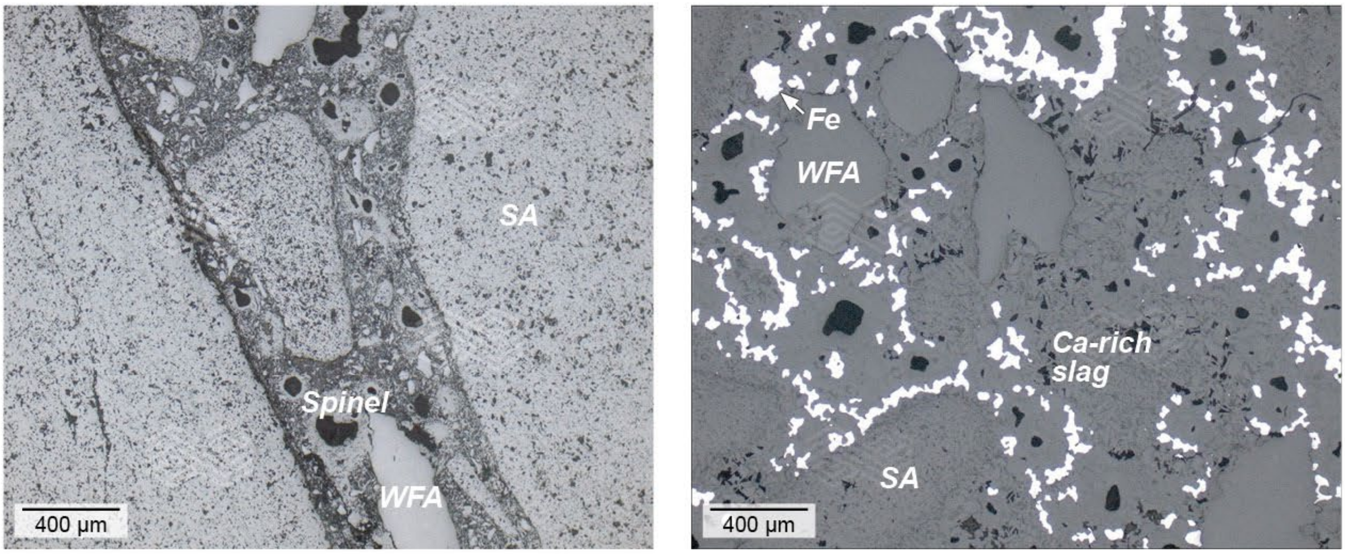
Using multiphase modelling with the Volume of Fluid (VOF) method and representative physical properties for liquid steel, slag, and air, it is possible to simulate flow behaviour and surface collapse. Parameters such as inclination angle, step height, and well block positioning are optimised to delay slag carryover and reduce the amount of residual steel at the end of ladle tapping.

In Brazil, CFD studies were conducted to evaluate full IBOS bottom designs in five major integrated steel plants. The operational characteristics of four of these units are shown in Table IV, while the fifth plant, Plant A, has already been described in Table II. Each case involved a comparison between the existing standard bottom and an optimised IBOS solution developed specifically for each plant.

The CFD methodology employed a multiphase VOF model to account for interactions between air, liquid steel, and slag phases. All simulations started from the same initial bath height and focused solely on the final drainage stage.

Figure 6.

Optical micrographs of postmortem samples taken from the block installed in the impact zone: (a) cold face and (b) hot face. Sintered alumina (SA), white fused alumina (WFA), MA spinel, and Fe infiltration are indicated.



(a) (b)

Table IV.

Operational characteristics of the steel plants evaluated in the CFD simulations. Abbreviations include ladle furnace (LF), RH degasser (RH), bottom stirring (BS), and composition adjustment by sealed argon bubbling-oxygen blowing (CAS-OB).

Operational parameters	Plant B	Plant C	Plant D	Plant E
Annual steel production [million tonnes]	2.5	3.2	3.1	2.4
Average ladle life [heats]	135	116	100	120
Ladle capacity [tonnes]	235	230	315	180
Average ladle utilisation [heats/day]	2.5	3.5	4.0	3.5
Primary refining route	BOF	BOF	BOF	BOF
Secondary refining route	LF, RH, BS	LF, RH	LF, RH	LF, RH, CAS-OB

Thermal effects were not considered. The computational meshes used were of the "poly-hexcore" type, with hexagonal elements concentrated in the core regions of the domain. The physical properties of the phases used in the CFD simulations are presented in Table V.

Based on the refractory designs provided by the plants, 3D models were created, the simulation domains defined, and the meshes generated. Figure 7 shows top views of the ladle bottoms used in the CFD comparisons and Figure 8 depicts the initial and final states of the simulation for Plant C.

Table V.

Physical properties of the phases used in the CFD simulations.

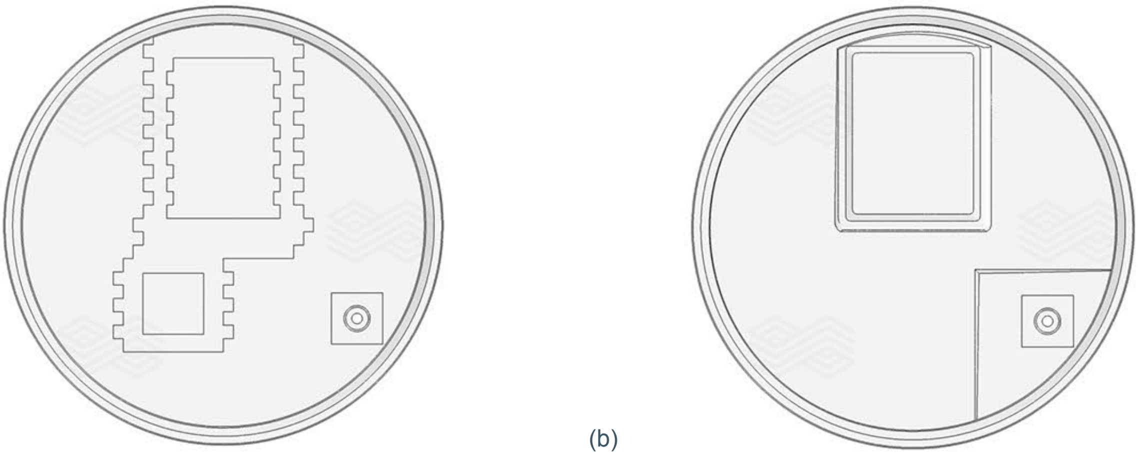
Physical property	Steel	Slag	Air
Density [kg/m^3]	7000	3000	1.225
Viscosity [kg/m·s]	0.005	0.5	0.000018

The collapse of the metal surface occurs as a drain sink, identified by a sudden change in density at the outlet of the simulated domain. At this point, the volume of residual steel can be estimated. The results of the simulations, including estimated steel savings achieved with the IBOS, are presented in Table VI.

The CFD results indicate that the IBOS system is capable of significantly reducing residual steel at the end of ladle tapping in all cases analysed. The simulated savings ranged from 0.586 to 2.210 tonnes per heat, while the relative reductions reached up to 74.6%. This demonstrates the system's effectiveness in scenarios with both high initial losses (e.g., Plant D with 3.20 tonnes of residual steel in the standard bottom) and more modest losses (e.g., Plant E with 0.786 tonnes of residual steel in the standard bottom).

Figure 7.

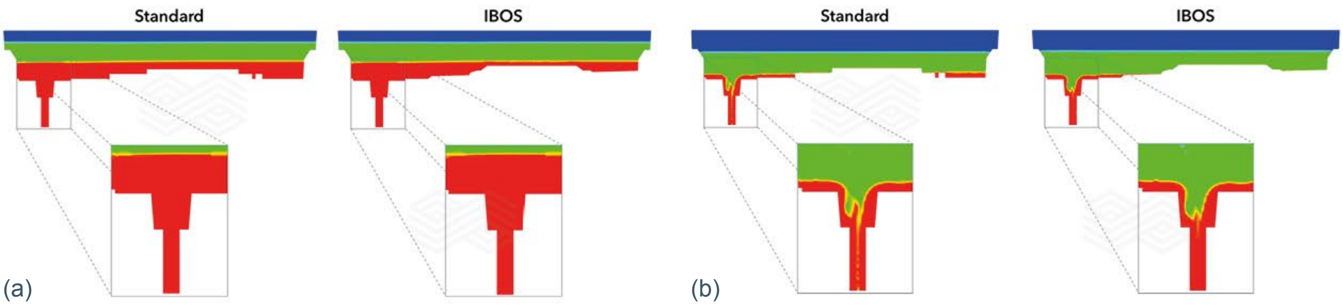
Top-view comparison of (a) standard and (b) IBOS bottom geometries used in the CFD simulation for Plant C.



(a) (b)

Figure 8.

(a) initial and (b) final states of the CFD simulation conducted for Plant C for the standard and IBOS bottom geometries.



(a) (b)

Table VI.

Comparison of the CFD simulated residual steel using standard and IBOS bottom geometries and estimated steel savings for Plants A–E.

CFD results	Plant A	Plant B	Plant C	Plant D	Plant E
Standard bottom residual steel [tonnes]	1.290	1.900	1.590	3.200	0.786
IBOS bottom residual steel [tonnes]	0.570	1.180	0.460	0.990	0.200
Steel savings [tonnes]	0.720	0.720	1.130	2.210	0.586
Steel savings [%]	55.8	37.9	71.1	69.1	74.6

Plant E achieved the best simulated performance, with a 74.6% reduction in residual steel, highlighting the potential of the IBOS technology even in operations that are already partially optimised. In contrast, Plant D stood out for its highest absolute gain, with simulated savings of 2.210 tonnes per heat, which represents a substantial economic impact on an industrial scale. Plant C also showed remarkable performance, with a reduction of 1.130 tonnes of residual steel and a relative improvement of 71.1%, reinforcing the robustness of IBOS across different bottom geometries and operational practices. Plants A and B had predicted savings of 0.720 tonnes each, with relative reductions of 55.8% and 37.9%, respectively. The lower percentage reduction simulated for Plant B may be attributed to a previously efficient stepped bottom configuration, although the absolute gain remains significant.

Figure 9 provides CFD generated visual representations of the remaining steel at the end of ladle draining for Plant E, highlighting the improved efficiency of the IBOS design.

IBOS Trials in Brazilian Steel Plants

The industrial validation of the IBOS technology was carried out in two prominent Brazilian steel plants, referred to in this article as Plant B and Plant C. The objective of the trials was to assess the practical application of the IBOS full-bottom geometry, focusing on key operational aspects such as installation time, structural stability, wear patterns, process integration, and efficiency of liquid steel drainage.

The evaluations were structured in progressive stages with technical monitoring under real industrial conditions, including visual inspections, laser measurements in hot conditions, postmortem inspections, and qualitative assessment of steel draining efficiency. Both plants operate at high production volumes with severe refractory wear demands, providing robust and representative validation data.

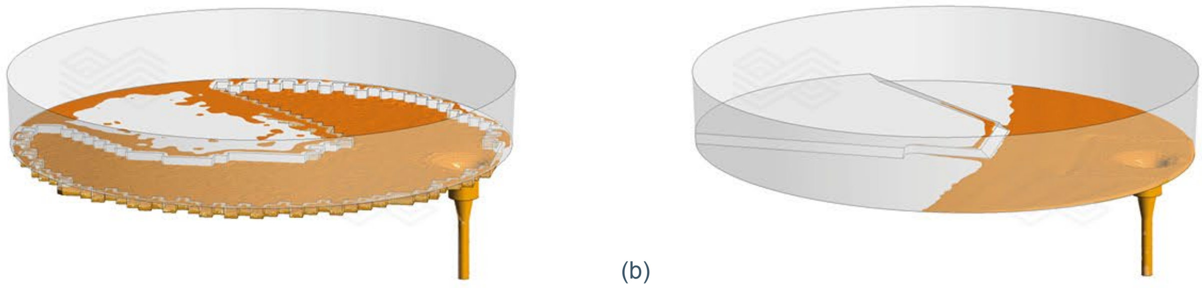
Plant B

At Plant B, the trial was conducted in two stages. The first involved the installation of a small precast block in the impact zone, aiming to validate the wear rate previously observed at Plant A. The second stage consisted of implementing the full IBOS bottom.

In the first stage, a block with dimensions of 608 × 400 × 380 mm was installed in January 2024, operated throughout the same month, and removed in February, completing a 30-day campaign at an average rate of 4.5 heats per day. A total of 135 heats was reached without any repairs being required. The final residual thickness was 127 mm, corresponding to an average wear rate of 2.02 mm per heat and a projected service potential of up to 168 heats. Figure 10 presents photographic records of the impact zone trial, showing the installation, post-heating condition, and the block status after 135 heats.

Figure 9.

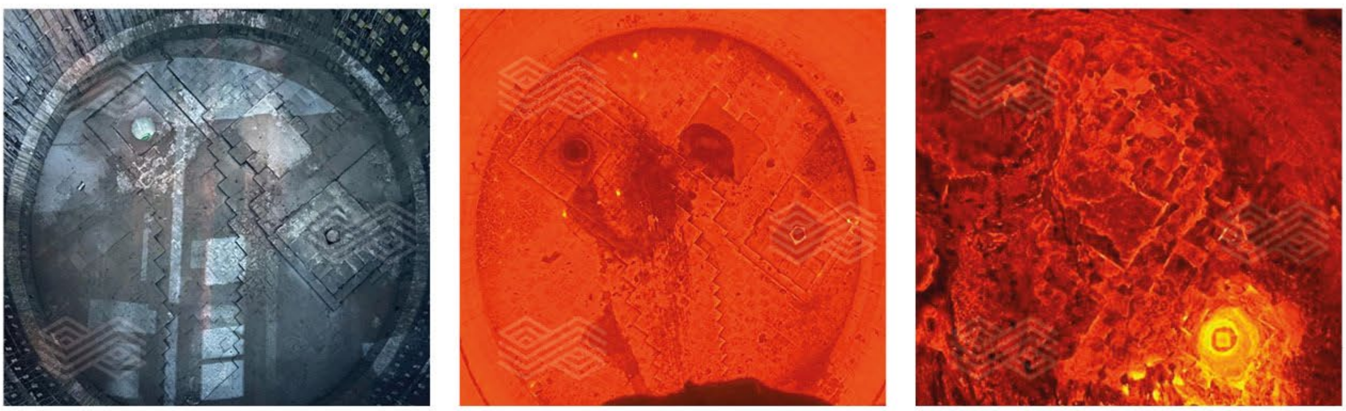
CFD visualisations of residual steel at the end of ladle draining: (a) 786 kg for the standard bottom and (b) 200 kg for the IBOS bottom design at Plant E.



(a) (b)

Figure 10.

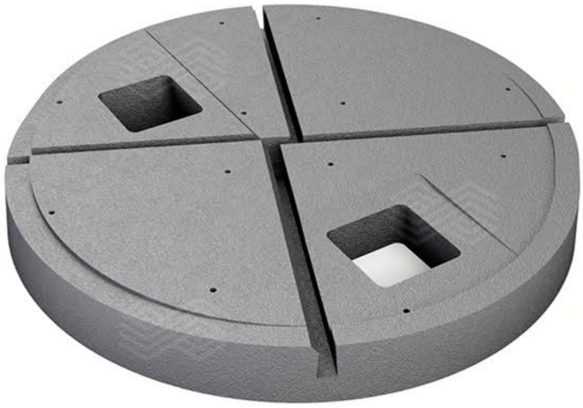
Photographs of the precast block in the impact zone after: (a) installation, (b) post-heating condition, and (c) after 135 heats at Plant B.



(a) (b) (c)

The second stage involved installation of the complete IBOS bottom. A schematic representation of the implemented layout is shown in Figure 11. The installation was carried out in October 2024 and resulted in a significant reduction in ladle bottom installation time, namely in 4 hours and 15 minutes, with clear potential for further optimisation. The process was deliberately executed in a step-by-step manner, without parallel activities, as it was the first IBOS bottom installation in Brazil. This approach allowed detailed monitoring of each stage, providing valuable insights for future implementations at this and other facilities. For comparison, RHI Magnesita's standard bottom design is typically installed in 6 hours, while a conventional competitor's design requires approximately 10 hours. Figure 12 documents the installation sequence of the IBOS precast blocks at Plant B.

Figure 11.
Schematic representation of the full IBOS bottom design developed for Plant B.



Operation began in October 2024, and the campaign ended in November 2024 after 87 heats. The shutdown was carried out to replace the seat blocks and inspect the bottom. Upon access to the ladle bottom, a large amount of scale was found adhered to the surface, requiring removal using oxygen lances and mechanical cleaning with a grab, which resulted in partial castable detachment. Figure 13 shows photographic records of the ladle operation during the campaign, with images after heating, 20 heats, and 84 heats.

Figure 12.
Step-by-step installation (a–d) of the four precast IBOS blocks at Plant B.

(a) (b) (c) (d)

Figure 13.
Photographs from a campaign with the full IBOS bottom after: (a) heating, (b) 20 heats, and (c) 84 heats at Plant B.

(a) (b) (c)

Plant C

Building on the experience accumulated from trials at Plants A and B with smaller impact zone blocks, Plant C proceeded directly to testing the full IBOS bottom. A schematic representation of the implemented layout is shown in Figure 14. Installation took place in October 2024 and was completed in just 1 hour and 15 minutes. By comparison, routine bottom installation at this plant typically takes around 7 hours. Figure 15 documents the installation sequence of the IBOS precast blocks at Plant C.

Operation began in October and concluded in November 2024, totalling 100 heats. To assess the impact of the IBOS geometry on steel draining efficiency, the plant implemented the following mass balance methodology:

Figure 14.

Schematic representation of the full IBOS bottom design developed for Plant C.

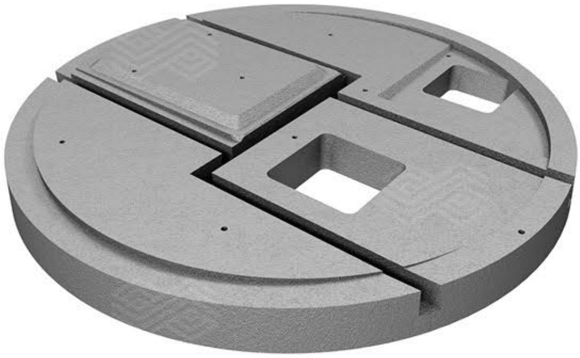
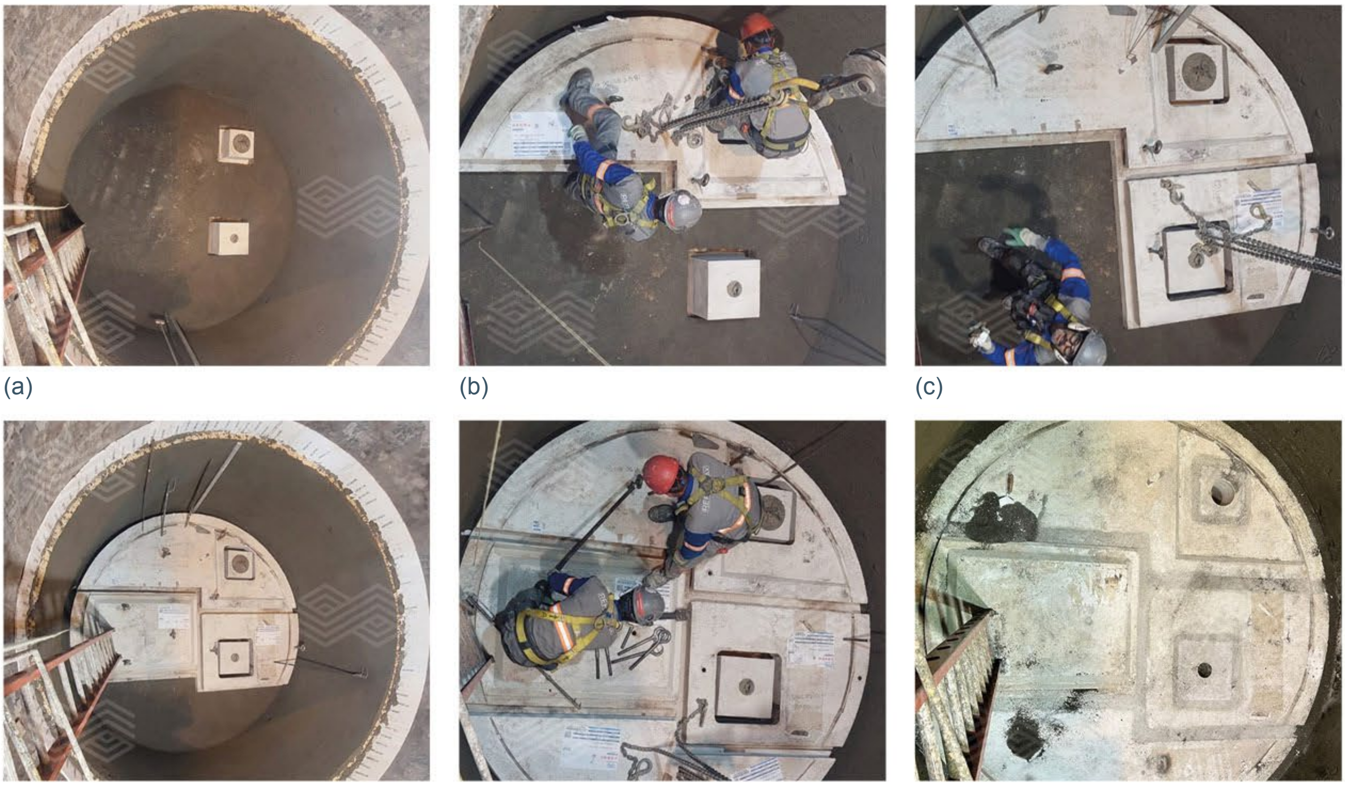


Figure 15.

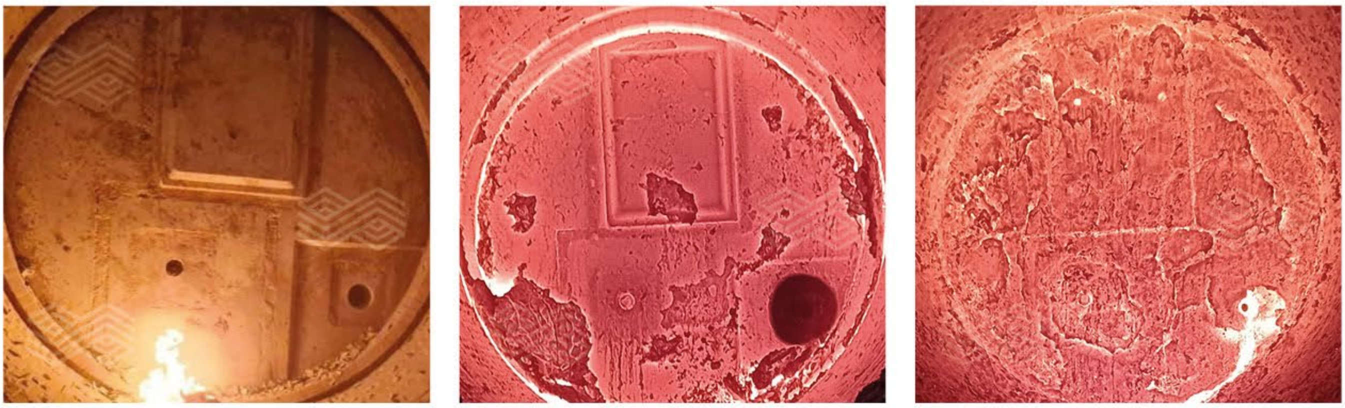
Step-by-step installation (a–f) of the four precast IBOS bottom blocks at Plant C.



(a) (b) (c) (d) (e) (f)

Figure 16.

Photographs of a campaign with the full IBOS bottom after: (a) heating, (b) 3 heats, and (c) 97 heats at Plant C.



(a) (b) (c)

- The ladle was weighed before and after draining using a load cell installed on the overhead crane.
- The slag mass per heat was estimated using RHI Magnesita's Ladle Slag Model software, which performs mass balance calculations based on the specific operational conditions of each heat.

From these data, it was possible to estimate the amount of residual steel remaining at the end of casting. The ladle equipped with the conventional bottom recorded an average of 1.98 tonnes of residual metal per heat, while the IBOS equipped ladle averaged only 1.51 tonnes. This reduction of 0.47 tonnes represented a 23.7% improvement in drainage efficiency attributed to the IBOS geometry. Figure 16 shows photographs of the ladle operation throughout the campaign, with images after heating, after 3 heats, and near the end at 97 heats.

Results

One of the most significant outcomes of the IBOS implementation is the improvement in occupational safety and ergonomics. Conventional ladle bottom installation requires the manual handling of hundreds of refractory bricks, involving elevated ergonomic demands due to the positioning and installation of components at the bottom of the vessel. With the IBOS, this task is replaced by the installation of only four precast refractory blocks per ladle, all positioned using an electric hoist, thereby eliminating direct manual handling by operators. As a reference, Plant C traditionally requires the handling of 580 bricks per bottom, while Plant B requires up to 844 bricks. With an average weight of 12.6 kg per brick, the ergonomic load is substantial. The use of the IBOS bottom contributes directly to long-term occupational health.

From a sustainability perspective, the IBOS technology also offers advantages in refractory material selection. Unlike conventional bricks, the IBOS blocks are formulated without carbon. This results in a quantifiable reduction in carbon usage—approximately 0.50 tonnes per ladle at Plant C and 0.72 tonnes at Plant B. Figure 17 presents the estimated annual carbon savings at plants B and C, if they were to fully adopt the IBOS technology. These estimates were derived from the data provided in Table IV:

- The number of annual heats was calculated by dividing the annual steel production by the average ladle capacity.
- The number of ladles used per year was estimated by dividing the number of annual heats by the average bottom campaign life.
- Finally, the number of ladles was multiplied by the carbon savings per ladle (0.72 tonnes for Plant B and 0.50 tonnes for Plant C), resulting in the estimated annual savings for each plant.

The IBOS also shows significant improvements in installation efficiency. Figure 18 compares the installation times required for the IBOS technology versus standard solutions from RHI Magnesita and a typical competitor. In both evaluated plants, the IBOS configurations reduced installation time by more than 29%, with a maximum reduction of 82% observed at Plant C. These improvements directly contribute to reduced downtime and increase flexibility in operational planning.

In addition to operational efficiencies, the IBOS geometries have demonstrated measurable gains in metal yield. At Plant C, steel drainage efficiency was quantified using load cell measurements from the overhead crane—recorded before and after ladle dumping at the end of casting—and slag mass estimates generated by the Ladle Slag Model software, developed by RHI Magnesita and implemented at the plant. The analysis revealed that the ladle equipped with the IBOS technology retained 0.47 tonnes less steel per heat compared to the standard configuration. This corresponds to a 23.7% improvement in liquid steel drainage efficiency. When extrapolated to the plant's annual

Figure 17.

Estimated annual carbon savings at Plants B and C if the IBOS technology was fully implemented.

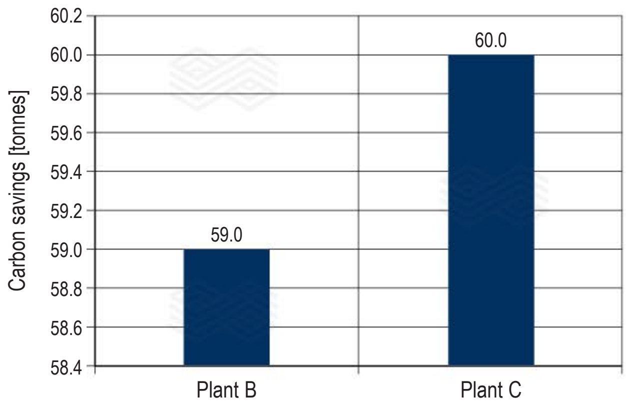
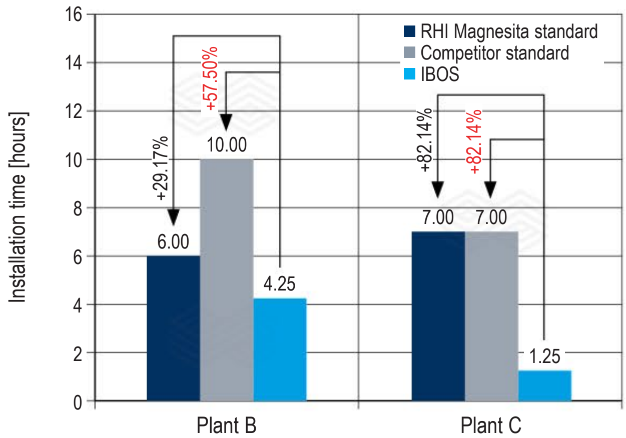


Figure 18.

Comparison of ladle bottom installation times required for the IBOS technology versus standard solutions from RHI Magnesita and a typical competitor at Plants B and C, as well as the percentage reductions achieved with the IBOS configurations.



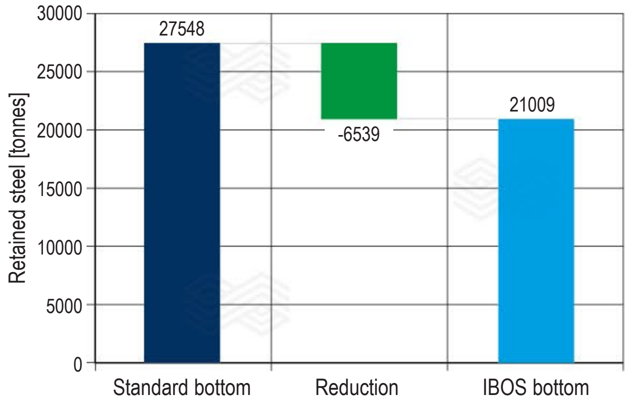
capacity—estimated at 13913 heats based on data from Table IV by dividing annual steel production by ladle capacity—the cumulative steel savings could reach approximately 6539 tonnes per year. Figure 19 summarises these results.

Conclusion

The IBOS technology was developed by RHI Magnesita to maximise metal yield in secondary refining ladles by minimising residual steel at the end of tapping. The system features a fully precast, high-performance refractory bottom, with the geometry customised for each site using CFD simulations to ensure optimal performance under plant-specific conditions. The results presented throughout this study consistently and comprehensively demonstrate the effectiveness of the IBOS as an innovative and strategic refractory solution for improving metallic yield, operational safety, ergonomics, and carbon reduction in steel ladle operations.

Figure 19.

Annual reduction of retained steel using the IBOS technology at Plant C.



CFD simulations were fundamental in developing customised geometries, enabling the evaluation of various configurations and confirming the superior performance of the IBOS compared to conventional designs, with estimated reductions in residual steel reaching up to 75% in some cases. This modelling phase was essential for establishing a data-driven, technical approach tailored to the specific conditions of each plant.

Industrial trials conducted at Plants B and C validated the concept at full scale. A key outcome was the substantial reduction in installation time, which exceeded 80% in some scenarios. More importantly, this reduction translated into measurable ergonomic and safety benefits. The conventional manual process of placing hundreds of individual refractory bricks was replaced by the precise installation of only four large precast blocks, all handled via electric hoist. This eliminated repetitive manual lifting tasks, reduced operator exposure, and improved overall working conditions.

Among the most relevant financial return results, the steel savings of 0.47 tonnes per heat observed at Plant C stand out. This figure represents a 23.7% improvement in liquid steel drainage efficiency compared to the conventional bottom previously in use. When projected over the plant's annual number of heats, this gain results in cumulative savings of approximately 6500 tonnes of steel per year, directly impacting productivity, reducing metallic losses, and recovering economic value.

Additionally, the use of the IBOS bottom contributes to a reduction in the consumption of carbon-based refractory materials. The total estimated reduction in carbon usage reached 60 tonnes per year at Plant C, reinforcing the alignment of this solution with the steel sector's decarbonisation objectives.

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Bulletin

The Journal of Refractory Innovations

2025

Published by RHI Magnesita GmbH, Vienna, Austria
Chief Editor Thomas Prietl
Executive Editors Rodrigo Nazareth Borges, Celio Carvalho Cavalcante, Thomas Drnek, Christoph Eglsäer, Celso Freitas, Thomas Frömmer, Harald Hotwagner, Alexander Leitner, Ben Markel, Eduardo de Matos, Ravikumar Periyasamy, Martin Pischler, Stefan Postrach, Jürgen Schmiedl, Peter Steinkellner, Hang Ye, Karl-Michael Zettl, Barbara Zocratto
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Technical Proofreader Clare McFarlane
Lingual Proofreader Clare McFarlane
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