LONG-TERM EXPERIENCES AND NEW DEVELOPMENTS IN AUTOCLAVE LININGS FOR HIGH-PRESSURE LEACHING AND PRESSURE OXIDATION PROCESSES

By

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ABSTRACT

Common processes to extract metals from refractory ores or laterite ores rely on high pressure applications in autoclaves, e.g. High Pressure Acid Leaching (HPAL) to extract nickel and cobalt or Pressure Oxidation (POX) in cases of copper, gold, zinc, etc.

In both processes ore is mined, crushed and a slurry is created by addition of water or acid. This slurry is treated at elevated temperature and pressure (e.g. T>200°C, P>30 bar) in an autoclave. To return the slurry to atmospheric conditions, an array of flash vessels is used.

Via decantation and selective precipitation the desired metal, metal oxide or metal salt can be accumulated and purified.

As each step requires a specific corrosion protection lining, different lining setups were used in autoclaves, flash vessels, etc.

Especially for high pressure applications in autoclaves and flash vessels combined linings of membranes, bricks and inserts of PTFE, titanium or Inconel are used.

Looking at various ore processing plants around the world, different kinds of membranes are combined with different types of brick linings aiming for a long-lasting and efficient corrosion protection.

Membranes protect the steel vessels against chemical attack. Widely used in pressure vessels are lead membranes, glass fiber reinforced coatings or rubber linings. Also explosion plated titanium or welded on Inconel is partially used.

The main task of the additional brick lining is to protect the membrane against abrasion or mechanical impact. Acid resistant ceramic bricks, carbon bricks, graphene bricks or different specialties are widely used. Depending on the local load (e.g. liquid phase, gas phase, transition zone) different types of mortars are used to install the brick lining.

During the presentation, we will look back on decades of experience with different lining combinations and show pros and cons in application, operation, maintenance, repair and relining

Keywords: HPAL, POX, Corrosion Protection, Combined Linings, Autoclave, Flash Vessel

INTRODUCTION

In the realm of metallurgy, the pursuit of efficient ore processing methodologies has been an enduring quest, driven by the imperative to extract valuable metals from increasingly complex ores. Among the arsenal of techniques, high-pressure acid leaching (HPAL) and pressure oxidation (POX) stand out as transformative methodologies, offering unparalleled opportunities to unlock the latent value of ores once deemed refractory.

HPAL involves subjecting ore slurries to elevated temperatures and pressures in the presence of sulfuric acid, facilitating the dissolution of valuable metals such as nickel, cobalt, and copper. Meanwhile, POX entails the oxidation of sulfide minerals under high temperature and pressure conditions, leading to the liberation of encapsulated metals and rendering them amenable to subsequent extraction.

Within this context, the autoclave emerges as the pivotal apparatus orchestrating the intricacies of HPAL and POX processes. An autoclave, essentially a robust pressure vessel, serves as the crucible wherein ore slurries undergo the rigors of elevated temperature and pressure conditions. Operating akin to a metallurgical alchemist's cauldron, the autoclave catalyzes the dissolution of minerals, liberating metals from their mineralogical confines and facilitating their downstream recovery.

Image 1: Inside View of a POX Autoclave during relining.

AUTOCLAVES

Autoclaves play a central role in both High-Pressure Acid Leaching (HPAL) and Pressure Oxidation (POX) processes, yet their operational characteristics and design nuances vary significantly between the two methodologies.

In HPAL processes, autoclaves are primarily tasked with facilitating the dissolution of valuable metals from ore concentrates through the application of elevated temperature and pressure conditions in the presence of sulfuric acid. These autoclaves are typically constructed from materials resistant to the corrosive nature of sulfuric acid, such as high-grade stainless steel or specialized alloys. The temperature and pressure regimes within HPAL autoclaves are tailored to promote the dissolution of specific metal sulfides, ensuring optimal extraction efficiencies while mitigating undesirable side reactions. Additionally, HPAL autoclaves often incorporate agitators or stirrers to enhance mass transfer and promote uniform mixing of the ore slurry with the acid solution, thereby maximizing metal recovery rates.

In contrast, autoclaves utilized in POX processes are engineered to catalyze the oxidative dissolution of sulfide minerals present in refractory ores, liberating encapsulated metals for subsequent extraction. Unlike HPAL autoclaves, which rely on sulfuric acid as the leaching agent, POX autoclaves operate under oxygen-rich atmospheres at elevated temperatures and pressures, driving the oxidation of sulfide minerals to soluble metal species. Consequently, POX autoclaves are constructed with materials capable of withstanding oxidative environments and are often lined with refractory bricks or coatings to resist high temperatures and abrasive slurries. The design of POX autoclaves prioritizes efficient gas-liquid-solid contact to facilitate the oxidation reactions, typically incorporating spargers or gas injection systems to disperse oxygen throughout the ore slurry and promote reaction kinetics.

While both HPAL and POX autoclaves share the fundamental objective of enhancing metal recovery from refractory ores, their distinct operating principles necessitate tailored designs and operational parameters. By understanding the nuanced differences between autoclaves employed in HPAL and POX processes, metallurgical engineers can optimize process performance and maximize the extraction of valuable metals from challenging ore sources.

FLASH VESSELS

Flash vessels are integral components in the metallurgical processing of ores, particularly in autoclave applications such as High-Pressure Acid Leaching (HPAL) and Pressure Oxidation (POX). These vessels play a crucial role in separating the liquid and gas phases following the high-pressure treatment of ore slurries, thereby facilitating efficient metal recovery and process optimization.

In HPAL processes, flash vessels are strategically positioned downstream of the autoclave to exploit the sudden reduction in pressure that occurs when the slurry exits the autoclave. As the high-pressure slurry is depressurized upon entering the flash vessel, the sudden drop in pressure induces flash vaporization of volatile components, including water and sulfuric acid. This vaporization effectively separates the liquid and gas phases, allowing the acidic solution laden with dissolved metals to be collected for further processing. Meanwhile, the liberated gases, which may include steam and sulfur dioxide, are vented or recycled for subsequent use within the process, thereby minimizing energy consumption and environmental impact.

Similarly, in POX applications, flash vessels serve as critical components for phase separation and gas-liquid disengagement following the oxidative treatment of sulfide ores. As the ore slurry exits the high-pressure autoclave and enters the flash vessel, the abrupt reduction in pressure triggers the release of dissolved gases, primarily carbon dioxide and sulfur dioxide, generated during the oxidation of sulfide minerals. This gas liberation promotes the separation of the gas and liquid phases, allowing the oxidized slurry to be collected for downstream processing, while the off-gases are typically directed to gas treatment systems for purification or environmental control.

The utilization of flash vessels in autoclave applications offers several advantages for metallurgical processing. By effectively separating the liquid and gas phases, flash vessels enable the recovery of valuable metals from ore slurries with enhanced efficiency and selectivity. Moreover, the controlled release and management of gases within flash vessels contribute to process safety and environmental compliance, minimizing the risk of gas emissions and ensuring regulatory compliance.

Overall, flash vessels represent indispensable components in the arsenal of equipment employed in autoclave-based metallurgical processes, playing a pivotal role in optimizing metal recovery, enhancing process efficiency, and maintaining operational integrity.

GENERAL LINING SETUPS – COMBINED LININGS

The setup of corrosion protective linings in Pressure Oxidation (POX) autoclaves and flash vessels is meticulously engineered to withstand the harsh chemical environments encountered during the processing of refractory ores. This dual-layered approach, comprising a membrane for the protection of the steel substrate and a brick lining consisting of acid-proof ceramic bricks, ensures robust corrosion resistance and prolonged equipment lifespan.

1. Membrane Lining: The first line of defense against corrosion in POX autoclaves and flash vessels is the application of a membrane lining directly onto the steel substrate. This membrane serves as a barrier between the corrosive process fluids and the underlying steel, preventing direct contact and corrosion-induced degradation. Membrane linings are typically composed of synthetic polymers or elastomers that exhibit excellent chemical resistance to acidic solutions, high temperatures, and mechanical stresses. Common materials used for membrane linings include fluoropolymers like PTFE

(polytetrafluoroethylene) or PVDF (polyvinylidene fluoride), as well as elastomeric compounds such as EPDM (ethylene propylene diene monomer) or chlorobutyl rubber. These materials form a flexible and impermeable barrier that effectively shields the steel substrate from corrosive attack, extending the service life of the equipment.

2. Brick Lining: In addition to the membrane lining, POX autoclaves and flash vessels are equipped with a secondary layer of protection in the form of acid-proof ceramic brick linings. These brick linings are installed atop the membrane lining to provide additional mechanical strength, abrasion resistance, and thermal insulation. Acid-proof ceramic bricks are composed of dense and chemically inert materials, such as silica or silicon carbide, which exhibit exceptional resistance to acidic environments and high temperatures. The bricks are tightly fitted and bonded together using acid-resistant mortars, forming a continuous and durable protective layer. The brick lining acts as a sacrificial barrier, absorbing the brunt of the corrosive attack from the process fluids and shielding the underlying membrane lining and steel substrate from direct exposure. Additionally, the thermal insulation properties of the brick lining help to maintain uniform temperature distribution within the vessel, optimizing process performance and energy efficiency.

By combining a membrane lining for direct corrosion protection of the steel substrate with a brick lining of acid-proof ceramic bricks for mechanical strength and thermal insulation, POX autoclaves and flash vessels are equipped to withstand the rigors of high-pressure oxidative leaching processes. This multi-layered approach to corrosion protection ensures the integrity and longevity of the equipment, enabling efficient and reliable processing of refractory ores while minimizing downtime and maintenance costs.

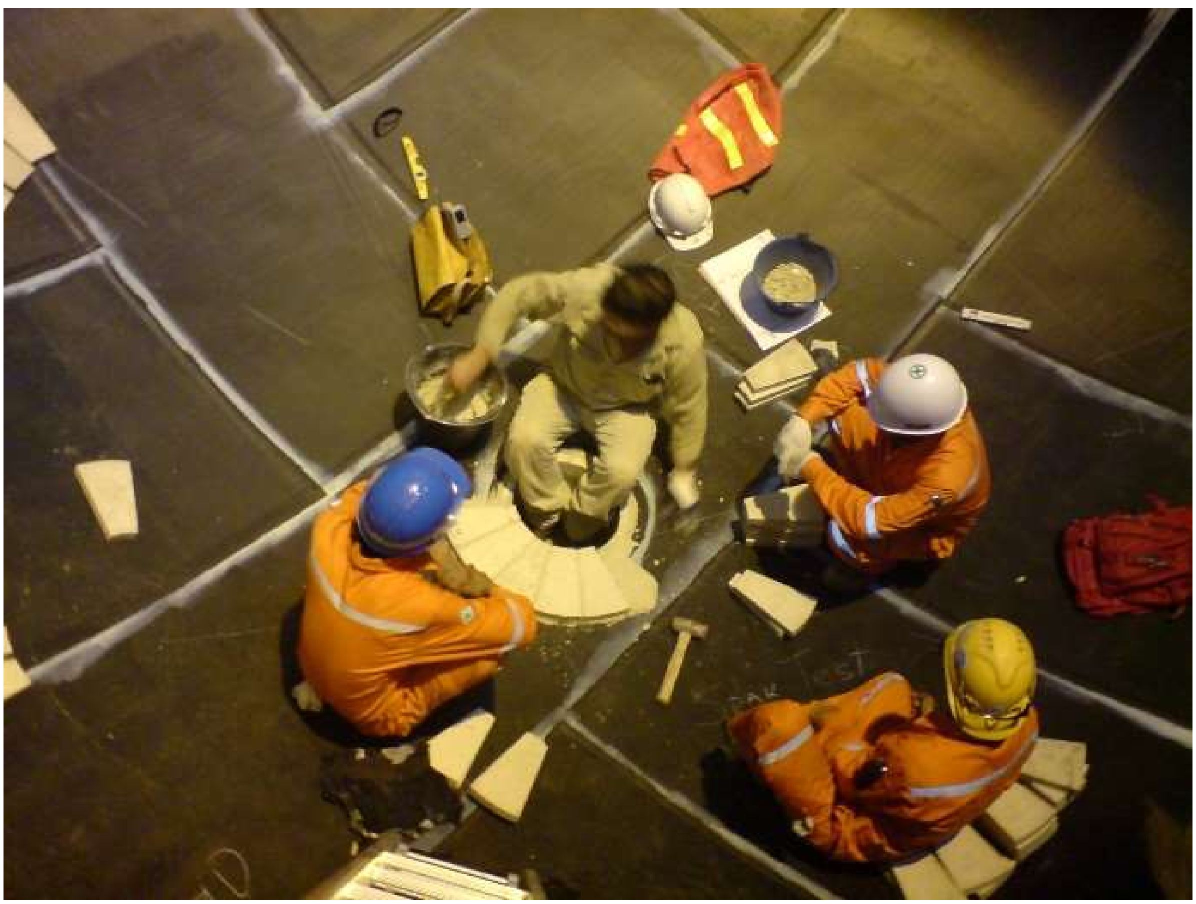

Image 2: Rubber Membrane in an Autoclave.

Image 3: Beginning of brick lining on top of the membrane.

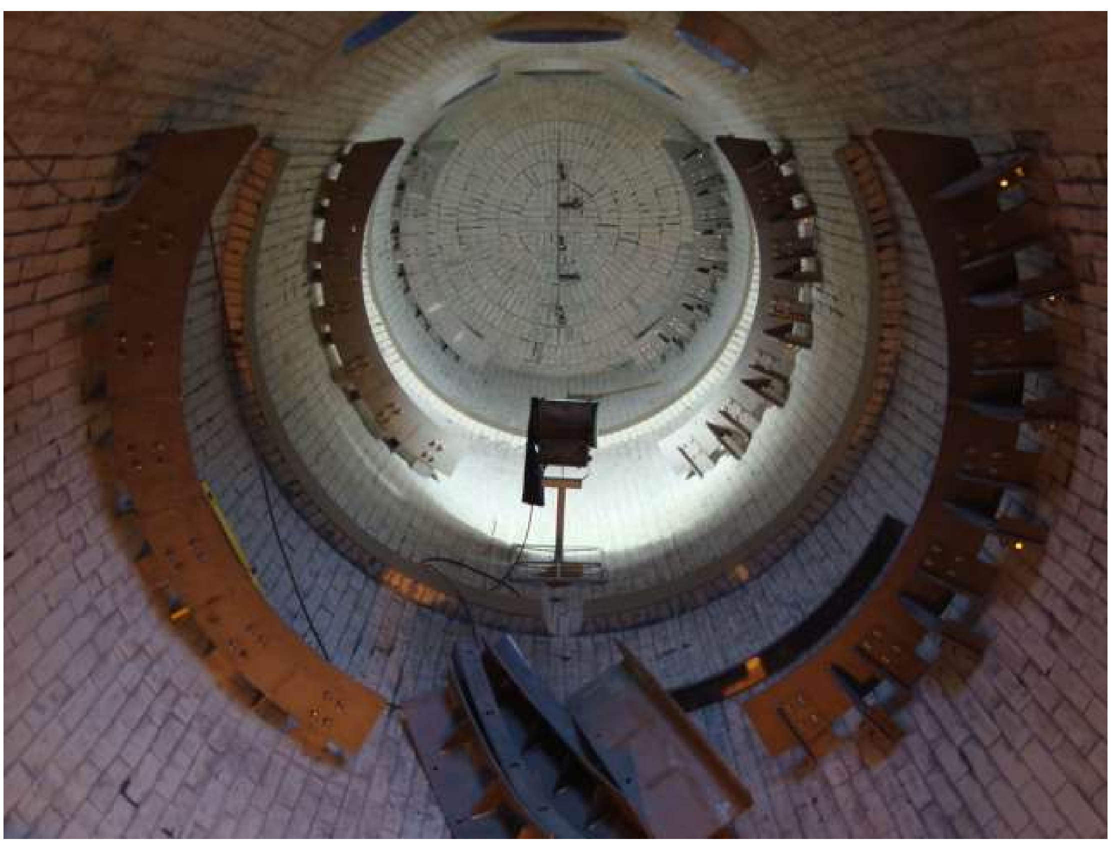

Image 4: Almost completed brick lining within an autoclave.

FINITE ELEMENT METHOD

The Finite Element Method (FEM) is a powerful numerical technique used to model and analyze complex engineering systems, including autoclaves used in metallurgical processes such as Pressure Oxidation (POX). FEM can be employed to predict and assess potential interferences between the internal brick lining and the steel vessel of these autoclaves, offering valuable insights into structural integrity, stress distribution, and potential failure modes.

Here's how the Finite Element Method can be utilized in this context:

1. **Geometry Modeling**: The first step involves creating a detailed geometric model of the autoclave, including its steel vessel, internal brick lining, and any other relevant components. This model accurately represents the dimensions, shapes, and material properties of each component, capturing the intricacies of the autoclave's internal structure.
2. **Mesh Generation**: The geometric model is then discretized into a finite number of smaller elements, or "mesh," using specialized software. The meshing process divides the autoclave geometry into finite elements, each of which is associated with specific material properties and geometric characteristics. The mesh density and element types are chosen to ensure accurate representation of the structural features and stress distribution within the autoclave.
3. **Material Properties**: Material properties, including mechanical properties such as elasticity, yield strength, and thermal expansion coefficients, are assigned to each element based on the properties of the steel vessel, brick lining, and any other components. These material properties are essential for accurately simulating the behavior of the autoclave under various loading conditions.
4. **Boundary Conditions**: Boundary conditions, such as applied loads, constraints, and thermal conditions, are defined to simulate the operating conditions experienced by the autoclave during POX processes. These boundary conditions mimic the effects of internal pressure, temperature gradients, and mechanical forces acting on the autoclave.
5. **Analysis**: The finite element model is subjected to numerical analysis, wherein the software solves a system of equations derived from the principles of solid mechanics, heat transfer, and fluid dynamics. This analysis predicts the distribution of stresses, strains, displacements, and temperature gradients within the autoclave, providing insights into potential areas of concern, such as regions of high stress or deformation.
6. **Interference Detection**: By analyzing the results of the finite element analysis, engineers can identify potential interferences or conflicts between the internal brick lining and the steel vessel. These interferences may manifest as excessive stresses, deformations, or contact pressures at the interface between the two components. Engineers can assess the severity of these interferences and explore mitigation strategies, such as adjusting the design parameters, optimizing material selection, or refining the manufacturing process.
7. **Validation and Optimization**: The finite element model can be validated against experimental data or benchmark simulations to ensure its accuracy and reliability. Additionally, the model can be used iteratively to explore design variations, optimize structural configurations, and enhance the performance and durability of the autoclave.

By leveraging the Finite Element Method, engineers can effectively predict and mitigate potential interferences between the internal brick lining and the steel vessel in POX autoclaves, ensuring their structural integrity, reliability, and safety throughout the demanding conditions of metallurgical processing.

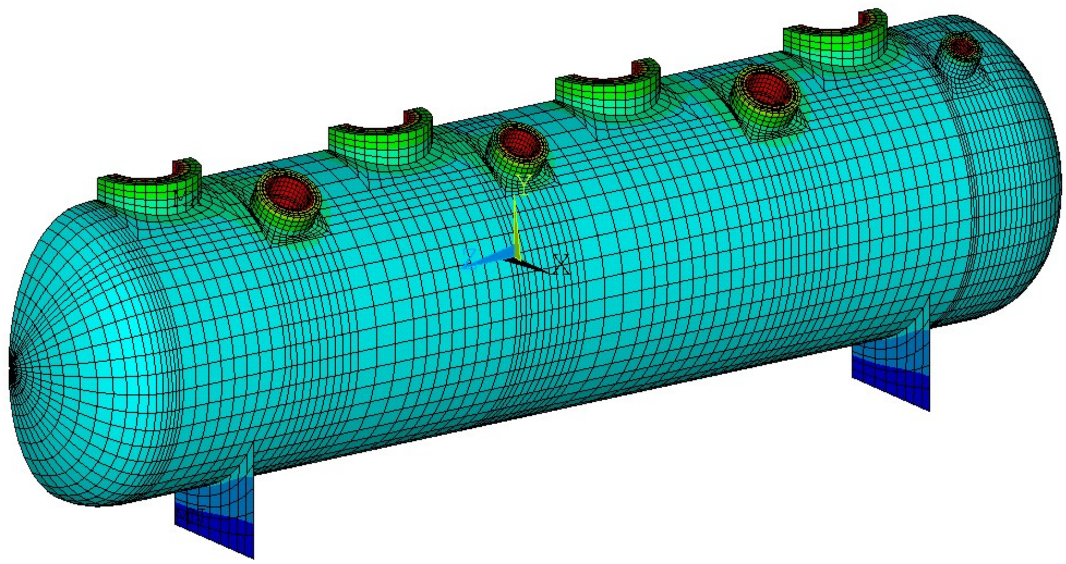

Image 5: FEA-model of an Autoclave: Expansion of brick lining inside an autoclave, Temperature distribution

MEMBRANES

Regarding the different parts of a Vessel lining the membrane is the most critical. It must provide an impervious seal to protect the steel against the corrosive, acidic media.
Membranes which are used for Autoclaves, Heater- and Flash Vessels are in general:

- Reinforced Plastic membranes (GRP)
- Elastomeric Rubber Linings
- Flexible thermoplastic sheet lining
- Plastic sheets made out PVDF, PTFE, and ECTFE
- Lead as sheet material or homogenous clad bonded
- Metal overlay welding like Inconel-cladding

INCONEL MEMBRANES / METAL OVERLAYS

Inconel, a family of nickel-chromium-based superalloys renowned for their exceptional corrosion resistance, mechanical strength, and high-temperature performance, finds widespread application as a membrane lining in autoclaves utilized in metallurgical processes such as Pressure Oxidation (POX). Here's how Inconel linings serve as robust barriers against corrosive environments within these autoclaves:

1. **Corrosion Resistance**: Inconel alloys, particularly grades such as Inconel 625 and Inconel 718, exhibit outstanding resistance to corrosion from a wide range of aggressive chemicals, including sulfuric acid, hydrochloric acid, and acidic solutions encountered in POX processes. The high nickel content in Inconel imparts excellent resistance to both oxidizing and reducing environments, making it an ideal choice for applications where corrosion is a primary concern.
2. **High-Temperature Performance**: POX autoclaves operate under elevated temperatures ranging from 150°C to 250°C or higher, depending on the specific process requirements. Inconel alloys maintain their mechanical strength and corrosion resistance at elevated temperatures, ensuring long-term integrity and reliability of the membrane lining even under harsh thermal conditions. This high-temperature stability allows Inconel linings to withstand the demanding thermal cycling and operating conditions experienced during POX processes without degradation or failure.
3. **Mechanical Strength**: Inconel alloys possess excellent mechanical properties, including high tensile strength, fatigue resistance, and toughness, which are essential for withstanding the mechanical stresses and pressures exerted on the membrane lining within the autoclave. The inherent strength of Inconel ensures structural integrity and dimensional stability of the lining, preventing deformation, buckling, or rupture under operating conditions.
4. **Compatibility with Process Fluids**: Inconel linings are compatible with a wide range of process fluids and chemicals commonly encountered in metallurgical processing, including acidic solutions, high-

pressure steam, and corrosive gases. The inert nature of Inconel minimizes the risk of contamination or chemical reactions with the process fluids, ensuring purity and integrity of the processed materials and final product.

5. **Fabrication and Installation**: Inconel membranes can be fabricated using various techniques, including welding, forming, and machining, to achieve precise dimensions and configurations tailored to the specific geometry of the autoclave. The membrane lining is securely installed onto the steel substrate using welding or mechanical fastening methods, creating a robust barrier against corrosive attack while maintaining tight seals and interfaces to prevent leakage.

Overall, the use of Inconel as a membrane lining in POX autoclaves provides a reliable and durable solution for protecting the steel substrate against corrosion and thermal degradation, thereby ensuring the long-term performance and integrity of the equipment in demanding metallurgical processing environments. However, material and installation price is very high. The main drawback is repairability or maintenance, which is usually not easy and needs to be designed carefully. Usually special welding equipment is needed which cannot be used in any point of an autoclave or which would require a rotation of the complete vessel.

LEAD MEMBRANES

The use of lead as a membrane lining in autoclaves, particularly in metallurgical processes like Pressure Oxidation (POX), serves as a specialized solution for corrosion protection in highly acidic and aggressive environments. Here's how lead membranes offer unique advantages and considerations:

1. **Corrosion Resistance**: Lead is renowned for its exceptional resistance to corrosion, particularly in acidic environments. In POX processes where sulfuric acid or other aggressive chemicals are present, lead provides a robust barrier against corrosion, preventing degradation of the steel substrate and ensuring long-term integrity of the autoclave.
2. **Chemical Inertness**: Lead is chemically inert and does not react with most acids or corrosive substances encountered in metallurgical processing. This inert nature ensures that the lead membrane remains stable and impervious to chemical attack, maintaining its protective properties over extended periods of operation.
3. **Malleability and Formability**: Lead possesses excellent malleability and formability, allowing it to conform closely to the contours of the autoclave's internal surfaces. This capability enables the fabrication of seamless lead membranes that provide complete coverage and protection, minimizing the risk of corrosion at joints or seams.
4. **Sealing and Insulation**: Lead membranes can be tightly sealed against the steel substrate, forming a continuous and impermeable barrier that prevents the ingress of corrosive fluids and gases. Additionally, lead exhibits moderate thermal insulation properties, helping to mitigate temperature differentials and maintain uniform conditions within the autoclave.
5. **Environmental Considerations**: While lead offers superior corrosion resistance, its use raises environmental and health considerations due to the potential for lead leaching or contamination. Special precautions must be taken during the fabrication, installation, and maintenance of lead membranes to prevent exposure to lead dust or fumes. Proper ventilation, personal protective equipment, and waste management practices are essential to ensure worker safety and environmental compliance.
6. **Durability and Maintenance**: Lead membranes require periodic inspection and maintenance to ensure their continued effectiveness in corrosion protection. Although lead is highly durable and resistant to degradation, factors such as mechanical damage, erosion, or exposure to extreme temperatures may compromise the integrity of the membrane over time. Regular inspections and repairs are necessary to address any signs of wear or damage and to prolong the service life of the lead lining.

In summary, the use of lead as a membrane lining in autoclaves offers unique advantages in terms of corrosion resistance, chemical inertness, and formability, making it well-suited for protecting steel substrates in aggressive metallurgical processing environments. However, careful consideration of environmental and health considerations is essential to ensure safe handling and operation of lead-lined autoclaves.

Compared to Inconel, lead shows a lower resistance at temperatures higher than 100°C. Homogeneous lead lining can only be installed in the 6 o'clock position (rotation of an autoclave may be needed during installation or repair). Lead panels (cladding on profiles) can be installed regardless of the orientation. But in this case the membrane is not completely attached to the substrate. Vacuum within this gap improves the lifetime.

GLASS FIBRE REINFORCED PLASTICS (LAMINATES BASED ON FURANIC RESINS)

Glass fiber-reinforced plastics (GRP), particularly those based on furanic resins, serve as versatile and durable membrane linings in autoclaves, offering a combination of corrosion resistance, mechanical strength, and thermal stability. Here's an overview of GRP membranes in autoclave applications, with a focus on furanic resin-based compositions:

1. **Composition and Structure**: GRP membranes are composed of a matrix resin reinforced with high-strength glass fibers. Furanic resins, derived from furfuryl alcohol, serve as the matrix material in these membranes. Furanic resins offer excellent chemical resistance, particularly to acidic and corrosive environments encountered in metallurgical processes. The glass fibers provide reinforcement, enhancing mechanical properties such as tensile strength, flexural strength, and impact resistance.
2. **Corrosion Resistance**: Furanic resin-based GRP membranes exhibit superior corrosion resistance, making them well-suited for protecting steel substrates against aggressive chemicals, including sulfuric acid, hydrochloric acid, and acidic solutions present in POX autoclaves. The chemically inert nature of furanic resins ensures long-term stability and integrity of the membrane lining, even in highly corrosive environments.
3. **Mechanical Strength and Durability**: GRP membranes offer high mechanical strength and durability, thanks to the reinforcement provided by glass fibers. This combination of materials results in membranes with excellent load-bearing capacity, dimensional stability, and resistance to deformation under mechanical stress. GRP membranes can withstand the rigors of autoclave operation, including high pressures, temperature fluctuations, and mechanical agitation, without compromising their structural integrity.
4. **Thermal Stability**: Furanic resin-based GRP membranes exhibit good thermal stability, allowing them to withstand the elevated temperatures encountered in autoclave processes. These membranes maintain their mechanical properties and dimensional stability over a wide range of operating temperatures, ensuring reliable performance under thermal cycling and transient heating conditions.
5. **Fabrication and Installation**: GRP membranes can be fabricated using various techniques, including hand lay-up, filament winding, or compression molding, to achieve precise dimensions and configurations tailored to the specific geometry of the autoclave. The membranes are securely bonded to the steel substrate using adhesives or mechanical fasteners, ensuring tight seals and interfaces to prevent leakage and corrosion ingress.
6. **Environmental Considerations**: Furanic resin-based GRP membranes offer environmental advantages compared to traditional materials such as lead or certain polymers. Furanic resins are derived from renewable biomass sources and can be formulated to minimize volatile organic compound (VOC) emissions during manufacturing. Additionally, GRP membranes do not pose the same health and safety risks associated with lead or certain plastics, making them a safer and more environmentally friendly option for autoclave linings.

In summary, glass fiber-reinforced plastics based on furanic resins offer a compelling combination of corrosion resistance, mechanical strength, thermal stability, and environmental sustainability, making them well-suited for membrane linings in autoclaves used in metallurgical processes like Pressure Oxidation. Their versatility and performance make them a preferred choice for protecting steel substrates and ensuring the long-term reliability and efficiency of autoclave operations. The unbeatable benefit of these organic membranes is of course their low price compared to metal membranes and their fast installation time.

PLASTIC SHEETING

Plastic sheets such as PVDF (Polyvinylidene fluoride), PTFE (Polytetrafluoroethylene), or ECTFE (Ethylene Chlorotrifluoroethylene) serve as effective membrane linings in autoclaves, offering a combination of chemical resistance, thermal stability, and non-stick properties. Here's how these materials are utilized as membranes in autoclave applications:

1. **PVDF (Polyvinylidene fluoride)**:
    - PVDF is a fluoropolymer known for its exceptional chemical resistance, mechanical strength, and thermal stability. These properties make it an excellent choice for membrane linings in autoclaves operating in corrosive environments.
    - PVDF membranes exhibit high resistance to a wide range of chemicals, including strong acids, bases, and organic solvents. This makes them suitable for protecting steel substrates against corrosion in processes involving acidic solutions, such as High-Pressure Acid Leaching (HPAL).

    - PVDF membranes have good thermal stability, withstanding temperatures ranging from cryogenic to elevated levels without significant degradation. This allows them to maintain their mechanical properties and integrity under operating conditions encountered in autoclave processes.
2. **PTFE (Polytetrafluoroethylene)**:
    - PTFE, commonly known by the brand name Teflon, is a fluoropolymer renowned for its non-stick properties, chemical inertness, and high-temperature resistance. These characteristics make it an ideal choice for membrane linings in autoclaves.
    - PTFE membranes exhibit unparalleled non-stick properties, preventing the adherence of process fluids, solids, or contaminants to the membrane surface. This facilitates easy cleaning and maintenance of the autoclave, reducing downtime and improving operational efficiency.
    - PTFE membranes offer excellent chemical resistance to acids, bases, solvents, and other corrosive substances encountered in metallurgical processes. They provide reliable protection against corrosion, ensuring the longevity and integrity of the steel substrate in autoclaves.
3. **ECTFE (Ethylene Chlorotrifluoroethylene)**:
    - ECTFE is a fluoropolymer known for its combination of chemical resistance, mechanical strength, and thermal stability. It offers superior performance in aggressive chemical environments, making it suitable for membrane linings in autoclaves.
    - ECTFE membranes possess good mechanical properties, including high tensile strength, impact resistance, and dimensional stability. This ensures that the membrane maintains its integrity and functionality under mechanical stresses and pressures encountered during autoclave operation.

In summary, plastic sheets such as PVDF, PTFE, and ECTFE serve as versatile and reliable membrane linings in autoclaves, providing effective protection against corrosion, thermal degradation, and contamination. Their unique combination of properties makes them well-suited for a wide range of metallurgical processes, enhancing the durability, efficiency, and safety of autoclave operations. However, beside their brought chemical resistance, the diffusion resistance is comparably low (small molecules like water can diffuse easily through a PTFE membrane). Thus, usually a combination of an underlying coating or furanic GRP system together with a plastic sheet is used.

A “loose bond” connection (no complete bond between membrane and substrate) leads to mechanical stress within the sheets caused by the different thermal expansions. Especially at nozzles, penetrating the plastic sheet cylinder build up a potential stress point, leakages are the consequences.

FLEXIBLE VISCOELASTIC SHEET LINING

Flexible viscoelastic sheet linings, such as those made from carbon-based materials, offer unique advantages as membrane linings in autoclaves. Here's how these materials are utilized in such applications:

1. **Viscoelastic Properties**: Viscoelastic materials exhibit both viscous (flow) and elastic (recovery) behavior under stress, allowing them to deform and conform to irregular surfaces while maintaining their structural integrity. This property makes them ideal for lining autoclaves with complex geometries, as they can easily adapt to the contours of the interior surfaces without sacrificing durability or effectiveness.
2. **Chemical Resistance**: Flexible viscoelastic sheet linings are engineered to provide resistance to a wide range of chemicals, including acids, bases, solvents, and corrosive substances commonly encountered in metallurgical processes.
3. **Application**: Viscoelastic sheet linings can be applied by butting adjacent sheets together. Seams are fused together with joint stripes. The sheets are attached to the metal surface by an open flame
4. **Temperature Resistance**: Viscoelastic materials exhibit good temperature resistance, allowing them to withstand the moderate to high temperatures encountered in autoclave processes. Polyurea, for instance, can withstand temperatures ranging from sub-zero to over 100°C, making it suitable for a wide range of metallurgical applications, including both low-temperature leaching processes and high-temperature oxidation reactions.
5. **Balancing different thermal expansion factors**: Viscoelastic membranes are intended to act as an expansion joint between steel and brick and thus balancing the different thermal expansion (thermal expansion of steel usually two to three times higher than the expansion coefficient of the brick lining).

The viscoelasticity allowing the membrane to act as an expansion joint, creates also the main drawback of this kind of membrane when in operation over a longer time period. During operation of a POX autoclave or a flash vessel, the membrane is heated to an elevated temperature e.g. 80°C. This results in a tremendous softening of the material allowing the membrane to flow. Thus an almost liquid membrane is set under pressure between an incompressible steel surface and a stiff brick lining. As long as this liquid material does not find an open gap to escape it can fulfill its purpose. But in case this “pressurized” liquid will find a crack or an open gap (e.g. at nozzles, flanges or manholes) it will be squeezed out. In this case the function as expansion joint can no longer be fulfilled and the bricklining shifts closer to the steel surface with all possible consequences for the lining integrity.

Image 6: Viscoelastic membrane at 80°C (original sheet size: 65 mm x 115 mm, thickness approx. 11 mm)
Surface pressure (below a standard ceramic brick 24 x 11.5 x 6.5 cm) ≈ 0,052 bar ≈ 0,005 MPa
After 20 h, 2 days, and 8 days.

ELASTOMERIC RUBBER LINING

Rubber linings serve as effective and versatile membrane linings in autoclaves, offering excellent corrosion resistance, flexibility, and durability. Here's how rubber linings are utilized in autoclave applications:

1. **Chemical Resistance**: Rubber linings, particularly those made from synthetic elastomers such as neoprene, EPDM (Ethylene Propylene Diene Monomer), or natural rubber, provide exceptional resistance to a wide range of chemicals, including acids, bases, solvents, and corrosive substances commonly encountered in metallurgical processes. This chemical resistance makes rubber linings well-suited for protecting steel substrates against corrosion in autoclaves used for processes such as High-Pressure Acid Leaching (HPAL) or Pressure Oxidation (POX).
2. **Flexibility and Conformability**: Rubber linings are inherently flexible and elastomeric, allowing them to conform closely to the contours of autoclave interiors, including irregular surfaces, weld seams, and joints. This flexibility ensures complete coverage and protection of the steel substrate, minimizing the risk of corrosion or leakage at vulnerable points. Rubber linings can be customized to accommodate complex geometries, ensuring uniform protection throughout the autoclave.
3. **Temperature Resistance**: Rubber linings exhibit good temperature resistance, allowing them to withstand the moderate temperatures encountered in most autoclave processes. While certain rubber formulations may have temperature limitations, such as neoprene or EPDM, new developments with new cross-linking systems offer enhanced temperature resistance and can withstand higher operating temperatures (up to 150°C). This versatility allows rubber linings to be tailored to specific process requirements, ensuring compatibility with a wide range of metallurgical applications.
4. **Mechanical Properties**: Rubber linings offer excellent mechanical properties, including high tensile strength, elongation at break, and tear resistance, which are essential for withstanding mechanical stresses and pressures encountered during autoclave operation. These materials can absorb impact and vibration, reducing the risk of damage or delamination, and providing long-term durability and reliability.
5. **Ease of Maintenance**: Rubber linings require minimal maintenance and can be easily repaired or replaced as needed to address wear, damage, or degradation over time. Routine inspections and maintenance activities, such as cleaning, patching, or recoating, help to prolong the service life of the rubber lining and ensure continued protection of the steel substrate. Even other membranes (e.g. lead membranes) could be repaired by rubber.
6. **Balancing different thermal expansion factors**: Due to its elastomeric behavior, rubber linings act as expansion joint between steel and brick surface. As explained above, the expansion coefficient of steel is much higher than the coefficient of the brick lining (combination of acid resistance brick and stiff mortar). However, rubber is an elastomeric material and thus cannot flow. Due to the cross-linking,

the rubber matrix cannot move. In case of open cracks or gaps runner material cannot be squeezed out.

In summary, rubber linings offer a robust and cost-effective solution for corrosion protection in autoclaves, providing excellent chemical resistance, flexibility, temperature resistance, and mechanical properties. Their versatility, ease of application, and durability make them well-suited for a wide range of metallurgical processes, enhancing the longevity, efficiency, and safety of autoclave operations.

SUMMARY

Autoclaves and flash vessels are the key equipment in hydrometallurgical ore processing plants like High Pressure Acid Leaching (HPAL) or Pressure Oxidation (POX). In most vessels a combined lining is used to protect the steel surface against chemical and mechanical attack. This combined lining usually consist of a membrane to protect the steel against corrosion and a brick lining to protect the membrane against mechanical impact and temperature. The interference between steel, membrane and brick lining can be analysed and predicted using a Finite Element Method (FEM). The main target in lining setup is to provide an impervious seal to protect the steel against the acidic and oxidizing media. Different types of membranes are in use. Inconel, lead, GRP, plastic sheeting, viscoelastic sheeting or rubber linings are the most common alternatives. Depending on resistance, applicability, repairability, price and other factors, all types exhibit different pros and cons which should carefully investigated when planning a new plant or maintenance at existing linings.

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