Use of carbon steel valves in a highly corrosive environment

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Abstract: This article presents an analysis to enable the use of carbon steel valves in highly corrosive industrial environments, defining their purpose under conditions defined as C4, which, according to ISO 9223, is characterized by high corrosivity. The methodology used was the 6M (Ishikawa Diagram), in addition to Failure Mode and Effects Analysis and bibliographic research, technical standards, and specialized articles. Thus, the main materials used in gate valves were identified, the corrosion susceptibility of the inserted components was verified, and the failure mechanisms associated with corrosion in aggressive environments were identified. An action plan focused on predictive and preventive maintenance was proposed. The conclusion is that the use of carbon steel valves in this industrial environment is possible, provided a strategic maintenance and integrity plan is implemented, which can significantly contribute to increasing asset availability, managing unscheduled shutdowns, and promoting greater operational predictability.
Keywords: Carbon steel valves, Maintenance, Integrity, Oil, Gas.

1. Introduction

Based on the study of A105 gate valves inserted in an industrial context, this article will analyze the behavior of this item and the survey of probable failure mechanisms that may justify a failure, interruption of function, deviations for safety and the environment, having as a stressor agent, that is, the agent linked to the potential failure mechanisms, the environment in which the valves will be used. The topic discussed served as inspiration due to the function the gate valve will perform versus its intended application in a hostile environment for operability. In this technical analysis, we will consider the location of the valves' use at Via Atlântica, BA-530, Camaçari-BA, Postal Code 42810-440.

According to ISO 9223, atmospheric environments are classified into six atmospheric corrosivity categories: C1-Very low corrosivity; C2-Low corrosivity; C3-Medium corrosivity; C4-High corrosivity; C5-Very high corrosivity; CX-Extreme offshore corrosivity [1]. The atmospheric corrosivity in which the valves will be used was evaluated, and, according to ISO 12944 part 2, it was found that the environment is characterized as C4, that is, high corrosivity [2].

Valves are widely used in flow control systems, especially in applications requiring complete fluid shutoff, and their main characteristic is tightness. Because there is an interaction between safety and operational performance, it is important to emphasize that operational safety always comes first. There is a direct correlation: the fewer failures, the longer the service life, and the lower the risk of accidents, whether due to the failure itself or to the actions taken to correct it [3].

In environments with high corrosive aggressiveness, an appropriate selection of materials and anti-corrosive protections is essential to ensure the longevity and reliability of equipment. Metal corrosion continues to be and will always be a problem in the design of any structures that resist the effects of the environment [4].

2. Methodology

The methodology for evaluating integrity and maintainability studies in the Oil & Gas context was based on searches in the main databases of scientific articles and journals. In this context, two fundamental databases were considered: Scopus and Web of Science.

Scopus and Web of Science are leaders in indexable bibliographic databases that cover a wide range of academic disciplines, including natural sciences, social sciences, health sciences, and humanities. It provides access to millions of peer-reviewed journal articles, conference papers, books, and patents.

Both platforms offer robust data analysis tools and queries, such as the h-index and impact factor, to assess the impact and influence of research.

They support researchers, innovators and publishers in exploring academic literature, monitoring guidelines and analyzing trends in global research collaboration.

For more targeted research, we considered study oriented standards, Brazilian federal government ordinances and articles published between 2019 and 2025, covering the following keywords: "Carbon steel valves", "Maintenance", "Integrity", and "Oil and Gas".

3. Literature Review

A gate valve made of carbon steel or a combination of stainless steel materials is found in the literature under the basic design for industrial applications, following at least the API 602-2009 standard, as well as API 598-2023, to ensure performance, quality, and safety, in addition to establishing detailed procedures for visual inspection and pressure testing, especially in the oil and gas industry [5].

The API 602 standard is published by the American Petroleum Institute (API) and establishes the design, manufacturing, inspection, and testing requirements for forged industrial valves in the gate, globe, and check profiles. These valves are generally used in pipelines up to 4 inches (DN100) [6].

Another very important issue in areas where high levels of corrosivity are considered is the need to select the appropriate materials and components based on the application design and the expected use in a given area.

Metal corrosion phenomena encompass a variety of mechanisms that can be grouped into four groups: Corrosion in aqueous media (90%); Oxidation and hot corrosion (8%); Corrosion in organic media (1.8%); and Corrosion by liquid metals (0.2%) [7].

Since the gate valve will meet the safety requirements established by the National Agency of Petroleum, Natural Gas, and Biofuels (ANP), we will discuss proper mechanical integrity management to prevent incidents such as leaks, fires, and explosions. The understandings refer to mechanical integrity management through inspections of pipelines, structures, and equipment in onshore or offshore installations throughout their operational life, as per Article 4 of ANP Ordinance No. 159/2023 [8].

Current configurations in the world of work, with the increasing multiplicity of variables affecting risk and safety management to which organizations are exposed, makes governance and operations management more complex, especially in sectors such as oil and gas. Accidents in the oil and gas sector are critical for human, social, environmental, and economic reasons [9]. Since stopping operations is undesirable, maintenance plans minimize disruption to normal operations and seek not to compromise the safety, reliability, and operational risk of the asset [10].

Therefore, to support the Institutional Strategic Policy, each organization, especially regarding the availability and reliability of its respective asset portfolio, must assign maintenance the crucial role of ensuring operational predictability regarding asset performance. According to NBR 5462, Availability is the ability of an item to be able to perform a certain function at a given time or during a given period, taking into account the combined aspects of its reliability, maintainability, and maintenance support, assuming that the required external resources are assured. Reliability is the ability of an item to perform a required function under specified conditions, during a given period of time [11]. Based on Ishikawa 6M and the survey of causes and effects for gate valve failure mechanisms, we present the probable failures associated with high corrosivity. Using these methodologies, we will define the main causes of gate valve failures as the exposure of these assets to high environmental corrosivity (C4). We present the probable failure mechanisms for gate valves [12,13,14].

To comply with the Ishikawa Methodology, the probable causes of failure of gate valves applied in an environment with high corrosivity were mapped as follows:

1 – Methods: Improper procedures can accelerate corrosion.

a) Lack of inspection, preventive and predictive maintenance;
b) Poorly specified painting or coating;
c) Incorrect cleaning processes;
d) Inadequate operating procedures (partial opening instead of full, which can cause erosion).

2 – Manpower: Untrained maintenance can incorrectly perform preservation.

a) Error in the application of coatings;
b) Maintenance carried out without technical knowledge;
c) Disregard for corrosion protection standards;
d) Lack of adherence to a procedure.

3 – Machinery: Exposed, unprotected gate valves deteriorate.

a) Valves without anti-corrosion coating;
b) Carbon steel equipment in untreated areas;
c) Lack of dehumidification systems;
d) Natural wear of internal components (such as the stem and seat).

4 – Materials: Unsuitable materials for gate valves significantly increase corrosion.

a) Use of metals not resistant to the C4 environment;
b) Lack of cathodic protection or anticorrosive paint;
c) Screws and metal parts not galvanized;
d) Material fatigue due to repeated operating cycles.

5 – Mother Nature: Aggressive conditions in the C4 environment.

a) High humidity (>80%);
b) Presence of contaminants (SO_2, chlorides);
c) Thermal oscillations that favor condensation;
d) Corrosive environments - C4.

6 – Measurement: Maintenance team's failure to monitor corrosion jeopardizes prevention.

a) Lack of humidity sensors;
b) Lack of corrosion rate monitoring;
c) Non-periodic inspections;
d) Incorrect readings that lead to wrong operational decisions.

4. Results

Table 1 shows the types of materials used in an A105 gate valve under the susceptibility of highly corrosive environments:

Table 1. Corrosion Susceptibility - Environment C4

Item	Name	Susceptibility	Material	Component
1	Body	Yes	A105N	Forged low carbon steel
2	Seat	Limited	A276-410	Martensitic S. Steel
3	Wedge	Limited	A276-410	Martensitic S. Steel
4	Stem	Limited	A182-F6A	Martensitic S. Steel
5	Bonnet gasket	Yes	Spirl wounded	Spirl wounded
6	Bonnet	Yes	A105N	Forged low Carbon Steel
7	Packing	Yes	Flexible grafite	Flexible grafite
8	Packing	Yes	Flexible graphite	Flexible graphite
9	Pin	Limited	A276-410	Martensitic S. Steel
10	Gland	Limited	A276-420	Martensitic S. Steel
11	Eyebolt	Limited	A193-B7	Carbon Steel chromium molybdenum
12	Gland flange	Yes	A105N	Forged low carbon steel
13	Eyebolt nut	Yes	A194-2H	Med. Carbon – Tempered/ Quenched
14	Gasket	Limited	A276-410	Martensitic S. Steel
15	Stem nut	Limited	A276-410	Martensitic S. Steel
16	Handwheel	Yes	A194-2HM	Med. Carbon – Tempered/ Quenched
17	Handwheel nut	Yes	A193—B7	Carbon steel chromium molybdenum
18	Bolt	Yes	A193—B7	Carbon steel chromium molybdenum

Below we present a **Figure 1**, that represents the process of vulnerability and susceptibility of materials to corrosion according to Table 1.

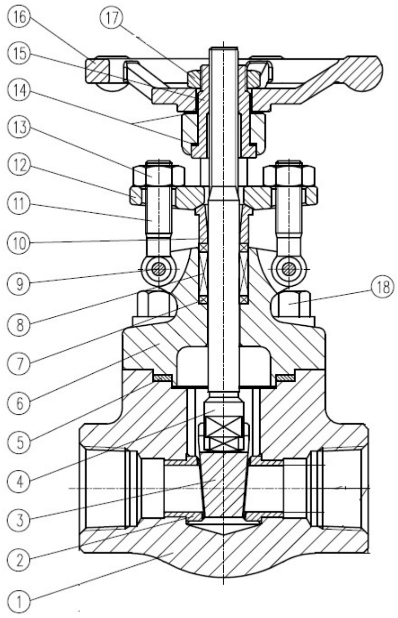

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Figure 2. Representation of the oxidative and corrosive process without the execution of the suggested maintenance plan as per Table 2.

CASA DAS VÁLVULAS. How to prevent oxidation and corrosion in industrial valves. Available at: https://casadasvalvulasmg.com.br/como-evitar-oxidacao-e-corrosao-em-valvulas-industriais/. Accessed on: September 8, 2025.

Due to the types of components used in gate valves, such as low carbon and mixed materials, we present below a suggested maintenance plan in Table 2, with the probable mechanisms that can interrupt operation or cause failures in gate valves.

Table 2. Suggested Maintenance Plan

Activity	Type	Frequency	Method	Objective
External visual inspect-ion	Preventive	Every three months	Visual inspect-ion with checklist	Detect visual damage and loss of protection
Ultra sonic thickness measurement	Predictive	Every six months	Portable Ultra sonic at critical points	Monitor for widespread corrosion
Liquid Penetrant Testing on the Rod	Predictive	Every six months	Liquid Penetrant at fatigue points	Detect fatigue / corrosion cracks
Insulation termography	Predictive	Every six months	Infrared camera	Identify corrosion under insulation points
Lubrication of the rod and mechanism	Preventive	Every three months	Grease compatible with saline environment	Reduce wear and cracks
Valve sealing test	Functional	Operational	Hydraulic/pneumatic operational test	Guarantee of watertightness
Reapplication of anti-corrosive paint	Preventive	Every two years (or sooner)	ISO 12944 [15] / Petrobras technical standards [16]	Restore protection against atmospheric corrosion

For the use of gate valves, ensuring the safe and high-quality operation of these items, given the critical nature of their exposure, as they are subject to a highly corrosive environment, the probable failure mechanisms associated with gate valves were detailed.

To understand the failure mechanisms based on the properties of materials normally used in gate valves for application in the oil and gas sector in highly corrosive environments and to anticipate the probable maintenance interventions necessary to ensure predictability, operational safety, and integrity of this item, we suggest using this action plan thus guiding the maintenance team on what to do and the likely cyclical actions to ensure the longevity of this important component.

5. Conclusion

The use of A105 gate valves in C4 corrosive environments requires special attention to materials, coatings, installation methods, and planning to ensure maintenance and integrity.

To manage the maintenance of these valves, ensuring reliability and availability, and ensuring the use of the best maintenance tools, the Maintenance Team must anticipate the failure mechanisms of gate valves. These valves are manufactured with low-carbon forged steel materials and also with martensitic stainless steel components, which can contribute to galvanic corrosion.

The correct specification based on international standards, such as ISO 12944, combined with the Strategic Integrity and Maintenance Plan with the appropriate assertive execution, providing prior inspections, treatment, painting and appropriate coating, ensures the durability and performance of the valves even in adverse environmental conditions.

However, structuring an Integrity and Maintenance Policy, structuring the Integrity and Maintenance macroflow, as well as providing multidisciplinary standards and procedures, align the expectations of the company's management with the expected results of excellence, above all with the role that the valves will play in the condition of the company with which they were designed to operate, sound like preponderant roles for the correct designation of operating standards, performance, assertiveness and operational predictability.

Maintenance will be responsible for anticipating failure mechanisms by developing, using quality tools, prior planning for the preservation of these valves, using the criteria, methods and technical specifications defined in the standards, to carry out painting and coating services on the valve surfaces, with a view to anti-corrosion protection, chemical resistance of metallic materials and durability, thus guaranteeing the minimization of the impacts of the C4 environment.

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