25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0595
ADEQUACY OF PRESSURE VESSELS UNDER REGULATORY STANDARD NR-13 IN A MINING COMPANY IN THE STATE OF MINAS GERAIS

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Abstract. *The pressure vessels are important equipments in the production processes of companies. These equipments have great potential of risk, which when not projected, improperly installed or used inappropriately and with non-periodic and irregular maintenance can cause accidents of various proportions. Therefore, the safety control of pressure vessels of an institution must be controlled effectively and be coupled with some mandatory principles of management of such equipment, for this there are the Regulatory Standards (Normas Regulamentadoras – NR), of the Ministério do Trabalho e Emprego - MTE, as well as the Brazilian Regulatory Standard (Normas Brasileiras de Regulamentação – NBR) of the Associação Brasileira de Normas Técnicas – ABNT. This work conducted the mapping, characterization and evaluation of the pressure vessels of a mining company in the state of Minas Gerais, specifically within two ore treatment units in order to establish an effective safety management of these assets through the application of the Brazilian norms to ensure a safe and reliable process focusing on the culture of accident prevention.*

Keywords: *Pressure Vessels, NR-13, ABNT NBR, Maintenance, Mining.*

1. INTRODUCTION

Work accidents involving pressure vessels have occurred in Brazilian industries in recent years, many of them due to some safety irregularity in operations related to recklessness, malpractice or negligence with minimum standards of health and safety regulations according to legislation.

According to Telles (2013), pressure vessels are not only the most important equipment of most process industries, but also generally occupy the greater physical space, weight and unit cost in the enterprise. Huppes (2013) complements that the pressure vessels are pressurized elements, so there is a concern about their physical and structural integrity, because in a possible rupture an explosive decompression occurs, generating material losses and possible human losses. It is important to highlight that pressure vessels are dangerous equipment that if badly designed and used improperly may cause work accidents (TELLES, 1996).

The prevention of accidents within organizations must be integrated with the legal norms and procedures of occupational safety. For specific activities with pressure vessels, the Regulatory Standards of the Ministério do Trabalho e Emprego - MTE are applicable, specifically the NR-13, which according to the standard has minimum guidelines related to the management of structural integrity of pressure vessels in aspects related to installation, inspection, operation and maintenance, aiming at the safety and health of workers (MTE, 2008). The Brazilian Regulatory Standard of the Associação Brasileira de Normas Técnicas – ABNT are also applicable; they are useful in standardizing the activities involving pressure vessels. It is important to highlight the ABNT NBR 15417 standard which, according to its definition establishes the minimum requirements for safety inspection of pressure vessels in service (ABNT, 2007), and ABNT NBR ISO 16035, which defines the minimum requirements for the construction of boilers and pressure vessel (ABNT, 2013).

Another important safety standard for activities with pressure vessels is the ASME Code. According to Falcão (2008), ASME codes aim to create safety rules for design and manufacture, presenting methodology and criteria for sizing, manufacturing, performing non-destructive tests, as well as applicable materials with the irrespective permissible stresses.

The standards, rules and procedures could be defined by Couto (2009) as a cluster of fundamental care that everyone must fulfill when undertaking a task or activity, in order to ensure that the vast majority of losses due to undesirable events and how they happen are avoided.

The present work aims to carry out an inspection plan of pressure vessels of the Mineral Treatment Units - UTM in a mining company in the state of Minas Gerais through the mapping, evaluation, characterization, and establishment of pressure vessel improvements according to the guidelines of NR-13 (MTE, 2008) and ABNT NBR 15417 (2007).

2. THEORETICAL REFERENCE

2.1 Pressure vessels

The pressure vessel can be defined according to item 13.5.1.1 of NR-13 as an equipment containing fluids under internal or external pressure, different from atmospheric pressure (MTE, 2018). The pressure vessel is a term used to refer generally to water tight and non-flame receptacles, of any type, size, shape or purpose, containing a fluid under internal or external pressure, other than atmospheric pressure (TELLES, 1996). The inspection of a pressure vessel should involve a set of detailed information and evaluation practices, requiring a legal technical knowledge of the professionals qualified for this function, allowing them to establish control of the company's assets.

2.2 NR-13

As specified by ENIT (2019), regulatory standards are complementary provisions to Chapter V of the CLT, characterized by establishing obligations, rights and duties of workers and employers in order to maintaining safety and health in the workplace. The Ministry of Labor is responsible for formulation and revising these standards through committees with the collaboration of government, employers and employees.

Following the definitions of NR-13, it establishes minimum requirements for structural integrity management of steam boilers, pressure vessels, their interconnection pipe lines, and metal storage tanks in aspects related to installation, inspection, operation and maintenance, aiming at the safety and health of workers (MTE, 2018).

When analyzed only on the bias pressure vessels, the NR-13 MTE (2018) is applicable in two cases:

a) Pressure vessels whose product P.V is greater than eight, where P is the maximum operating pressure in kPa, in module, and V the internal volume;

b) Pressure vessels containing fluid of the independent class of the dimensions and product P.V.

The pressure vessels according to NR-13 MTE (2018) can be classified into categories according to the fluid class and the risk potential according to Table 1.

Table 1: Classification of pressure vessels. Source: Author (2019), adapted from NR-13 (MTE, 2018).

Fluid Class	Risk Potential Group				
	1 P.V ≥ 100	**2** P.V < 100 P.V ≥ 30	**3** P.V < 30 P.V ≥ 2,5	**4** P.V < 2,5 P.V ≥ 1	**5** P.V < 1
	Category				
A - Flammable fluids and fuels fluids with equal or higher temperature to 200 °C; - Toxic with tolerance limit ≤ 200 ppm (parts per million); - Hydrogen; - Acetylene.	I	I	II	III	III
B - Fuels fluids with a temperature less than 200 °C; - toxic fluids with tolerance limits < 20 ppm.	I	II	III	IV	IV
C - Steam water; - Simple suffocating gas; - Compressed air;	I	II	III	IV	V
D - Other fluids.	II	III	IV	V	V

The NR-13 MTE (2018) defines the types of inspections to be performed in three types: initial, extraordinary and periodic.

- The initial safety inspection shall be carried out in new pressure vessels, before to their start-up, at the definitive place of installation, and should include external and internal examinations;
- The extraordinary safety inspection should be performed:

a) Whenever the pressure vessel is damaged by accident or other occurrence that compromises its safety;
b) When the pressure vessel is submitted to repairs or major changes capable of changing its safety condition;
c) Before the pressure vessel is put back into operation, when it remains inactive for more than twelve months;
d) When there is a change in the installation local of the pressure vessel, except for mobile vessels.

- The periodic safety inspection should comprise external and internal testing and must follow the maximum time limits set as Tables 2 and 3.

Table 2: Establishment that do not have Own Equipment Inspection Service – SPIE. Source: Author (2019), adapted from NR-13 (MTE, 2018).

Vase Category	External Examination	Internal Examination
I	1 years	3 years
II	2 years	4 years
III	3 years	6 years
IV	4 years	8 years
V	5 years	10 years

Table 3: Establishments that have Own Equipment Inspection Service – SPIE. Source: Author (2019), adapted from NR-13 (MTE, 2018).

Vase Category	External Examination	Internal Examination
I	3 years	6 years
II	4 years	8 years
III	5 years	10 years
IV	6 years	12 years
V	7 years	at the discretion

"The safety inspection of pressure vessels must be performed under the technical responsibility of a Qualified Professional – PH" according to item 13.5.4.12 of NR-13 (MTE, 2018).

According to NR-13 MTE (2018), for the purpose of this standard, it is considered PH the one who has legal competence to exercise the profession of engineer in the activities related to construction project, operation and maintenance follow-up, inspection and supervision of boiler, pressure vessels, pipelines and metal tanks, as well as his accordance with professional regulations in force in Brazil.

3. METHODOLOGY

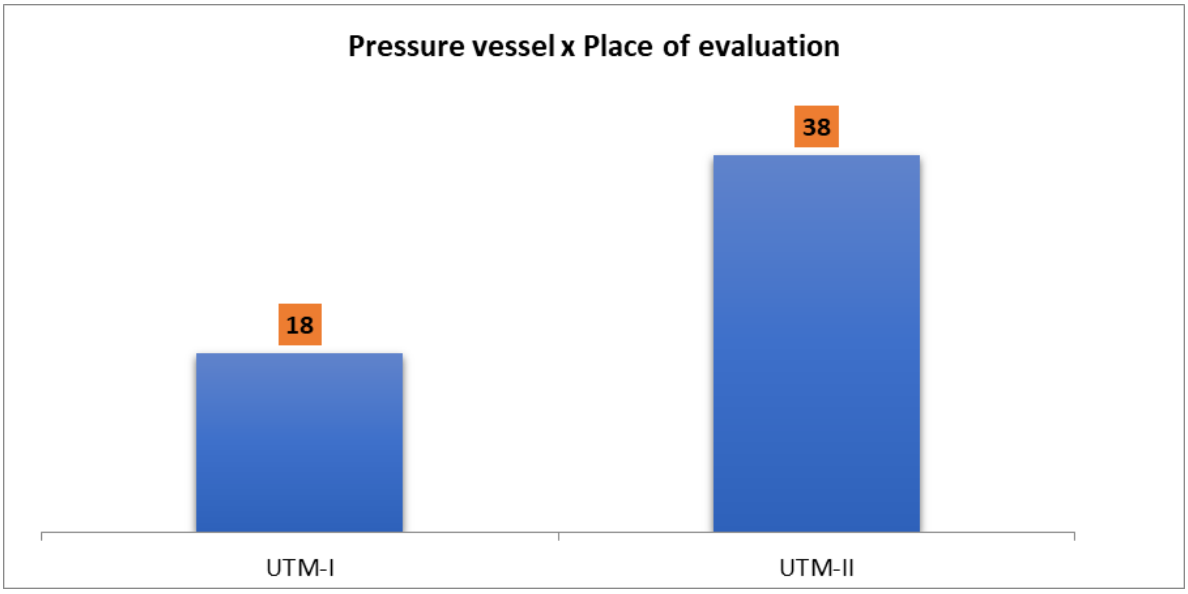
In this work, a field study was carried out in the ore treatment units of a company in the state of Minas Gerais. This study was divided into sequential stages, which include the phase of diagnosis of the scenario through mapping and characterization, on-site inspection in which the documents were interpreted and the structures evaluated, until data consolidation and the establishment of opportunities of improvement for of the security management process of pressure vessels.

3.1 Mapping and characterization

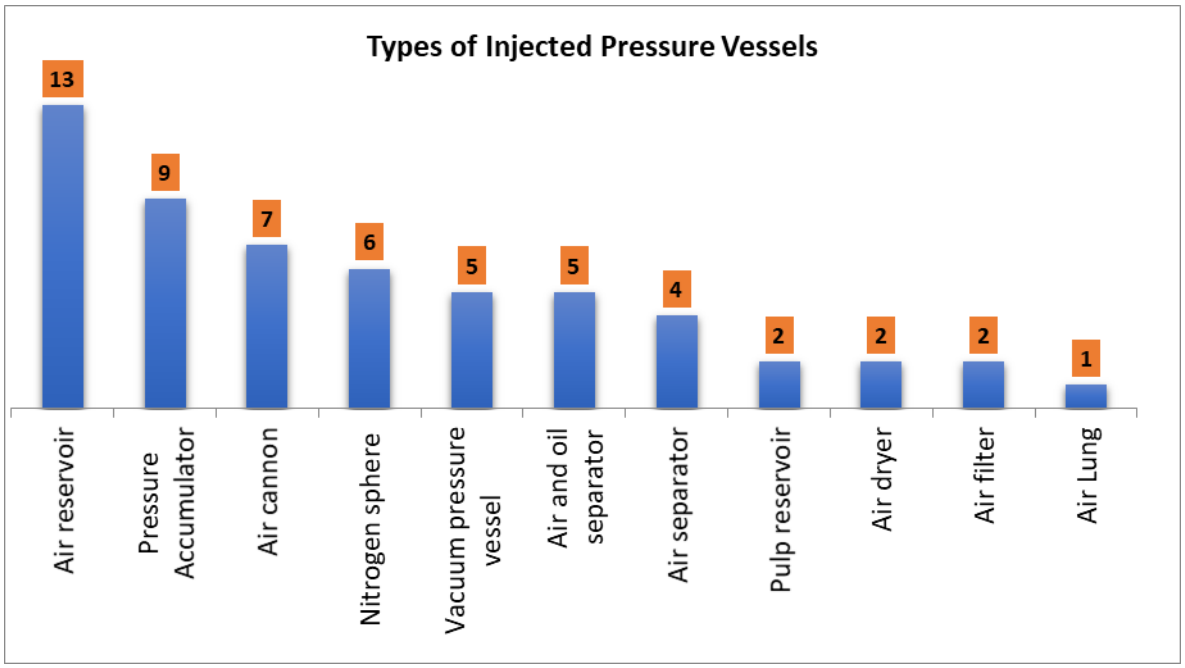
Through the analysis of the documents related to the projects of the pressure vessels, 56 vessels were mapped in the operating areas of the miner within the two units of the ore treatment sector, and then the installation locations for all the vessels, manometers and valves were created on the SAP ERP Software *Systeme, Anwendungen und Produkte*. Table 4 represents the mapping and characterization, then the pressure vessels are measured by area and type, as shown in Graphics 1 and 2.

Table 4: Mapping and characterization of pressure vessels inspected. Source: Author, 2019.

Industry	Identification code	Type of fluid	Product P(Kpa) V(m3)	Location of installation
Mining	RA-IA-101	Compressed air	2451,6625	8000-MB1-SACO-RAI01
Mining	RA-SA-101	Compressed air	9449,68794	8000-MB1-SACO-RAS01
Mining	RA-FT-FG-101	Compressed air	137,2931	8000-MB1-FILT-FTF11-RA1
Mining	RA-CP-SA-101	Compressed air	250,069575	8000-MB1-SACO-CAP01-RA1
Mining	RA-CP-SA-102	Compressed air	250,069575	8000-MB1-SACO-CAP02-RA1
Mining	RA-CP-SA-103	Compressed air	250,069575	8000-MB1-SACO-CAP03-RA1
Mining	CA-RE-101	Compressed air	71,980811	8000-MB1-RECE-SRR01-VP1
Mining	CA-RE-102	Compressed air	71,980811	8000-MB1-RECE-SRR01-VP2
Mining	CA-RE-103	Compressed air	71,980811	8000-MB1-RECE-SRR01-VP3
Mining	CA-RE-104	Compressed air	71,980811	8000-MB1-RECE-SRR01-VP4
Mining	RP-RJ-101	Pulp	2160,895328	8000-MB1-BORE-BRJ22-VP2
Mining	CA-FL-101	Compressed air	383,047749	8000-MB1-FLOT-VPR01
Mining	CA-RJ-101	Compressed air	273,605535	8000-MB1-BORE-BRJ22-VP1
Mining	DA-RJ-101	Nitrogen	2999,800278	8000-MB1-BORE-BRJ22-EN1
Mining	DA-RJ-102	Nitrogen	3000,211335	8000-MB1-BORE-BRJ22-EN2
Mining	DA-RJ-103	Nitrogen	3000,053194	8000-MB1-BORE-BRJ22-EN3
Mining	VA-FG-101	Pulp/air	353,0394	8000-MB1-FILT-VAF11
Mining	VA-FG-102	Pulp/air	353,0394	8000-MB1-FILT-VAF12
Mining	RA-IA-101	Compressed air	3399,99999	8000-MB2-ARCO-COM03-VPR
Mining	RA-PA-101	Compressed air	3399,99999	8000-MB2-ARCO-COM01-VPR
Mining	RA-PA-102	Compressed air	3399,99999	8000-MB2-ARCO-COM02-VPR
Mining	FT-SC-SA-101	Compressed air	39,99999988	8000-MB2-ARCO-COM01-FA1
Mining	FT-SC-SA-102	Compressed air	39,99999988	8000-MB2-ARCO-COM02-FA1
Mining	RA-SC-SA-101-A	Compressed air	299,9999991	8000-MB2-ARCO-COM01-RA1
Mining	RA-SC-SA-102-A	Compressed air	299,9999991	8000-MB2-ARCO-COM02-RA1
Mining	RA-SC-SA-101-B	Compressed air	299,9999991	8000-MB2-ARCO-COM01-RA2
Mining	RA-SC-SA-102-B	Compressed air	299,9999991	8000-MB2-ARCO-COM02-RA2
Mining	SA-SC-SA-101	Compressed air	69,9999998	8000-MB2-ARCO-COM01-SA1
Mining	SA-SC-SA-102	Compressed air	69,9999998	8000-MB2-ARCO-COM02-SA1
Mining	SO-SC-SA-101	Compressed air	59,99999982	8000-MB2-ARCO-COM01-SA2
Mining	SO-SC-SA-102	Compressed air	59,99999982	8000-MB2-ARCO-COM02-SA2
Mining	RA-FG-101-A	Compressed air	200,05566	8000-MB2-FILT-VSA01
Mining	RA-FG-102-A	Pulp/air	1088,53815	8000-MB2-FILT-VSA02
Mining	RA-FG-101-B	Pulp/air	1088,53815	8000-MB2-FILT-VSB01
Mining	RA-FG-102-B	Pulp/air	1088,53815	8000-MB2-FILT-VSB02
Mining	AP-BR-102-A	Oil	116,8553613	8000-MB2-BRPE-BRB02-SHD-AT01
Mining	AP-BR-102-B	Oil	116,1549759	8000-MB2-BRPE-BRB02-SHD-AT02
Mining	AP-BR-102-C	Oil	118,6525083	8000-MB2-BRPE-BRB02-SHD-AT03
Mining	AP-BR-102-D	Oil	116,1549759	8000-MB2-BRPE-BRB02-SHD-AT04
Mining	AP-BR-102-E	Oil	116,1549759	8000-MB2-BRPE-BRB02-SHD-AT05
Mining	AP-BR-102-F	Oil	116,8553613	8000-MB2-BRPE-BRB02-SHD-AT06
Mining	AP-BR-102-G	Oil	116,5749042	8000-MB2-BRPE-BRB02-SHD-AA00
Mining	AP-BR-102-H	Oil	56,69999983	8000-MB2-BRPE-BRB02-SHD-AP02
Mining	AP-BR-102-I	Oil	187,1099976	8000-MB2-BRPE-BRB02-SHD-AP01
Mining	DA-RJ-102-A	Nitrogen	2902,994105	8000-MB2-ESPE-RJA02-EN1
Mining	DA-RJ-102-B	Nitrogen	3000,00025	8000-MB2-ESPE-RJA02-EN2
Mining	DA-RJ-102-C	Nitrogen	3000,200259	8000-MB2-ESPE-RJA02-EN3
Mining	RA-SA-103	Pulp	2149,181551	8000-MB2-ESPE-RJA02-VPR
Mining	RA-SA-104	Compressed air	1327,286203	8000-MB2-BRPE-VPR01
Mining	SE-SA-103-A	Air/oil	183,5999995	8000-MB2-ARCO-COM01-SEP-SS01
Mining	SE-SA-103-B	Air/oil	183,5999995	8000-MB2-ARCO-COM02-SSE-TS02
Mining	SC-SA-103	Compressed air	105,7597515	8000-MB2-ARCO-COM03-SA1
Mining	SC-SA-104	Compressed air	105,7977832	8000-MB2-ARCO-COM03-SA2
Mining	CA-BP-101	Compressed air	69,99900905	8000-MB2-BRPE-PCV01-CA1
Mining	CA-BP-102	Compressed air	69,93081192	8000-MB2-BRPE-PCV01-CA2
Mining	CA-BP-103	Compressed air	69,97854522	8000-MB2-BRPE-PCV01-CA3



Graph 1: Pressure vessel x Place of evaluation. Source: Author, 2019.



Graph 2: Types of Injected Pressure Vessels. Source: Author, 2019.

3.2 Inspection

After the pressure vessel data collection stage, visual inspections were carried out in the operational areas and the evaluation of the legal documents of the equipment, in order to raise possible pending issues and opportunities for improvement.

According to the item 12, the letter "a" of NBR 15417 "It is the responsibility of the users of pressure vessels to keep up to date all periodic inspections determined by the NR-13 of all the vessels installed in their plant, as well as the extraordinary ones" (ABNT 2017).

The on-site inspection of all mapped pressure vessels was carried out by a certified company and subsequently an auxiliary list of external and internal inspections on pressure vessels in service was created by the PH together with maintenance engineering sector, according to NR-13 and the item 8 of ABNT NBR 15417 2017 as shown in Tables 5 and 6, in order to note the checked pending issues. According to Table 1, the vessels were classified, and then the

internal and external inspection time was determined according to Table 2, since the company does not have its own inspection service for this type of equipment.

Table 5: External Inspection Roadmap. Source: Author, 2019.

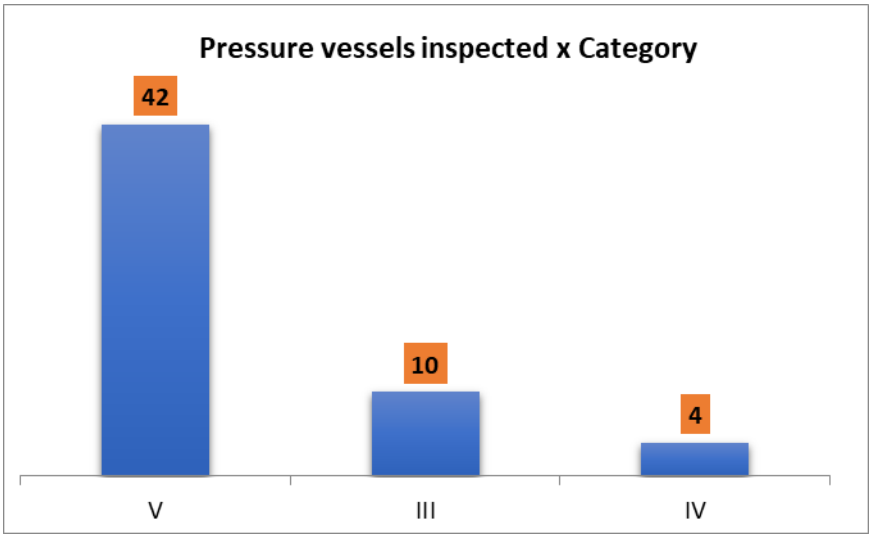
EXTERNAL INSPECTION
DO RISK ANALYSIS.
IS DOCUMENTATION AVAILABLE, COMPLETE AND UPDATED?
IS THERE FLUID LEAKING IN VASE INSTALLATIONS?
ARE THERE DAMAGES TO SCREWED OR WELDED CONNECTIONS?
ARE THERE DAMAGES IN CONSERVATION OF THE CONCRETE BASE?
ARE THERE DAMAGE TO THE EXTERIOR VESSEL SURFACE?
ARE THERE DAMAGES IN THE CONSERVATION OF ADJACENT METAL STRUCTURES?
ARE THERE DAMAGES IN THE CONSERVATION OR OBSTRUCTION OF DRAINS?
IS THERE ACCUMULATION OF MATERIAL OR WASTE ON THE VESSEL?
IS THERE ANY CONDITION WHICH CONSTITUTES AMENDMENT OR REPAIR?
ARE THERE SAFETY RECOMMENDATIONS OR ATTESTED DETERIORATION?
IS ELECTRICAL GROUNDING AND IS IN GOOD CONDITION?
IS LIGHTING IN GOOD CONDITION AND ACCORDING TO STANDARD?
IS EMERGENCY LIGHTING WORKING AND IN GOOD CONDITION?
MAKE INSIDE INSPECTION OF SAFETY VALVE (S).
CALIBRATE SAFETY VALVE (S) WITH ISSUE OF PHOTO REPORT.
CALIBRATE PRESSURE INDICATOR (S) WITH ISSUE OF PHOTOGRAPHIC REPORT.
IS THERE A DEVICE TO PREVENT THE LOCKING OF THE SAFETY VALVE (S)?
IS SIGNAL PLATE IN GOOD CONDITIONS AND ACCORDING TO STANDARD?
THERE ARE 2 DISABLED, SIGNED AND DIRECT OUTPUTS?
IS THERE EASY AND SAFE ACCESS TO MAINTENANCE AND OPERATION ACTIVITIES?
THERE ARE GUARDS WITH DIMENSIONS THAT PREVENT THE FALL OF PEOPLE?
IS THERE PERMANENT VENTILATION THAT CAN NOT BE BLOCKED?

Table 6: Internal Inspection Roadmap. Source: Author, 2019.

INTERNAL INSPECTION
DO RISK ANALYSIS.
IS DOCUMENTATION AVAILABLE, COMPLETE AND UPDATED?
ARE THERE DAMAGE TO ACCESS WINDOWS INSIDE THE VESSEL?
IS THERE ACCUMULATION OF MATERIAL OR RESIDUES INSIDE THE VESSEL?
THERE ARE HOLES OR TRINKS ON THE INTERNAL SURFACE OF THE VESSEL?
THERE IS CORROSION ON THE INTERNAL VASE SURFACE?
THERE IS EVIDENCE OF HYDROSTATIC TESTING OR SIMILAR EXAMINATION?
IS THERE ANY CONDITION WHICH CONSTITUTES AMENDMENT OR REPAIR?
ARE THERE SAFETY RECOMMENDATIONS OR ATTACKED DETERIORATION?
THERE IS SAFETY VALVE (S) AND IS CALIBRATED (S)?
THERE IS PRESSURE INDICATOR (S) AND IS CALIBRATED (S)?
MEASURING THICKNESS (APPLICABLE STANDARD) WITH MINIMUM THICKNESS CALCULATION.
RECALCULATE PMTA WITH MEMORIAL BASED ON LAST THICKNESS FOUND.
INSPECT SAMPLING WELDING USING NON-DESTRUCTIVE APPLICABLE TEST.
RECALCULATE REMAINING LIFE WITH MEMORY OF CALCULATION.

According to the vessel class, 112 inspection plans were created with the scripts of Tables 4 and 5 that contemplate the internal and external inspections in the SAP ERP software in the PM module.

After the definition of the class, the degree of risk of all pressure vessels was obtained, and the amount of vessel per class was quantified according to the Graph 3.



Graph 3 – Pressure vessels inspected x Category. Source: Author, 2019.

In order to validate the inspection performed on the pressure vessels, the contracted company prepared an individual report for each pressure vessel concluding the process. According to item 11 from NBR 15417, the inspection report to prove the inspection of the pressure vessels in accordance with the requirements of NR-13 is mandatory and must be done in a unitary manner for each equipment evaluated (ABNT, 2017).

4. RESULTS AND DISCUSSIONS

According to the inspections performed and analysis of the documentary data of the eighteen pressure vessels of the UTM1, eight were subject to external inspections overdue, among which, two pressure vessels with nomenclature VA-FG-101 and VA-FG-102 were reproved, since they presented risk of accident, due to the work of repair without the project and significant corrosion according to Figures 1 and 2, characterizing a non-compliance with standards and unsafe condition of operation.

According to NR-13, the Alteration and Repair Project - RAP, must be designed or approved by an authorized professional named PH, who also needs to determine materials and execution procedures, as well as quality control and qualification of personnel and repairs or changes in equipment covered by this NR. The PH must also respect the respective design and post-construction codes and the manufacturer's requirements regarding materials, performance procedures, quality control procedures, and qualification and certification of personnel (MTE, 2018).

Ten vessels of the UTM1 had not been inspected, being observed that the calibration of safety valves and manometers were overdue.

Figure 1: Vacuum filter -VA-FG-101. Source: Author, 2019.

Figure 2: Vacuum filter - VA-FG-102. Source: Author, 2019.

According to the items identified with deviation in the UTM 1, external inspections were carried out in the eight vessels and initial inspections in those that needed it, besides calibrating manometers and safety valves in all equipment. The two vessels that were disapproved by the external inspection were immediately interdicted. Subsequently, it was decided by the maintenance engineering team and the PH of the company to carry out the exchange of the equipment

already flagged with deviation since the elaboration of a new project for them would be impracticable with respect to cost and operational demand.

In the UTM2 all vessels were with the inspections accordingly, but it was also observed that the calibration of safety valves and manometers were expired, resulting in the application of corrective measures.

For both pressure vessels inspected, most of them had deviations in the emergency lighting, grounding, and control of opening and closing of valves connected in the vessel lines, as there was no control of the keys of the valve closing locks. Thus, an action plan was created to survey these deviations in the equipment, and also for the corrective measures that must be performed.

5. CONCLUSION

Pressure vessels should be periodically inspected in order to monitor deviations and avoid possible accidents that are directly related to the lack of severe safety control in the work place. This work makes clear the importance of following the NR-13 standard correctly, as well as the way of creating the inspection scripts, which should be very careful and take into consideration the standards in force. In this way, a process capable of generating reliability of the equipment is created; consequently, the company will have an operation with fewer risks for its employees, besides having a longer useful life of their pressure vessels.

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7. RESPONSIBILITY NOTICE

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