ESSAYS

Novel redesign of welded pressure leach autoclaves for the platinum industry

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The base metals refinery of a major platinum producer in South Africa refines converter matte-containing base metals and platinum group metals (PGMs) using a five-stage hydrometallurgical process. The second-stage leach produces a PGM-rich residue through the extraction of copper and any remaining base metals from the first-stage leach solid residue material.

Leaching is performed in a high-pressure autoclave, under highly oxidising conditions in a concentrated H_2SO_4 solution at a temperature of 150 °C. The original design utilised a heavy-walled carbon steel shell with lead lining and two layers of acid bricks. These autoclaves were heavy, maintenance-intensive and prone to catastrophic failure. A radical redesign using duplex SAF 2205 stainless steel[1] was proposed, eliminating the need for lead and brick lining and substantially reducing the wall thickness requirements. The first duplex stainless steel unit has been in continuous operation for more than 78 months.

Background

Impala Platinum Limited (Implats) is one of the world's leading producers of PGMs, with operations in the Bushveld Complex in South Africa and the Great Dyke in Zimbabwe. The Implats Base Metals Refinery (BMR) processes ore that contains base metals and PGMs supplied to the refinery in the form of converter matte. At the BMR, five separate leaching steps are used to refine the matte, yielding a PGM-rich concentrate (which is processed further at the platinum metals refinery), nickel in briquette or powder form, copper cathodes and cobalt powder.

The second-stage leach process at the BMR produces a PGM-rich residue through the extraction of copper and any remaining base metals from the first-stage leach solid residue material. The PGM-rich residue is further processed in the third-stage leach. The second-stage leaching process is performed in autoclaves operating at a design pressure of 1070 kPag and a temperature of between 120 and 140 °C. Concentrated H_2SO_4 is added to the feed to produce a solution with a free-acid content. Oxygen is passed into the first and second compartments of the autoclave.

As a result of the aggressive, highly oxidising conditions in the autoclave, the original autoclave design for the second-stage leach utilised a three-layer configuration, consisting of a heavy carbon steel shell (with a wall thickness of 40 mm), a lead lining and two layers of acid bricks. The bricks acted as a wear-resistant material and ensured a low surface temperature at the skin of the lead lining, whereas the lead lining acted as a corrosion barrier to protect the steel shell from acid corrosion.

The bricks were layered with mortar to ensure that they were held firmly in position, while preventing the penetration of the corrosive solution between the bricks. The total thickness of the lead lining and the two layers of bricks was between 200 and 250 mm. The bricks and the lead lining, if damaged, had to be replaced immediately, as contact between the acidic solution and the carbon steel shell resulted in rapid corrosive attack. The autoclave also utilised a vertical partition wall made up of two brick layers, which created four buffer zones (compartments) for the different stages of the process. An agitator was installed inside the autoclave, which increased the leach efficiency. During the agitation process, vibrations were created in the autoclave shell, which could cause damage to the bricks and liners.

Vessels of this type had become the industry standard for this application and had been in use in the platinum industry for many years.

Limitations of the original autoclave design

The original second-stage leach autoclave design exhibited several

1. SAF 2205, also known as Sandvik SAF 2205, is a Sandvik-owned trademark for a 22Cr duplex (ferritic-austenitic) stainless steel. SAF derives from Sandvik Austenite Ferrite.

Installation of the completed second-stage leach autoclave at the BMR in June 2007.

problems that caused reduced productivity levels and efficiency in operation. The main concerns were the following:

- The autoclaves required extensive maintenance due to bricks collapsing at the nozzles and partition walls, necessitating frequent maintenance intervals to avoid the deterioration of the main shell, and underperformance due to the collapse of the partition walls.
- As a result of frequent collapses, the brick composite material contaminated the final product, further reducing productivity.
- Each vessel was costly to manufacture and required a substantial capital investment.
- The duration of manufacture was lengthy. This was further exacerbated by the need to have the brick lining installed in situ.
- Due to the heavy design of the autoclave, heavy lifting equipment was required. This increased the installation costs of the vessel.
- Bricklaying involves manpower working in confined spaces under hazardous conditions, thus necessitating the implementation of special precautions, the use of breathing apparatus and special equipment to comply with the Occupational Health and Safety Act and other statutory requirements.
- Workers installing the lead lining were exposed to extremely hazardous conditions. The use of lead is governed by specific regulations, and is restricted in several countries around the world. South Africa has promulgated Lead Regulations that control the use and application of lead in the National Occupational Health and Safety Act.
- When the vessel is decommissioned, strict procedures have to be adhered to when disposing of it. Due to the heavy weight of the autoclave and the brick lining, it is not feasible to lift the vessel as a whole unit. The bricks have to be removed, and the vessel has to be rotated and heated above the melting point of lead to allow the molten lead to flow out through the nozzles. This required a specialised and highly skilled workforce.
- Since the brick lining tends to swell, it was essential to ensure that the manufacturer maintained strict out-of-round control so that the permissible tolerances were not exceeded. It was common to have 0.5% out-of-round on the brick lining, whereas the code of construction on pressurised equipment limited the out-of-round to 1% of the diameter size. This necessitated additional manufacturing jigs, spiders and temporary bracing to maintain circularity within permissible tolerances.
- The vessel has four compartments with a large agitator to mix the product. It was common for this agitator to have a run-out that induced vibrations, thus weakening and cracking the mortar and causing the brickwork to collapse.
- The vessel had to be placed on a heavy foundation that would withstand the weight of the shell, lead lining and the two layers of brick linings.

Finding an innovative solution

The solution that had to be found would have to be one that would ensure the safety of personnel on the

Table 1: The typical chemical composition of SAF 2205 (weight percentage, balance Fe)

Chromium (Cr)	Nickel (Ni)	Carbon (C)	Manganese (Mn)	Silicon (Si)	Nitrogen (N)	Molybdenum (Mo)
21–23%	4.5–6.5%	0.03 max	2.0 max	1.0 max	0.08–0.20	2.5–3.5

plant, limit pollution and environmental degradation at the end of the vessel's operating life, provide cost-saving advantages throughout the life cycle of the vessel and yield an autoclave design that is easy to operate and maintain.

Available literature suggested the use of titanium, titanium clad or superduplex stainless steel autoclaves as alternatives to brick and lead-lined autoclaves in applications involving long-term exposure to operating conditions similar to those in the second-stage leach autoclave at the BMR. These materials are, however, expensive, difficult to fabricate and often not readily available. The use of a more general-purpose duplex stainless steel, known as SAF 2205, but also referred to as EN 1.4462 (according to EN 10088 and EN 10028[2]) and S31803 (according to ASTM A240[3]), was therefore investigated. SAF 2205 is a highly alloyed duplex stainless steel of Swedish origin, with a typical chemical composition as shown in Table 1.

SAF 2205 displays excellent corrosion resistance in a wide range of environments, resists localised corrosion, is highly resistant to intergranular corrosion and is not susceptible to chloride stress corrosion cracking. It has a hardness of 8 on the Mohs scale[4]. SAF 2205 stainless steel is a high-strength alloy, with a typical yield strength of 520 MPa and an ultimate tensile strength of 760 MPa. For comparison purposes, the brick lining used until recently at the BMR has a typical hardness of Mohs 9, but without any tensile mechanical strength. SAF 2205 material is readily available, and has a dual-phase ferritic-austenitic structure, which ensures the good mechanical properties and excellent corrosion resistance required in this application.

Samples of SAF 2205 and a lower-alloyed AISI 316 ℓ stainless steel[5] were placed into an original second-stage leach autoclave in a region of the partition wall where the agitating effect was at a maximum. The AISI 316 ℓ stainless steel samples rapidly deteriorated in this environment, which is in agreement with available literature. However, the SAF 2205 samples did not show any evidence of wear or chemical attack. This suggested that SAF 2205 is compatible with the environment inside the second-stage leach autoclave.

Redesign of the second-stage leach autoclave

On completion of the successful in situ trials, the second-stage leach autoclave was completely redesigned using SAF 2205 duplex stainless steel as construction material. This design takes into consideration the recent improvements in technology in duplex stainless steel products. The newly designed autoclave does not require any lead or brick lining, and the first installed vessel has already been in continuous operation for more than 78 months (with one minor design change to the partition walls). The main advantages of the newly designed autoclave are that downtime is minimised, allowing for reduced maintenance servicing, working volume is increased substantially, which minimises batch-time processing and increases the output of the plant, and the internal components can be easily adjusted according to process requirements.

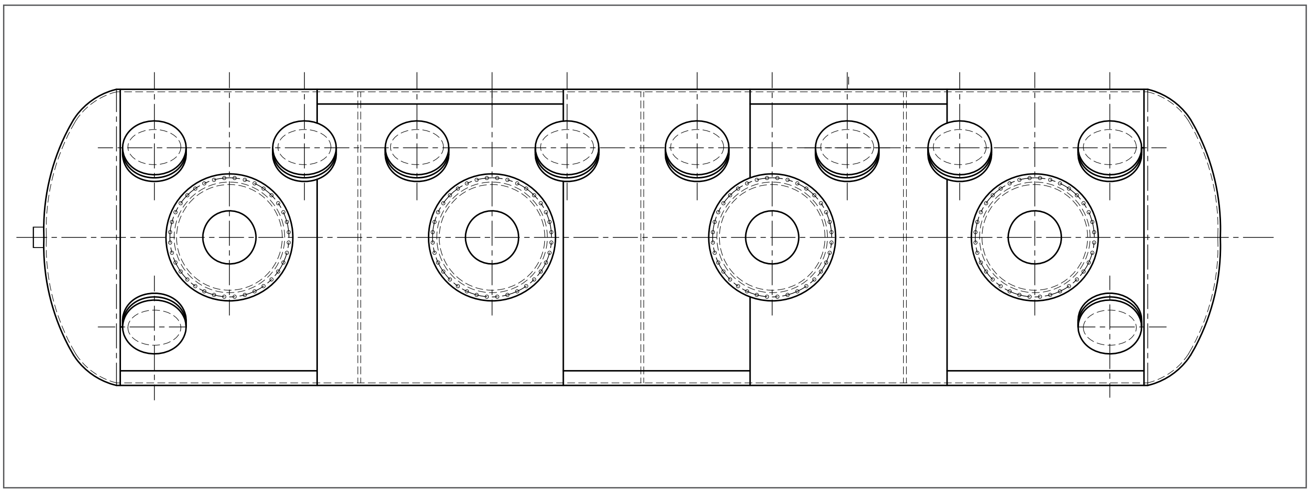
The product, the adjustable internal baffles and the agitators have been patented, in addition to a registration deed for the utilisation of duplex materials without the need for additional brick layers (which would have been necessary as a corrosion barrier in the conventional autoclave design). Table 2 compares the brick-line autoclave (old) to the solid SAF 2205 (new), in terms of weight and the effecient working volume of the vessels, which are from the same outer dimensions.

The vessel shell is manufactured from SAF 2205 plates, which are formed in circular sections, assembled in an abutting end-to-end arrangement and welded to form an elongated cylindrical body. The plates are stepped and welded in a staggered array to increase rigidity and to avoid a continuous circumferential seam.

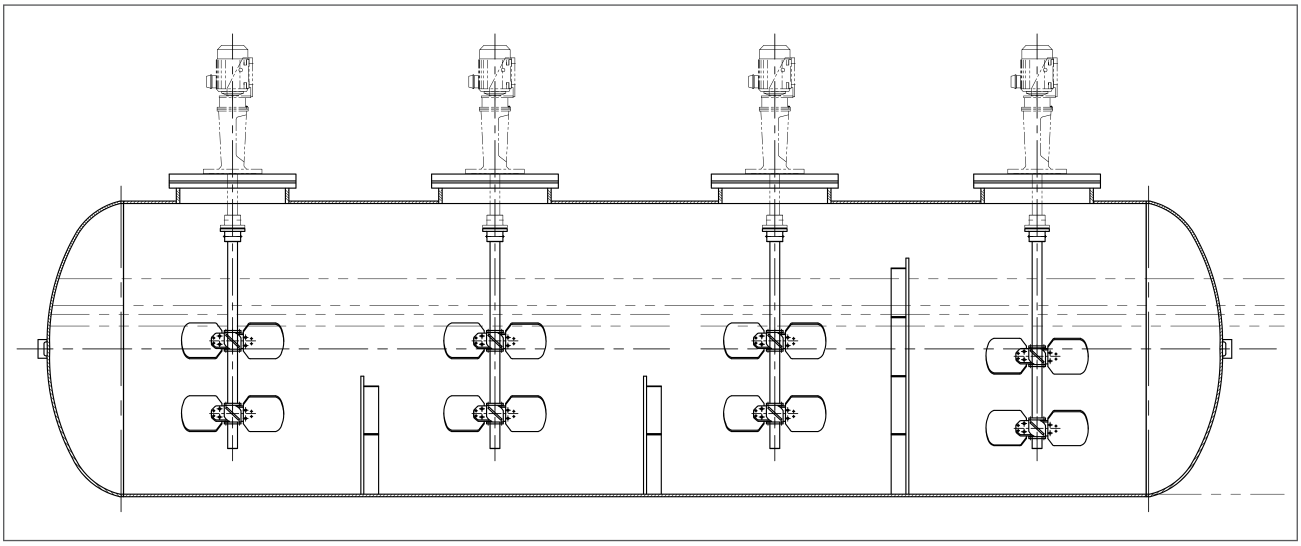
Table 2: Comparison of brick-lined and SAF 2205 autoclaves

Property	Brick autoclave	SAF 2205 autoclave
Construction material	BS 1501–1510430A	SAF 2205
Before bricking		
Shell thickness	40 mm upper 25 mm lower	22 mm throughout
Dish head thickness	25 mm	16 mm
Brick lining	Yes	N/A
Lead	Yes	N/A
After bricking		
Pass partition width	345 mm brick	30 mm SAF 2205
Vessel weight (empty)	83 620 kg	19 183 kg
Working volume	53.70 m^3	78.58 m^3

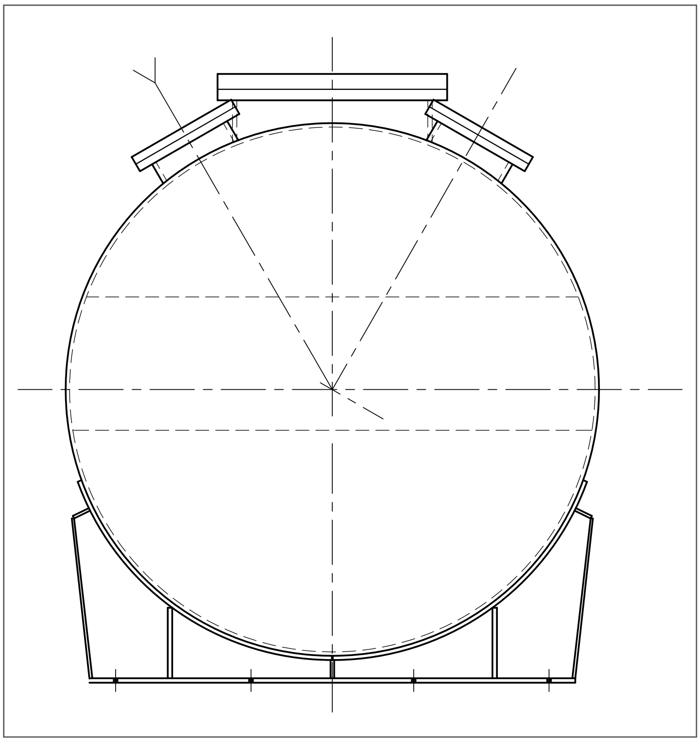
2. EN refers to the European Standards, developed by the European Committee for Standardization (CEN).
3. Standards developed by ASTM International, formerly known as the American Society for Testing and Materials (ASTM).
4. A scale developed by German mineralogist Friedrich Mohs to compare the hardness or scratch resistance of minerals.
5. A standardisation system developed by the American Iron and Steel Institute (AISI).



→ *Figure 1: Top view of the redesigned second-stage leach autoclave*



→ *Figure 2: Autoclave with agitators*



→ *Figure 3: Side view of the redesigned second-stage leach autoclave*

Strict quality control was maintained during all stages of fabrication. The dished ends were hot-formed and welded to the cylindrical body to form the vessel. Several manhole and nozzle openings were included for access and for connections to the process piping. The nozzles were hot-formed and welded to the vessel body using partial penetration fillet welds. Figure 1 shows the top view of the autoclave. Figure 2 is an elevation drawing, and Figure 3 is a side view.

A number of internal baffles with adjusting of baffle height based on process requirements were installed in order to generate compartments. Hydrofoil agitators were installed to ensure proper mixing during the leaching process. The agitator profile has been optimised regarding performance and energy consumption. The outer diameter of the blades are smaller than the agitator nozzle, which enables removing of the entire agitator through the flange without the need of dismantling in the autoclave.

Finite Element Method (FEM) analysis was carried out for all the components subjected to cyclic stresses to demonstrate the integrity of the elements and to prove that the operating stresses in the shell and other elements do not exceed the maximum permissible stresses allowable for the construction material.

Benefits of the new autoclave design

After more than 78 months in service in the same environment and under the same operating conditions as used for the original brick and lead-lined autoclaves, the first solid duplex stainless steel autoclave showed no signs of corrosion and the leaching process proceeded normally. The throughput was, however, significantly increased due to the larger open volume in the autoclave. The elimination of the brick lining also removed the risk of brick collapse as a result of the agitation action. The maintenance requirements of the newly designed vessels were substantially reduced.

In the older version of the autoclave, the use of lead substances made for a hazardous and dangerous working environment. Eliminating the use of lead in the redesigned autoclave therefore provides for a safer working environment during the manufacture of the vessel, as well as for plant operators, and also during disposal of the vessel at the end of its operating life.

Furthermore, from an environmental point of view, toxic and harmful lead substances have been eliminated and replaced with more environmentally sustainable duplex stainless steel. The new material ensures a longer lifespan owing to the fact that the duplex stainless steel is resistant to corrosion in the solution used in the leach process.

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