

Pressure vessels: mechanical design based on theoretical and normative principles in recent reviews

Pressure Vessels: Mechanical Design According to Theoretical and Normative Fundamentals in Recent Reviews

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SUMMARY

This paper addresses the theoretical, constructive, and normative fundamentals applicable to the mechanical design of pressure vessels, equipment widely used in various industries. This study focuses on industrial sectors such as petrochemical, food, and energy. Its objective is to analyze the requirements of ASME Section VIII and ABNT NBR 13.531 standards, as well as their impacts on the safety and structural integrity of these devices. Aspects such as acting forces and stresses, construction methods, and minimum thickness calculation were discussed, in addition to the importance of the proper application of safety factors. The research also emphasizes integrity assessment methods and failure criteria, essential for ensuring the safe and continuous operation of the vessels. Based on the literature review, it is concluded that compliance with technical standards and correct mechanical dimensioning are crucial for the reliability, efficiency, and longevity of pressure vessels.

Keywords: pressure vessels; mechanical design; ASME Section VIII; ABNT NBR 13.531; structural integrity; operational safety.

ABSTRACT

This study addresses the theoretical, constructive, and normative fundamentals applicable to the mechanical design of pressure vessels, which are widely used across various industrial sectors such as petrochemical, food, and energy. The main objective is to analyze the requirements established by ASME Section VIII and ABNT NBR 13.531 and their impact on the safety and structural integrity of these devices. The discussion covers aspects such as acting stresses and loads, constructive forms, and the calculation of minimum wall thickness, in addition to the importance of properly applying safety factors. The research also emphasizes integrity assessment methods and failure criteria, which are essential to ensure the safe and continuous operation of pressure vessels. Based on the bibliographic review, it is concluded that compliance with technical standards and proper mechanical design are crucial for the reliability, efficiency, and longevity of pressure vessels.

Keywords: pressure vessels; mechanical design; ASME Section VIII; ABNT NBR 13.531; structural integrity; operational safety.

INTRODUCTION

Pressure vessels are containers designed to contain pressurized fluids and They play a fundamental role in various sectors of the economy, such as in industries. petrochemical, food, and power generation industries. Due to the severe operating conditions, It becomes essential that your mechanical design strictly meets the requirements.



Operating and safety regulations, ensuring its structural integrity and efficiency. operational (Silva, 2017). Given this relevance, this study proposes to review the Theoretical foundations and technical standards governing the design of pressure vessels. with emphasis on the guidelines of ASME Section VIII and the ABNT standards, seeking to understand how these regulations contribute to performance and reliability. of the equipment.

The central problem guiding this research is: how do the guidelines of the standards ASME Section VIII and ABNT techniques contribute to integrity and safety in Mechanical design of pressure vessels? It is assumed that such standards play a role. Essential to ensuring the standardization of sizing criteria, the appropriate selection of materials and the reduction of failures during operation, which ensures greater reliability and safety in industrial facilities

The overall objective of this study is to analyze the theoretical foundations and technical standards. applicable to the mechanical design of pressure vessels, based on scientific and technical literature. updated. As specific objectives, the aim is to identify the main criteria of Mechanical dimensioning, encompassing the acting forces and the most common types of stresses. relevant; present the safety factors required by the standards; and compare the requirements established by ASME Section VIII and ABNT.

The methodology adopted consists of a qualitative literature review, with Collection of scientific articles, technical manuals, standards and specialized documents. The research will be conducted using databases such as SciELO, Google Scholar, and ABNT. ASME prioritizes publications between 2015 and 2025. This approach will allow us to identify the main criteria and standards that guide the mechanical design of pressure vessels, contributing to a deeper understanding of good engineering practices and of Regulatory parameters that underpin the safety and efficiency of this equipment.

CONCEPT AND CLASSIFICATION OF PRESSURE VESSELS

Pressure vessels, in addition to storing fluids under pressure, play a role... strategic in complex industrial processes, where reliability and safety are paramount. They are indispensable. Their design requires rigorous attention to design parameters, such as wall thickness, materials used, and operating conditions. As they point out Martins, Brandão and Rodrigues (2020), the design of a pressure vessel should always prioritize

structural integrity, in order to prevent collapses, leaks or ruptures resulting from overpressure or fatigue of materials.

These devices can operate under internal pressure, when the internal pressure is higher than atmospheric pressure , or under external pressure, as occurs in vacuum vessels. In both In these cases, the mechanical resistance must be dimensioned based on precise calculations that... take into account factors such as tangential, longitudinal, and radial stresses. Henn and Konno (2022) highlight that the analysis of these stresses is crucial for failure prevention. being one of the central points of international design standards, such as ASME Section VIII.

The choice of material used in manufacturing also directly influences the Vessel performance. Materials such as carbon steel, stainless steel, and special alloys are frequently used, varying according to the type of fluid and the temperature range of Operation. In applications involving corrosive fluids, the use of internal coatings Or, selecting corrosion-resistant alloys is essential to extend the service life of... equipment and ensure operational safety (Martins; Brandão; Rodrigues, 2020).

In addition to structural aspects, the geometry of the pressure vessel is another element. A key factor in its efficiency is the use of cylindrical and spherical vessels, which are the most common configurations. common, as they distribute stresses evenly and allow for better utilization of material. Spherical vessels, for example, withstand higher pressures with less thick walls, making them suitable for storing gases at high pressure. Cylindrical vessels are preferred for their ease of manufacture and maintenance (Henn; Konno, 2022).

With regard to regulatory classification, ASME Section VIII subdivides vessels. in Divisions 1, 2, and 3, according to the level of complexity and the degree of risk associated. A Division 1 covers simpler projects, while Division 2 involves detailed calculations. and more stringent design and inspection requirements. Division 3, in turn, applies to vessels. extremely high pressure, generally used in critical processes in the chemical industry and nuclear (Santos, 2022).

ABNT also adopts similar criteria in its related standards, emphasizing The importance of considering the risk category and the potential for damage in case of failures. This national standardization seeks to ensure harmonization between Brazilian requirements and those of other countries. international initiatives, contributing to industrial safety and the competitiveness of companies. Therefore, regulatory compliance is not only a technical requirement, but also... legal, since it regulates the manufacture, operation and periodic inspection of vessels (Martins;

Brandão; Rodrigues, 2020).

In the classification of vessels according to their function within the industrial process. Vessels Storage vessels have the primary purpose of containing pressurized fluids; vessels of These processes carry out chemical or physical transformations under pressure; and heat exchanger vessels. Heat transfer devices are designed to transfer thermal energy between fluids. Each category requires Specific design and maintenance requirements, considering variables such as heat exchange, Thermal expansion and fatigue resistance (Santos, 2022).

Regular maintenance and inspection of pressure vessels are essential steps. For the preservation of operational safety. The ASME and ABNT standards. They determine the need for non-destructive testing, dimensional checks, and control. rigorous welding inspection, with the aim of identifying potential structural defects before... result in catastrophic failures. According to Henn and Konno (2022), the correct application of these Preventive measures significantly reduce the risk of accidents and extend the lifespan of vehicles. equipment, reinforcing the importance of complying with standards from the design phase to the final product. operation.

Figure 1: Types of pressure vessels



Source: <https://www.mindus.com.br/blog-posts/vasos-de-pressao>

ACTING FORCES AND STRESSES: INTERNAL, EXTERNAL, THERMAL AND BY ASSEMBLY

Pressure vessels are subjected to a complex set of stresses and Voltages vary according to operating conditions, fluid type, and temperature. and the manufacturing process. Proper analysis of these stresses is essential to ensure the structural integrity of the equipment and preventing catastrophic failures. According to Silva (2017), Understanding the behavior of internal and external forces allows for sizing.

correctly determine the wall thicknesses, reinforcements, and structural supports, ensuring that the vessel operates within safe limits.

Internal stresses are the most common and result from the pressure exerted by the fluid contained within the vessel. This pressure generates tensile forces on the walls, distributed in circumferential (or rim) stresses and

longitudinal. Circumferential stress is the most critical, as it tends to separate the vessel from the circumferential stress along its length, being the main factor in its sizing. As for tension...

The longitudinal axis of the vessel acts along its axis and, although with less intensity, it must also... to be considered to ensure stability and security (Henn; Konno, 2022).

When the vessel operates under vacuum conditions or is subjected to external pressures, the structural behavior is reversed. In these situations, the walls of the container undergo compression, which can lead to instability and collapse due to buckling if there is no reinforcement suitable. The calculation for external pressure is therefore distinct and more rigorous, requiring additional checks are performed for minimum thickness, stiffness, and resistance to elastic collapse. These parameters are established by the ASME Section VIII and ABNT standards, which guide the... design of pressure vessels subjected to partial or total vacuum (Santos, 2022).

In addition to the tensions generated by pressure, there are also those stemming from... Thermal variations. In industrial environments, the temperature difference between the interior and the exterior is a significant factor. The exterior of the vessel can be significant, causing differential dilatations that induce thermal stresses. These stresses tend to concentrate in weld areas, nozzles, and... connections, where geometric variations are greater. Thermal analysis, therefore, is indispensable in the project and must consider temperature gradients, thermal cycles and effects. fatigue resistance ensures that the material withstands repeated variations without loss of strength. (Henn; Konno, 2022).

Thermal effects become even more relevant in vessels used in cyclic processes, such as in reactors and heat exchangers, where heating and cooling occurs continuously. Under these conditions, thermal fatigue can cause surface microcracks that evolve into more serious defects. Therefore, the use of materials with high fatigue resistance and good thermal conductivity, it is recommended, therefore... such as the implementation of interior coatings and temperature control systems. (Silva, 2017).

During the manufacturing and assembly process, stresses arise. residual stresses, resulting mainly from welding and cold forming. They remain in the material even after production is complete, and may affect performance.



of the vessel in operation. According to Santos (2022), if they are not properly treated, the Residual stresses can generate deformations, cracks, and premature failures, especially in Equipment subjected to repetitive loading and unloading cycles.

To reduce the effects of residual stresses, treatments are commonly employed. Thermal relief procedures, performed after welding. This procedure consists of heating the The vessel is brought to a controlled temperature and then cooled slowly, promoting the Uniform redistribution of internal stresses. This treatment increases the ductility of the material, reduces the risk of cracking and improves mechanical behavior under load (Henn; Konno, 2022).

Dimensional control and precision are key during equipment assembly. Minor misalignments, poorly executed welds, or local deformations can generate Additional stresses that compromise the vessel's safety. Therefore, monitoring is necessary. Rigorous control of manufacturing, inspection, and non-destructive testing stages is indispensable. According to Silva (2017), the joint analysis of internal, external, thermal and residual forces allows a more robust project, aligned with technical standards and capable of guaranteeing safety and Durability throughout the equipment's lifespan.

SAFETY FACTORS: HISTORY AND PRACTICAL APPLICATION

The concept of a safety factor has its origins in the early days of engineering. structural, when knowledge about the properties of materials and methods of Calculation was limited. In early designs for pressure vessels and other metal structures, The engineers adopted high safety factor values as a way to compensate for the Uncertainties associated with load variations, geometric imperfections, and process failures. of manufacturing. According to Zeferino (2023), this empirical criterion guaranteed a margin comprehensive security, even if it resulted in oversized equipment and less economically efficient.

With advances in materials science and the development of techniques Based on experimental principles, the safety factor began to be established based on sound reasoning. statistical and mechanical strength analyses. International standards, such as ASME. Section VIII, and Brazilian standards, such as ABNT NBR 13.531, define criteria.

specific sizing criteria that take into account allowable stresses, the The behavior of materials under pressure and the environmental conditions to which the vessel will be subjected.

exposed (Conceição, 2023). Thus, the concept evolved from a simple empirical margin to a technical parameter based on scientific data.

In practical application, the safety factor is used to ensure that the vessel... pressure that withstands forces exceeding those anticipated during normal operation, offering a reserve of resistance against possible overloads. According to Oliveira HGD (2023), the The sizing must take into account the design pressure, which is greater than the operating pressure. ensuring that small variations do not compromise the integrity of the equipment. This The difference between the pressure values ensures that, even in emergency situations, the vessel... Maintain its structural stability.

Safety factors are determined by taking into account various elements. such as the type of material, the manufacturing process, the welding method, and the conditions environmental factors. In vessels subject to corrosion, for example, additional thicknesses are adopted and Larger safety margins, preventing loss of strength over time. Already in For equipment exposed to intense thermal cycles, the safety factor must take into account the following. Thermal stresses and fatigue effects, which can reduce the lifespan of the material (Zeferino, 2023).

Historically, ASME Section VIII recommends safety factors in the range of 3.5 to 4.0 for metallic materials, values that have been adjusted over the decades. as technology advances and quality control processes improve. A ABNT NBR 13.531 follows similar principles, but adapts the criteria to reality. Brazilian industry, considering aspects of manufacturing, inspection and maintenance. specific to the country (Conceição, 2023). These adjustments allow for a balance to be achieved between safety, performance and economic viability.

In addition to the design phase, the safety factor plays a significant role during the... Operation and periodic inspections of pressure vessels. In technical audits and During inspections, the value used in the sizing is verified as an essential item of conformity, being an integral part of the equipment's technical documentation. Oliveira

HGD (2023) highlights that failure to meet normative values may imply This could lead to the equipment being shut down and even legal penalties, given the seriousness of the risks. associated with potential failures.

The correct application of the safety factor also directly impacts the Operational reliability and maintenance costs. Vessels designed with Adequate margins result in a lower probability of failure and require less... Corrective interventions are less frequent and they have greater durability. However, a safety factor is also important.

Excessively high heights can increase the weight and cost of the equipment, compromising its performance. Economic efficiency. Therefore, the design engineer must seek the ideal balance between safety and structural optimization, considering the context of use of the vessel (Zeferino, 2023).

It is observed that the safety factor, more than just a simple number in the calculation of Resistance represents a principle of technical and ethical responsibility in engineering. This reflects the need to ensure the protection of people, the environment, and facilities. Industrial protection against accidents resulting from structural failures. The careful application of this The concept, supported by established standards and practices, ensures that pressure vessels operate reliably, safely and sustainably throughout their entire lifespan (Oliveira HGD, 2023).

CONSTRUCTION FORMS AND GEOMETRY: CYLINDERS, SPHERICAL SHAPES, LIDS ELLIPTICALS, AMONG OTHERS

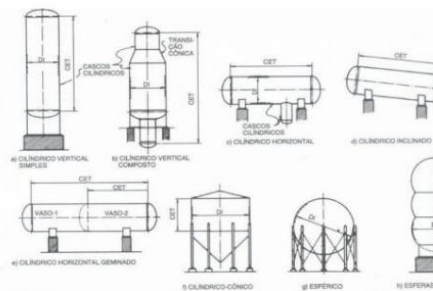
The geometry of pressure vessels has a direct influence on their capacity to... to support internal and external loads, as well as the efficiency of material use. Among the Of the various possible shapes, the cylindrical shape is the most widely used in processes. industrial, especially due to their simplicity of manufacture, ease of transport and maintenance. According to Santos (2022), cylindrical vessels are preferred in applications of medium-sized, in which cost and ease of assembly are determining factors. In addition Furthermore, the cylindrical shape allows the use of curved flat metal sheets, reducing the... It reduces material waste and facilitates the execution of longitudinal and circumferential welds. Spherical vessels, on the other hand, exhibit superior structural behavior in that This refers to the distribution of stresses. This geometry is capable of withstanding internal pressures. high temperatures with smaller wall thicknesses, due to the uniformity in the distribution of Efforts are being made in all directions. However, the manufacture of spherical vessels is more complex and... expensive, requiring high-precision welding processes and strict control of quality. For this reason, they are more commonly used in gas storage systems. tablets and volatile liquids, in which safety and pressure resistance are priorities (Santos, 2022).

Elliptical, hemispherical, and torispherical caps are widely used in... extremities of pressure vessels, as they significantly reduce concentrations of

Stresses that occur in the transition regions between the body and the caps. The elliptical caps
 These are the most common, offering a good balance between mechanical strength and ease of use.
 manufacturing. However, semi-spherical caps offer better performance.
 structural, but they demand greater precision in shaping. Torispherical covers, for their
 In turn, they are an intermediate solution, widely used in large diameter vessels or
 moderate pressure, as they offer an excellent cost-efficiency ratio (Santos,
 2022).

In addition to form and geometry, the choice of construction type should consider
 practical aspects such as the space available for installation, the type of fluid stored and
 the operating conditions. Horizontal vessels are generally used when there are
 height restriction or the need for mounting on linear foundations, while the vessels
 Vertical windows are recommended for small spaces or when it is necessary to facilitate movement.
 Phase separation. Thus, the definition of the constructive and geometric form of the pressure vessel.
 It's not just a matter of resistance, but also of process optimization.
 maintenance and safety, ensuring the best possible technical and economic performance.
 within the regulatory requirements (Santos, 2022).

Figure 2: Pressure vessels and construction forms



Source: <https://tercal.com.br/vasos-de-pressao/>

FUNDAMENTALS OF CALCULATING MINIMUM WALL THICKNESS

Calculating the minimum wall thickness is one of the most critical elements in
 pressure vessel design, as it defines the structural strength required to withstand the
 safe operating conditions. According to Henn and Konno (2022), this calculation
 Its main purpose is to prevent plastic deformation, ruptures, and collapses resulting from...
 of the internal pressure. The thickness must be dimensioned in such a way as to ensure that the stresses
 generated emissions remain within the permissible limits of the material, taking into account the

geometric characteristics of the vessel and the type of predominant stress, whether circumferential, longitudinal or combined.

Technical standards, such as ASME Section VIII and related ABNT standards, They present specific formulas for thickness calculation, considering factors such as internal design pressure, vessel diameter, allowable stress and joint coefficient of weld. These equations are derived from thin-shell theory, which states that the thickness of the The wall thickness should be proportional to the pressure and diameter, and inversely proportional to the... material resistance. Henn and Konno (2022) highlight that, although the theoretical calculation is Essentially, it must always be complemented by experimental checks and inspections of quality.

Also relevant is the inclusion of the corrosion margin in the calculation of thickness. As many vessels operate in harsh environments or store fluids In corrosive environments, the gradual loss of material over time needs to be anticipated. Standards They recommend adding an extra thickness, called "corrosion allowance," which ensures that, even with natural wear and tear, the vase maintains its structural integrity. throughout its designed service life (Henn; Konno, 2022).

In addition to corrosion, the manufacturing process and welding methods also influence... directly in determining the minimum thickness. Imperfections in welds, variations in Plate thickness and residual stresses are factors that require the adoption of coefficients of additional safety. In welded vessels, for example, a joint factor (E) is applied which It reduces the allowable stress, compensating for possible discontinuities. This adjustment is fundamental to preventing localized failures and ensuring proper operational performance. (Henn; Konno, 2022).

The calculation of the minimum thickness must be validated through tests and Non-destructive testing, as specified in design standards. Techniques such as Ultrasound, radiography, and hydrostatic tests allow confirmation of the uniformity of thickness and the absence of defects that could compromise safety. Compliance Strict adherence to these steps ensures that the pressure vessel operates within the parameters of Established safety measures, extending their durability and reducing the risk of accidents. industrial applications. Therefore, calculating the minimum thickness is not just a requirement. It's normative, but one of the fundamental pillars of responsible and safe mechanical design. (Henn; Konno, 2022).

CODES AND TECHNICAL STANDARDS: MAIN ASME REQUIREMENTS

SECTION VIII AND ABNT NBR 13.531 AND RELATED STANDARDS

Technical codes and standards represent the regulatory basis that guides the design and The manufacture of pressure vessels, ensuring uniformity, safety and reliability in industrial processes. ASME Section VIII, widely recognized internationally, was developed by the American Society of Mechanical Engineers and is a global reference for the design and manufacture of pressure equipment. It establishes detailed criteria that They range from calculating wall thickness to welding procedures and testing. of resistance and final inspection. The Brazilian standard ABNT NBR 13.531 adapts these... guidelines adapted to local conditions, taking into account factors such as the availability of materials, manufacturing processes and labor and environmental regulations specific to Brazil (Oliveira, 2023).

ASME Section VIII is divided into three main divisions, each with Different levels of requirements and applications. Division 1 addresses the design of pressure vessels. Conventional criteria, with general calculation and safety requirements. Division 2 presents criteria. more rigorous, including advanced stress analyses and the use of numerical methods, such as finite element. Division 3, on the other hand, is intended for ultra-high pressure vessels, used in Critical applications, such as in the nuclear and aerospace industries. This structure of divisions allows the standard to be adapted to different degrees of complexity and risk (Oliveira, 2023).

One of the central points of ASME Section VIII is the calculation of design pressure and... minimum wall thickness, which must be determined considering the properties the material, the operating temperature, the type of fluid, and corrosion factors. The standard It establishes specific equations and tables for different geometries, such as cylindrical vessels and... spherical, as well as minimum safety factors. Furthermore, it requires that the designs consider a hydrostatic test pressure higher than the operating pressure, as a way to validate structural resistance prior to commercial use (Oliveira, 2023).

ASME requires the application of qualified welding procedures, with Certified professionals, in addition to rigorous inspections at all stages. Non-testing. Destructive methods, such as radiography and ultrasound, are mandatory for detecting discontinuities. Internal factors that could compromise the integrity of the equipment. The technical documentation. A detailed description of the entire process is mandatory, ensuring traceability and compliance with safety standards (Oliveira, 2023).

ABNT NBR 13.531, in turn, follows the same conceptual line as ASME, but This standard incorporates adaptations to the Brazilian industrial context. It defines the requirements. minimum requirements for the design, manufacture, inspection and maintenance of pressure vessels, as well as for the registration of equipment with regulatory bodies, such as the Ministry of Work. Brazilian regulations also emphasize the importance of creating a record of... pressure vessel, mandatory document containing all technical data of equipment, from design to operation (Oliveira, 2023).

Among the main requirements of ABNT NBR 13.531 are thickness calculations. and the strength of the materials, the definition of the operating pressure and the rigorous control of welding. The standard also mandates periodic inspections and tests. hydrostatic inspections, carried out under the supervision of qualified engineers. These inspections are fundamental for identifying wear, cracks, or corrosion that could compromise the performance and safety of the vessel. Failure to meet these requirements may result in legal sanctions and prohibition of the equipment (Oliveira, 2023).

The regulations also address aspects related to operational safety and... worker protection. Both ASME and ABNT establish pressure limits and temperature, criteria for selecting safety valves and relief devices, and Guidelines for positioning and anchoring the vessels. These devices are essential. to prevent serious accidents, such as explosions and leaks of toxic substances or Flammable materials. Therefore, compliance with regulations not only ensures the integrity of equipment, but it also preserves human lives and the environment (Oliveira, 2023).

Safety in the design, manufacture, and operation of pressure vessels depends not on... only from the application of ASME Section standards

VIII and ABNT NBR 13.531, but also the observance of a set of standards. supplementary and national legislation that regulates aspects of inspection, maintenance, professional qualification and technical responsibility. These standards ensure that the equipment lifecycle, from design to decommissioning, occurs within the legal and safety standards required (Oliveira HGD, 2023)

In Brazil, the main legal instrument that deals with pressure vessels is the Standard. Regulatory Standard No. 13 (NR-13), issued by the Ministry of Labor and Employment. It establishes the minimum requirements for the installation, operation, maintenance and inspection of these. equipment, also determining the need for operator training, development Technical documentation and inspection records. NR-13 is mandatory throughout the territory. nationally, it is considered one of the most important regulatory milestones in security.

industrial (Conceição, 2023). NR-13 classifies pressure vessels into risk categories. (I a V), taking into account the product of the internal volume by the operating pressure. This Classification is fundamental for defining the frequency of inspections and the type of test. required and the level of qualification of the professionals involved. High-pressure vessels or Large volumes fall into higher categories, requiring more rigorous inspections and frequent (Santos, 2022).

NR-13 also highlights the requirement that all pressure vessels possess a technical file, a document that compiles the project, the calculations of sizing, the material used, the manufacturing and welding procedures, the Test results and inspection history. This record must be kept. updated and available at the equipment installation site, being indispensable in audits and inspections (Henn; Konno, 2022).

In addition to NR-13, other ABNT technical standards complement the guidelines of NBR 13.531, expanding the approach to safety, inspection, and maintenance. Among other things, Of particular note is ABNT NBR 15587, which deals with the periodic inspection of pressure vessels and This standard establishes criteria for evaluating structural integrity. It defines methods for... Determining the remaining life of the equipment and fault analysis procedures. found during inspections (Oliveira HGD, 2023).

ABNT NBR 15378, which addresses the requirements for the inspection of boilers and vessels. of pressure in operation. It provides guidance on conducting non-destructive tests, such as ultrasound and radiography, in addition to providing for the documentation of the results for the purposes of Traceability and integrity history. Adopting this standard helps with standardization. of the inspection processes, ensuring uniformity and reliability in the technical reports. (Conceição, 2023).

Additionally, ABNT NBR 12235 provides guidelines for the control of manufacturing and qualification of welders and welding procedures applicable to vessels pressure. This standard ensures that the professionals and processes used meet the required levels. Quality standards required by international regulations. Welding control is considered a one of the most critical factors in the structural integrity of this equipment (Santos, 2022).

API 510 (Pressure Vessel Inspection Code), developed by the American The Petroleum Institute is another reference frequently used in Brazil in conjunction with... ABNT and ASME standards. It provides detailed criteria for inspection, repair, Modification and reclassification of pressure vessels, especially in the oil and gas industries. Adopting API 510 ensures compatibility with international practices and is recommended.



for companies that operate in highly critical environments (Henn; Konno, 2022).

ABNT NBR ISO 9712, which defines the qualifications and certifications required for professionals who perform non-destructive testing. This standard is essential to ensure that Only properly trained technicians should carry out inspections, avoiding misinterpretations. incorrect descriptions of defects or flaws that could compromise the safety of the vessel (Zeferino, 2023).

Brazilian legislation also requires the inspection and maintenance of vessels. Pressure tests must be carried out under the responsibility of a qualified engineer, duly... Registered with CREA (Regional Council of Engineering and Agronomy). This professional must issue technical reports and integrity assessments. ensuring that the equipment complies with standards and can continue operating safely (Conceição, 2023).

In addition to design and operational requirements, the supplementary standards address... Risk management and accident prevention. NR-13, for example, mandates that all... facilities have an emergency action plan, containing procedures for cases of Leakage, explosion, or structural failure. These plans should be reviewed periodically and Workers must receive adequate training for rapid response in situations of emergency (Santos, 2022). In addition, ABNT NBR ISO 45001 can be integrated with Pressure vessel management, creating a safer and more controlled work environment. A The simultaneous application of technical and management standards strengthens the safety culture in industrial organizations (Zeferino, 2023).

The supplementary regulations also address registration requirements and Equipment certification. The National Institute of Metrology, Quality and Technology (INMETRO) acts as a conformity certification body, requiring that pressure vessels imported or domestically manufactured goods must be approved according to national standards. The process ensures that only tested and qualified equipment is used in Brazilian territory (Oliveira HGD, 2023).

The integration between international standards (ASME, API) and national standards (ABNT, NR-13 creates a robust system of technical and legal control. This harmonization facilitates the import and export of equipment, in addition to ensuring that Brazilian projects maintain technical equivalence with global standards. Thus, companies that follow These guidelines achieve greater competitiveness and reliability in the market (Conceição, 2023).

Compliance with these standards ensures the safety of workers and their integrity. of the facilities and environmental preservation. Together, they consolidate engineering.

of pressure vessels as a responsible, evidence-based technical practice and committed to excellence and sustainability (Santos, 2022).

INTEGRITY ASSESSMENT AND FAILURE CRITERIA

Integrity assessment and failure criteria. The assessment of the integrity of vessels. Pressure testing involves the periodic verification of possible structural flaws or damage, such as cracks, Corrosion, deformation, and wear. This analysis can be done through non-destructive tests. Non-destructive testing (NDT), such as ultrasound, liquid penetrant testing, and radiography. Failure criteria These are defined by technical standards and involve acceptable limits of damage before... The need for replacement or repair. An efficient assessment ensures that Safe continuity of operation, avoiding accidents and unscheduled shutdowns (Conceição, 2023; Oliveira HGD, 2023).

Among the main methods used for integrity assessment are... Non-destructive testing (NDT), which allows the detection of internal or surface imperfections. without compromising the structure of the vessel. Ultrasound is widely used to measure thicknesses and identify internal discontinuities, while the penetrant liquid is efficient. to detect surface cracks in critical areas, such as welds and nozzles. Radiography, on the other hand, is used for this purpose. Industrial technology provides a detailed view of the interior of welded joints, revealing porosities, inclusions, and other imperfections that may affect structural strength. (Oliveira HGD, 2023).

These tests should be performed periodically, according to the frequency. established by technical standards, such as ASME Section VIII and ABNT NBR 13.531. A The frequency of inspections depends on factors such as the type of fluid stored and the pressure. of operation, maintenance history and exposure environment. Vessels operating under Harsh conditions, such as high temperatures or the presence of corrosive substances, require shorter inspection intervals. Conceição (2023) highlights that monitoring Continuous monitoring of equipment conditions is an increasingly common practice, allowing for Early detection of anomalies and the adoption of immediate corrective measures.

The failure criteria defined by technical standards determine the limits of Acceptance for different types of damage. For example, moderate levels of corrosion or Small surface cracks may be tolerable, provided they do not compromise the... Overall integrity of the vessel. However, when the damage exceeds the limits

If specified, repairs or component replacement become mandatory. These limits are established based on residual strength analyses, ensuring that the equipment maintains an adequate safety factor even in degraded conditions. (Oliveira HGD, 2023).

Corrosion is one of the most common and concerning failure mechanisms in vessels. It can occur in a generalized or localized way, the latter being more common. Dangerous because it causes punctures in specific areas. To minimize its effects, protective coatings, paint systems, and fluid pH control are used. Visual inspection combined with ultrasound is a recommended practice for process. Visual inspection combined with ultrasound is a recommended practice for to identify critical areas and assess the rate of corrosion over time (Conceição, 2023).

Vessels subjected to repetitive cycles of pressure and temperature undergo variations. continuous stress, which can generate microcracks that progressively evolve until... rupture. ASME and ABNT standards require that the design consider the estimated number of ruptures. operating cycles and that periodic tests be carried out to assess the aging of the material. Oliveira HGD (2023) emphasizes that monitoring structural fatigue is fundamental to avoid unexpected failures in equipment operating under controlled conditions. continuous.

The results obtained from the inspections should be analyzed and recorded in reports. Technical reports that compile the vessel's integrity history inform decision-making. about predictive maintenance, repairs and replacements, and also serve as documents mandatory in audits and inspections. The regulations require that any intervention, Welding or modification to the equipment must be properly documented and approved by qualified engineers. This traceability is essential for risk management and for... legal compliance (Conceição, 2023).

Integrity assessment and failure criteria represent the final link between the The design and safe operation of pressure vessels. They ensure that the equipment, Even under natural aging and operational wear, they continue to meet standards. security measures required by international standards. Effective integrity management does not It not only prevents accidents and reduces costs associated with unexpected downtime, but also reinforces the Industrial safety culture, an indispensable element in any facility that operates with pressurized fluids (Oliveira HGD, 2023).

CONCLUSION

An analysis of the theoretical, normative, and constructive foundations related to Pressure vessels highlight the importance of a thorough mechanical design that ensures both the structural integrity and operational safety of the equipment. These devices play an essential role in various industrial sectors, such as... petrochemical, food and energy industries, and, because they operate under severe pressure and conditions temperature-related issues require strict compliance with technical standards and engineering practices. consolidated. The ASME Section VIII and ABNT NBR 13.531 standards, in establishing Detailed guidelines for design, manufacturing, testing, and inspection ensure standardization and... reliability of pressure vessels. Meeting these requirements reduces significantly reduces the risk of failures, ensuring that the equipment can operate correctly. continuous and safe throughout its entire lifespan. Furthermore, the correct application of the factors... Safety and the precise calculation of the minimum wall thickness are key steps. fundamental in the prevention of industrial accidents.

Studies on stress, tension, and construction methods show that the choice The appropriate geometry, materials, and manufacturing methods are crucial for... performance and durability of the vessels. The analysis of internal, external, thermal and residual conditions allow the design of equipment capable of withstanding different conditions. operation, preserving its structural stability and efficiency. In this context, the Proper sizing and quality control become indispensable to ensure that... The designed parameters remain within the normative limits.

The periodic performance of non-destructive tests, combined with the correct Technical documentation and traceability of inspections are one of the pillars of maintenance. Modern predictive technology. This preventative approach not only extends the lifespan of... equipment, but it also prevents unexpected downtime, reduces operating costs, and increases the safety of the professionals involved.

It is concluded, therefore, that the study and application of normative principles and Technical expertise in the design of pressure vessels is not only a legal requirement, but also a The ethical and professional commitment of engineering to industrial safety and efficiency. The integration of theory, practice, and regulation allows for the development of More reliable, sustainable equipment that complies with international standards. Thus, strict adherence to regulations, coupled with efficient integrity management, is

the path to ensuring the full performance of pressure vessels and the preservation of life.
Human and environmental impact in industrial facilities.

REFERENCES

- CONCEIÇÃO, KV da.** *Analysis of the application of NR-13 in the asset management of a set of pressure vessels: the case of a company in the steel sector.* 2023.
- DE SOUSA, RAF; et al.** *Statistical determination of the maximum operating pressure in pressure vessels.* *Observatorio de la Economía Latinoamericana*, v. 23, n. 1, e8538–e8538, 2025.
- HENN, BC; KONNO, D.** *Pressure vessels: comparison of component sizing between ASME Section VIII Division 1 and EN 13445 standards applied to the pulp and paper industry.* 2022. Undergraduate Thesis (Bachelor of Mechanical Engineering) — Federal Technological University of Paraná, 2022.
- MARTINS, AG; BRANDÃO, SM; RODRIGUES, RFN.** *Maintenance and inspection of pressure vessels – a systematic review.* *Proceedings of the National Symposium on Science and Engineering (SINACEN)*, Anápolis, v. 5, n. 2, p. 57–75, 2020. Available at: <https://anais.unievangelica.edu.br/index.php/SINCEN/article/view/7598/3756>. Accessed on: [date not informed].
- OLIVEIRA, SG de.** *Study on a practical case of pressure vessel inspection.* 2023.
- OLIVEIRA, HGD de.** *Inspection methodology for pressure vessels applied to NR-13: a case study.* 2023.
- SANTOS, VN** *Mathematical modeling and optimization of a pressure vessel for green hydrogen storage.* 2022.
- SILVA, KO** *Theoretical study of thick-walled and composite-walled pressure vessels.* 2017. Final Project (Mechanical Engineering) — São Paulo State University, Guaratinguetá, 2017. 64 p.
- ZEFERINO, J. de S.** *Global optimization of a pressure vessel with ASME Section VIII standard constraints using the GSA metaheuristic algorithm.* 2023.