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Novel redesign of a pressure leach autoclave by a South African platinum producer

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Novel redesign of a pressure leach autoclave by a South African platinum producer

Abstract

The Impala Platinum Limited Base Metals Refinery in Springs, South Africa, refines convertor matte containing base metals and PGM's (platinum group metals) using a hydrometallurgical process. In addition to a PGM-rich concentrate that is further refined, the Base Metals Refinery produces nickel (in powder or briquette form), copper cathodes and cobalt powder. Five leaching stages are utilized to remove the base metals and impurities from the PGM concentrate. The project described in this paper involves a radical redesign of the second stage leach autoclave with the aim of reducing maintenance costs and downtime, increasing throughput and ensuring a safer working environment.

The second stage leach process at the Base Metals Refinery, 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 an autoclave operating at a pressure of 600 kPaG and a temperature of 140°C to 150°C. Concentrated H₂SO₄ is added to the feed to produce a solution with a free acid content between 10 and 30 g/L and a pH of less than 2. Oxygen is passed into the 1st and 2nd compartments of the autoclave.

As a result of the aggressive, highly oxidizing conditions within the autoclave, the original design utilized a heavy wall carbon steel shell with 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. These brick lined autoclaves were heavy, maintenance intensive and prone to catastrophic failure.

A radical autoclave redesign was needed to reduce the high costs of manufacturing, installation and operation. Finite element modelling was used to optimize the design and various high alloy materials were investigated for the application. Based on extensive test work, the carbon steel shell was replaced with duplex SAF 2205 stainless steel in the new design. The use of this highly corrosion resistant material, eliminates the need for the lead and brick linings and reduces the wall thickness requirements substantially, resulting in an increase in the available volume for the same external shell dimensions. The vessel is welded in circular sections to form an elongated, impermeable, cylindrical body, with several agitator nozzles and compartments.

The first new duplex stainless steel unit has been in continuous operation for more than 24 months and its performance has exceeded the highest expectations. The design was so successful that a patent has been registered. The major benefits of the new stainless steel design include increased throughput, improved performance, less downtime and a safer working environment. Lead has been eliminated and replaced with a more environmentally safe material, and the total lifespan of the vessel has been extended. In addition, the autoclave project has made significant developments in advancing the field of welding and optimizing the integrity of welding quality standards in South Africa.

Keywords

platinum, african, south, autoclave, pressure, producer, leach, novel, redesign

Disciplines

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Novel redesign of a pressure leach autoclave by a South African Platinum producer

by J.O. Roux*, M. du Toit†, and D. Shklaz‡

Synopsis

The Impala Platinum Limited Base Metals Refinery in Springs, South Africa, refines convertor matte containing base metals and PGM's (platinum group metals) using a hydrometallurgical process. In addition to a PGM-rich concentrate that is further refined, the Base Metals Refinery produces nickel (in powder or briquette form), copper cathodes and cobalt powder. Five leaching stages are utilized to remove the base metals and impurities from the PGM concentrate. The project described in this paper involves a radical redesign of the second stage leach autoclave with the aim of reducing maintenance costs and downtime, increasing throughput and ensuring a safer working environment.

The second stage leach process at the Base Metals Refinery, 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 an autoclave operating at a pressure of 600 kPaG and a temperature of 140°C to 150°C. Concentrated H₂SO₄ is added to the feed to produce a solution with a free acid content between 10 and 30 g/L and a pH of less than 2. Oxygen is passed into the 1st and 2nd compartments of the autoclave.

As a result of the aggressive, highly oxidizing conditions within the autoclave, the original design utilized a heavy wall carbon steel shell with 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. These brick lined autoclaves were heavy, maintenance intensive and prone to catastrophic failure.

A radical autoclave redesign was needed to reduce the high costs of manufacturing, installation and operation. Finite element modelling was used to optimize the design and various high alloy materials were investigated for the application. Based on extensive test work, the carbon steel shell was replaced with duplex SAF 2205 stainless steel in the new design. The use of this highly corrosion resistant material, eliminates the need for the lead and brick linings and reduces the wall thickness requirements substantially, resulting in an increase in the available volume for the same external shell dimensions. The vessel is welded in circular sections to form an elongated, impermeable, cylindrical body, with several agitator nozzles and compartments.

The first new duplex stainless steel unit has been in continuous operation for more than 24 months and its performance has exceeded the highest expectations. The design was so successful that a patent has been registered. The major benefits of the new stainless steel design include increased throughput, improved performance, less downtime and a safer working environment. Lead has been eliminated and replaced with a more environmentally safe material, and the total lifespan of the vessel has been extended. In addition, the autoclave project has made significant developments in advancing the field of welding and optimizing the integrity of welding quality standards in South Africa.

Introduction

Background

The Impala Platinum Limited base metals refinery in Springs processes ore containing base metals and platinum group metals (PGM's) sourced from mines in the Rustenburg area and supplied to the refinery in the form of convertor matte. At the BMR, a hydrometallurgical process is used to refine the matte. The main products of the BMR include:

- a PGM-rich concentrate, which is further refined at the Platinum Metals Refinery
- nickel in briquette or powder form
- copper cathodes and
- cobalt powder.

During the refining process, five separate leaching stages are used to remove the base metals and impurities from the PGM-rich concentrate. This report will focus on a complete redesign of the autoclaves used in the 2nd stage leaching step.

The second stage leach process at the Base Metals Refinery produces a PGM-rich residue through the extraction of copper and any remaining base metals from the first stage leach solid residue material. A PGM-rich residue is produced, which is further processed in the 3rd stage leaching step.

The second stage leaching process is performed in a number of autoclaves (an autoclave is defined as a heavy vessel for chemical processing under high pressure) operating at a pressure of 600 kPaG and a temperature of 120°C to 140°C. Concentrated H₂SO₄ is added to the feed to produce a

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solution with a free acid content of between 10 and 30 g/L and a pH of less than 2. Oxygen is passed into the 1st and 2nd compartments of the autoclave.

As a result of the aggressive, highly oxidizing conditions within the autoclave, the original autoclave design for the 2nd stage leach process utilized a three-layered configuration, consisting of a heavy carbon steel shell (with a wall thickness of 40 mm), followed by lead lining and two layers of acid bricks. The bricks act as a wear resistant material and ensure a low surface temperature at the skin of the lead lining, whereas the lead lining acts as a corrosion barrier to protect the steel shell from acid corrosion. The layers of bricks are positioned one on top of the other with mortar to ensure that the bricks are 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 is between 200 mm and 250 mm. The bricks and the lead liner, if damaged, must be replaced immediately as contact between the acidic solution and the carbon steel shell results in rapid, corrosive attack. The autoclave also utilises a vertical partition wall made up of two brick layers which create four buffer zones (compartments) for the different stages of the process. An agitator is installed inside the autoclave to ensure proper agitation, which increases the leach efficiency. During the agitation process, vibrations are created in the autoclave shell, which can cause damage to the bricks and liners.

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

Limitations of the original 2nd stage leach autoclave design

The original autoclave design, described above, exhibits several problems which cause reduced productivity levels and efficiency in operation. The main concerns are as follows:

- 1) The autoclaves require extensive maintenance due to bricks collapsing at the nozzles and partition walls, which necessitates frequent maintenance intervals to avoid deterioration of the main shell and under performance due to the collapse of the partition walls.
- 2) As a result of the frequent collapse of the brick lining, the brick composite material contaminates the final product, thereby further reducing productivity.
- 3) Each vessel is exceedingly costly to manufacture, which requires the outlay of substantial capital investment.
- 4) The duration of manufacture is lengthy, which is further exacerbated by the need to have the brick lining constructed *in situ*. This is both time consuming and requires skilled labour, managed by suitable project managers. Furthermore, it requires heavy lifting and handling equipment, as well as storage and warehousing for the brick and mortar materials.
- 5) Due to its heavy design, which consists of a thick carbon steel shell, lead lining and bricks, suitable foundations and heavy lifting equipment are required. This raises the installation costs of the vessel considerably.

- 6) Brick laying involves manpower working in confined spaces under hazardous conditions which necessitates 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.
- 7) Workers laying the lead lining in the workshop are exposed to extremely hazardous conditions, such as fumes, lead vapours and a high risk of poisoning. The use of lead is governed by specific regulations, and is restricted in several countries around the world. South Africa has promulgated Lead Regulations which stipulate the use and application of lead in the National Occupational Health and Safety Act.
- 8) When the vessel is decommissioned, strict regulations have to be adhered to when disposing of the vessel. Due to the extremely 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, following which 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 requires a specialized and highly skilled workforce. As well as the inconvenience of having to suspend production, the dangers associated with the handling of the lead are plentiful, including contamination, fumes and the need for a safety zone for personnel who have to be dressed in personal, safety protection gear.
- 9) Problems exist relating to manufacturing tolerances caused by the brick lining. Since the brick lining tends to swell, it is essential to ensure that the manufacturer maintains very strict out-of-round control to ensure that the permissible tolerances are not exceeded. It is common to have 0.5% out-of-round on the brick lining, whereas the code of construction on pressurized equipment limits the out-of-round to 1% of the diameter size. This necessitates additional manufacturing jigs, spiders and temporary bracing to maintain circularity within permissible tolerances.
- 10) The vessel contains four compartments with a large agitator to mix the product during processing. It is common for this agitator to have a run-out which induces severe vibrations, thereby weakening and cracking the mortar and causing the brickwork to collapse.
- 11) Finally, the vessel has to be placed on a heavy foundation, which must withstand the hefty mass of shell, lead lining and the two layers of brick lining.

A radical autoclave redesign was, therefore, needed to reduce the high costs of manufacturing, installation and operation.

Solving the problems associated with the original 2nd stage leach autoclave design:

To engineers who had been operating these autoclaves for years, it was evident that a solution to the problems, described above, had to be developed. This solution had to be innovative, with a view to providing a safe working

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environment and reducing the costs associated with manufacturing, installation, operation, downtime for maintenance and disposal of the unit. Combining all these factors is difficult, since resolving one of these parameters has implications for the other aspects, for example a cost saving in manufacturing may bring about an increase in production costs, or vice versa.

A need was, therefore, identified for a solution that would be safe, operable, maintainable and disposable, and which would not cause pollution and degradation of the environment at the end of the vessel's operating life. This solution was needed to ensure that the manufacturers, as well as the operators working in the plant, remained safe and that the equipment operated more efficiently, reliably and provided cost saving advantages throughout the life cycle of the vessel. In order to satisfy these requirements, the following design criteria were stated:

- ▶ The solution envisaged needed to be technologically innovative and compatible with the platinum being produced in the plant
- ▶ The material of construction had to be readily available and possess excellent mechanical properties
- ▶ The material of construction had to be resistant to the high temperatures in the process and at the same time provide the corrosion resistance required
- ▶ The material of construction needed to be amenable to the rolling, forging and welding processes used during fabrication
- ▶ The material had to be resistant to vibrations induced by agitation in the autoclave
- ▶ The material of construction needed to have similar corrosion resistance to that of the brick lining used in the original design to protect the steel shell from the aggressive solution in the autoclave.

Material of construction

Available literature suggests the use of titanium, titanium clad^{1,2} or superduplex stainless steel^{3,4} autoclaves as alternatives to brick and lead lined autoclaves in applications involving long-term exposure to operating conditions similar to those within the 2nd stage leach autoclave at the BMR^{1,2,3}. 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, EN 10028 and S31803 according to ASTM A240), was therefore, investigated. SAF 2205 is a highly alloyed duplex stainless steel of Swedish origin, with a typical chemical composition as shown in Table I. SAF 2205 displays excellent corrosion resistance in a wide range of environments, resists localised corrosion (such as pitting and crevice corrosion), is highly resistant to intergranular corrosion and is not susceptible to chloride stress corrosion cracking. It has a typical hardness of 293 HB (hardness on the Brinell hardness scale) or 31 HRC (hardness on the Rockwell C scale)⁵. This is equivalent to a hardness of 8 on the MOH scale (a practical method of comparing the hardness or scratch resistance of minerals). SAF 2205 stainless steel is a high strength alloy, with a typically 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 MOH 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. Table II summarizes selected properties of SAF 2205 duplex stainless steel.

Samples of SAF 2205 and a lower alloyed AISI 316L stainless steel were placed into an original 2nd stage leach autoclave in a region of the partition wall where the agitating effect was at a maximum. The AISI 316L stainless steel samples displayed rapid deterioration in this environment, which is in agreement with available literature⁶⁻⁸. The SAF 2205 samples, however, did not show any signs of wear or chemical attack, and no evidence of pitting corrosion was observed. This suggested that SAF 2205 is compatible with the environment inside the 2nd stage leach autoclave.

Novel redesign of the 2nd stage leach autoclave

On completion of the successful *in situ* trials, the 2nd stage leach autoclave was completely redesigned using SAF 2205 duplex stainless steel as material of construction. 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 the last 24 months. Its performance has exceeded the highest expectations. The main advantages of the newly designed autoclave are:

1. Downtime is minimized, allowing for reduced maintenance servicing.
2. Working volume is increased substantially, which minimizes batch-time processing and therefore ensures an increase in the output of the plant.
3. The internal components can be easily adjusted according to process requirements.

The product has been patented, in addition to a registration deed for the utilization of duplex materials without the need for additional brick layers (which would have been necessary as a corrosion barrier in the conven-

Table I

The typical chemical composition of SAF 2205 (weight%, balance Fe)⁵

Cr	Ni	C	Mn	Si	N	Mo
21–23%	4.5–6.5%	0.03 max.	2.0 max.	1.0 max.	0.08–0.20	2.5–3.5

Table II

Selected properties of SAF 2205 duplex stainless steel⁵

Hardness	Density	Thermal expansion	Heat resistance	Thermal conductivity
293 HB	7850 kg/m ³	13.5x10 ⁻⁶	No embrittlement up to 300°C	17 W/mK

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tional autoclave design) (Patent 2004/8085 for the use of strip-lining of SAF 2205 duplex stainless steel on carbon skin as material of construction for high pressure leach autoclaves; and Patent 2005/08637 for the use of solid SAF 2205 duplex stainless steel as material of construction for high pressure leach autoclaves.) Table III compares the operating parameters and dimensions of the newly designed SAF 2205 autoclave with those of the original brick and lead lined vessels.

The vessel shell was manufactured from SAF 2205 duplex stainless steel plates which were formed in circular sections assembled in an abutting end-to-end composition and welded together to form an elongated impermeable cylindrical body. The plates were stepped and welded in a staggered array to increase rigidity and to avoid a continuous circumferential seam. Strict quality control was maintained during all stages of fabrication. The dished ends were hot forged and welded to the cylindrical body to form the vessel. Several manhole and nozzle openings were included for access to the interior of the vessel and for connections to the process piping, where required. The nozzles were hot forged and welded to the vessel body using partial penetration fillet welds. Figure 1 shows a drawing of the top view of the autoclave, Figure 2 an elevation drawing, and Figure 3 a side view.

A number of internal baffles were fixed at suitable locations inside the body of the vessel in order to create compartments for the different stages of the process. Isometric views of the two types of partition walls used in the autoclave are shown in Figures 4 and 5. Agitators were positioned inside of the autoclave to ensure proper mixing of

Table III

Comparison of brick lined and SAF2205 autoclaves

Property	Brick autoclave	SAF 2205 autoclave
Material of construction	BS 1501-1510430A	SAF 2205
Design temperature	165°C	185°C
Design pressure	1034 kPa	1070 kPa
<i>Before bricking</i>		
Inside diameter	2845 mm	2955 mm
Tan to tan	10316 mm	10473 mm
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
Agitator nozzle A1 – A4	777 mm	1073 mm
Service nozzle N1 – N10	300 mm	437 mm
Nozzle angles	32°	32°
<i>After bricking</i>		
Inside diameter	2555 mm	2955 mm
Tan to tan	10316 mm	10473 mm
Agitator nozzle A1 – A4	670 mm	1073 mm
Service nozzle N1 – N10	240 mm	437 mm
Pass partition width	345 mm brick	30 mm SAF 2205
Vessel weight (Empty)	83620 kg	19183 kg
Vessel volume	53.7 m ³	78.58 m ³

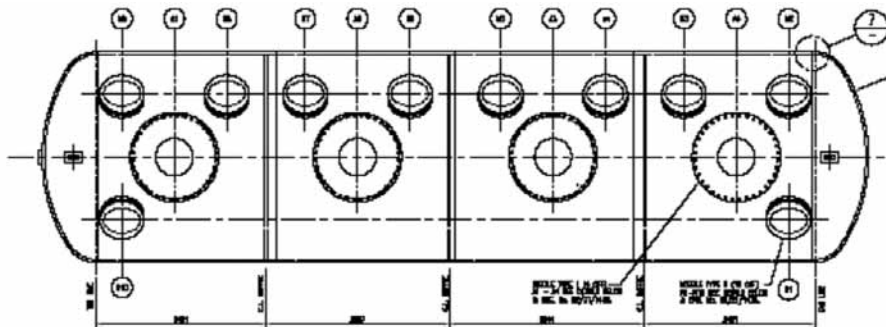


Figure 1—Top view drawing of the redesigned 2nd stage leach autoclave

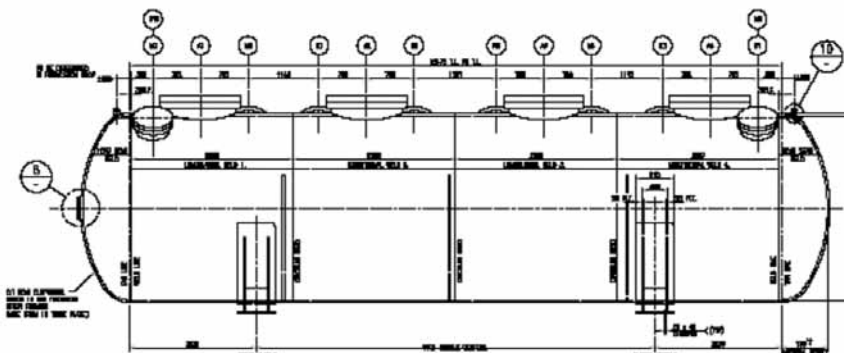


Figure 2—Elevation drawing of the redesigned 2nd stage leach autoclave

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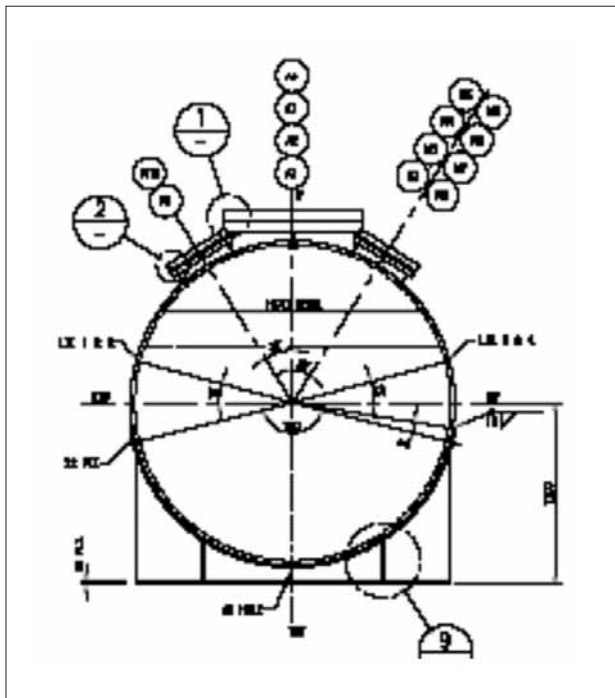


Figure 3—Side view drawing of the redesigned 2nd stage leach autoclave

the acidic substances used in the leaching process. These agitators have to be well supported and secured to manholes to reduce vibrations as far as possible, thereby reducing stresses and avoiding fatigue failure of the vessel components.

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 material of construction. The calculated stress profile in one of the two types of partitioning wall used in the second stage leach autoclave is shown in Figure 6. An isometric side view of the agitator opening and the calculated stress distribution are shown in Figures 7 and 8, respectively. The Codes of Design and Construction applicable to the autoclave had to be strictly followed and rigorous calculations were required to verify that the acceptance criteria were met.

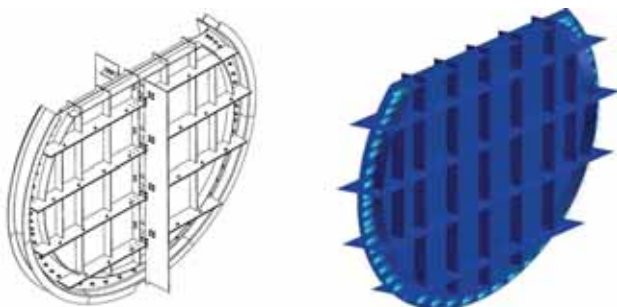


Figure 4—Three-dimensional isometric views of a type I partition wall in the 2nd stage leach autoclave

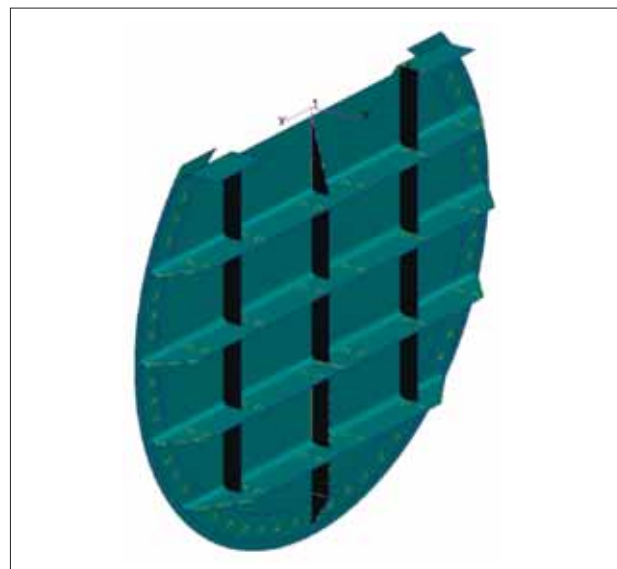


Figure 5—A three-dimensional isometric view of a type II partition wall in the 2nd stage leach autoclave

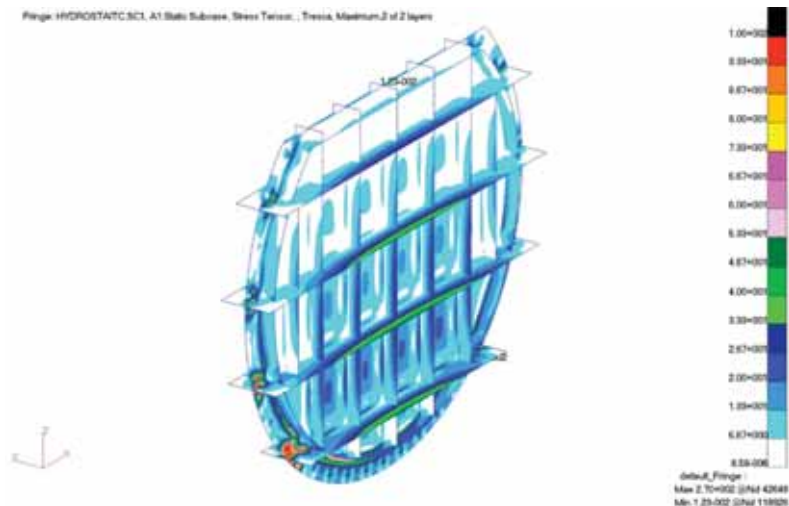


Figure 6—Calculated stress distribution in a type I partition wall

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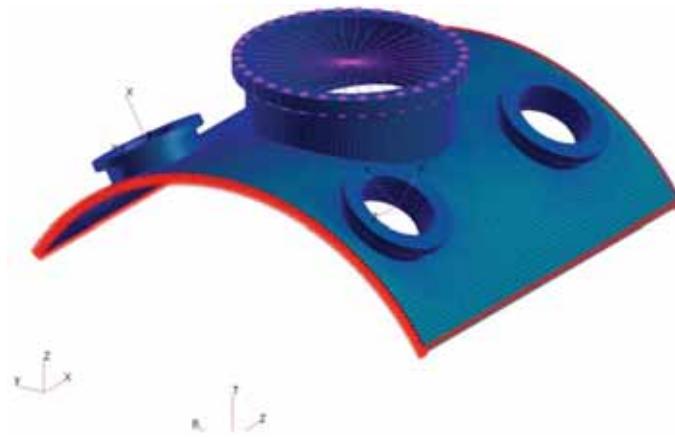


Figure 7—Isometric side view of the agitator opening in the 2nd stage leach autoclave

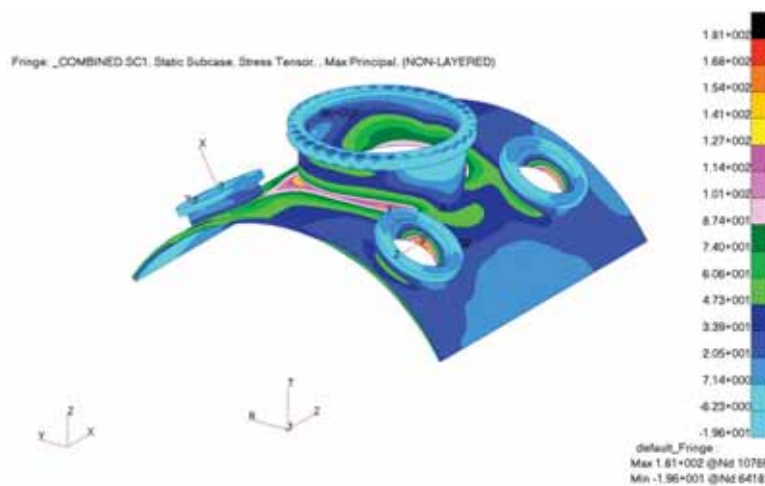


Figure 8—Calculated stress profile in the shell surrounding the agitator opening

According to code requirements, materials of construction must be listed in the code for material properties. SAF 2205 is listed in the ASME Section VIII Division 1 code under the designation ASME SA 240-S31803, with the following design properties:

- ▶ Allowable stress at ambient temperature 177.195 MPa
- ▶ Ultimate tensile strength at ambient temperature 620 MPa
- ▶ Yield stress at ambient temperature 448 MPa
- ▶ Young's modulus at ambient temperature 1.95x10⁵ MPa

Benefits of the new autoclave design

After approximately 24 months in service in the same environment and under the same operating conditions as those used for the original brick and lead lined autoclaves, the solid duplex stainless steel 2nd stage leach autoclave showed no signs of corrosion and the leaching process proceeded as normal. 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 collapse and fall of brick parts as a result of the

agitation action. The maintenance requirements of the newly designed vessels were substantially reduced.

Sustainability

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 for those handling the different materials used during the manufacture of the vessel, as well as for plant operators, and also during the disposal of the vessel at the end of its operating life. An attempt was, therefore, made to address the issue of occupational health regulations by optimising working conditions in the processing plant.

Furthermore, from an environmental point of view, the use of toxic and harmful lead substances had been eliminated and replaced with more environmentally sustainable duplex stainless steel. The new materials will ensure a longer and more durable lifespan. This is owing to the fact that the duplex stainless steel material is resistant to corrosion in the acidic solution used in the leach process, thereby lengthening the lifespan and increasing the sustainability of the vessel.

Novel redesign of a pressure leach autoclave



Figure 9—Delivery of the completed second stage leach autoclave at the BMR in June 2007



Figure 10—Installation of the completed second stage leach autoclave at the BMR in June 2007

Two photographs of the completed vessel during delivery and installation at the Impala Platinum Base Metal Refinery are shown in Figures 9 and 10.

Acknowledgements

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