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Escuela de Ciencias Químicas e Ingeniería

Comprehensive analysis of natural gas processing schemes for power generation

Trabajo de integración curricular presentado como requisito para la obtención del título de Petroquímica

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DEDICATION

I want to dedicate this work to my mother Matilde Herrera because she always trusted me and supports me in the most difficult moments of my life. This is the best way to restart all the efforts that she has made for me and I want to emphasize that thanks to her "Este barquito no se ha hundido."

In addition, I want to dedicate this effort to my son Mathias Yanez and I would like to apologize that for academic reasons I have not been able to dedicate enough time to him. However, I want you to know that I love you and you are my inspiration to move forward and give you more opportunities for your development. Also, I want to dedicate my degree work to friends who did not stop believing in me such as Tefo, Gino, Pancho, and Aracely. In the course of my student life, they have been the people who have accompanied me through good and bad moments. However, I thank Tefo for being the best person I have ever known, Gino for always making our day, Pancho for being there when I need him most, and Aracely for always count on your help and company.

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Finally, and without diminishing it, I want to thank myself for the effort made throughout my life and for never giving up.

RESUMEN

La corrosión es un proceso químico continuo de la industria del petróleo y el gas. Este fenómeno afecta la integridad del sistema de tuberías que transportan gas natural. La formación de productos de corrosión dentro de las tuberías se debe a la presencia de CO_2, H_2S y presencia de microrganismos. Por esa razón, este trabajo trata de prevenir la corrosión de los gaseoductos a través de métodos operacionales tales como la identificación de amenazas potenciales, la evaluación de riesgos, la valorización de la integridad del sistema de tuberías y respuesta y mitigación de las amenazas encontradas. En primer lugar, se deben identificar las amenazas potenciales revisando la documentación disponible de la operación del gaseoducto de estudio, se deberán analizar los riesgos y posibles consecuencias en este punto. Luego, estos riesgos deberán ser evaluados a través de métodos cualitativos como es la categorización de probabilidad de que ocurra y una categoría de consecuencia del riesgo. Como resultado, se deben interpolar los dos métodos para el diseño de una matriz de riesgos y evaluar los riesgos en consecuencias y probabilidad a que ocurra. Entonces, se debe valorizar la integridad del sistema de tuberías a través de métodos intrusivos y no intrusivos. Para aplicar alguno de los dos métodos se debe tener en cuenta que los métodos intrusivos son aquellos que interfieren con la estructura del gaseoducto y los métodos no intrusivos son aquellos que no interfieren con la estructura de las tuberías de gas. Así mismo, los métodos intrusivos se jerarquizan con el uso de "Pigs" de limpieza, pruebas de presión y valoración directa de la corrosión externa. Por otro lado, los métodos no intrusivos se jerarquizan con el uso de Magnetic Flux Leakage (MFL), Ultrasound (UT), Electric Acoustic Trnsducers (EMAT), y Eddy currents(ET). Para usar un método intrusivo y no intrusivo se debe conocer las características operacionales del ducto de estudio. A continuación, se debe mitigar y dar respuesta a los riesgos encontrados a través de la selección de materiales de construcción, uso de revestimiento orgánicos e inorgánicos, corridas de "pigs", estudio de fugas, mantenimiento correctivo y preventivo y por ultimo brindar las recomendaciones para que el riegos no vuelva a ocurrir o si ocurre poderlos mitigar rápidamente. Finalmente, se desarrolla un mapa conceptual para la toma de desiciones para mitigar la corrosion temprana.

Palabras clave: corrosión, matriz de riesgo, gas natural, gasoductos, valorización de la integridad, respuesta y mitigación.

ABSTRACT

Corrosion is a continuous chemical process in the oil and gas industry. This phenomenon affects the integrity of the pipeline system that carries natural gas. The formation of corrosion products inside the pipes is due to the presence of CO_2, H_2S, and the presence of microorganisms. For this reason, this work tries to prevent the corrosion of gas pipelines through operational methods such as the identification of potential threats, risk assessment, the assessment of the integrity of the pipeline system, and response and mitigation of the threats found. In the first place, the potential threats must be identified by reviewing the available documentation of the operation of the gas pipeline under study, the risks and possible consequences must be analyzed at this point. Then, these risks must be evaluated through qualitative methods such as the categorization of the probability of their occurrence and a category of the consequence of the risk. As a result, the two methods must be interpolated to design a risk matrix and evaluate the risks in consequences and the probability of their occurrence. Then, the integrity of the piping system must be valued through intrusive and non-intrusive methods. To apply either of the two methods, it must be taken into account that intrusive methods are those that interfere with the structure of the gas pipeline and non-intrusive methods are those that do not interfere with the structure of the gas pipes. Likewise, intrusive methods are ranked with the use of cleaning "Pigs", pressure tests, and direct assessment of external corrosion. On the other hand, non-intrusive methods are ranked with the use of Magnetic Flux Leakage (MFL), Ultrasound (UT), Electric Acoustic Transducers (EMAT), and Eddy currents (ET). To use an intrusive and non-intrusive method, the operational characteristics of the study pipeline must be known. Next, the risks found must be mitigated and through the selection of construction materials, use of organic and inorganic coatings, pigs run, leak studies, corrective and preventive maintenance, and finally, provide recommendations so that the risks do not return, do not occurred or if it happens, they can be mitigated quickly. Finally, a concept map is developed for decision making to mitigate early corrosion.

Keywords: corrosion, risk matrix, natural gas, pipelines, integrity assessment, response and mitigation.

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CHAPTER I: PURPOSE AND SIGNIFICANCE OF THE STUDY

1. Introduction

Currently, the globalization of the economy and the factors associated with the increase in effectiveness in production, safety, and quality; constantly increases pressure on roduction businesses. In this context, the hydrocarbon industry has special relevance because businesses must produce more and more and for this, they make use of fuels that come from hydrocarbons that are found in deposits hundreds of kilometers from consumption centers and reach these through ducts.[1] Likewise, the pipelines are steel pipes that can measure up to 40 inches in diameter and extend long distances from the fields to the cryogenic plants where the gas will be processed to obtain energy sources for the industry. Pipeline systems that transport gas are subjected to different risks such as internal and external corrosion, design and materials, movements, among others. These risks have a varied probability of occurrence and consequence that can result in injuries, material damage, or damage to the environment. [2]

Technological methods are used to assess gas transport piping systems to verify corrosion in the piping system.[3] These methods can be intrusive and non-intrusive, depending on the operational characteristics of the gas piping system. These methods are important to avoid any leakage, and preventive maintenance since a high non-program represents a high cost. [1]This is because natural gas is not delivered to customers, or it can cause strong impacts on the environment. For that reason, it is important to implement an integrity management plan to meet the goal of the incident and corrosion-free operation. [4]

Nowadays, there are several methods to determine the integrity of a piping system for the prevention of corrosion. However, this work tries to implement a qualitative method that mitigates corrosion products through preventive plans such as the analysis of potential risks, risk assessment, assessment of potential risks, and their responses and mitigation.

1.1.Problem Approach

Corrosion is a phenomenon that affects pipelines that transport natural gas, for that reason it is important to find an operational method that can mitigate this problem. There are several preventative methods to mitigate corrosion, however these can be confusing and unintelligible to unfamiliar people. For this reason, the present work tries to analyze a qualitative method for the reduction of corrosion products, for example, the corrosion product called black powder. This corrosion affects the functioning of the pipes because they can slow down the flow of gas and compromise service instruments such as compressors, pumps, filters, valves, among others. Consequently, natural gas extraction plants must have unscheduled operational shutdowns, which causes a decrease in production and less energy generation, which results in increased maintenance and corrosion mitigation costs.

1.2.Objectives

1.2.1. General.

Schematize a decision-making diagram evaluation of the integrity of the pipelines that transport natural gas for the early prevention of corrosion.

1.2.2. Specifics.

- ✓ Analyze the processes for the identification of potential threats in the pipelines that transport natural gas.
- ✓ Study the risk assessment for the mitigation of gas pipeline corrosion through qualitative methods.
- ✓ Generate a risk matrix through the interpolation of the occurrence of a risk and its possible consequences.
- ✓ Evaluate the methods to assess the integrity of pipelines that transport natural gas through intrusive and non-intrusive methods.

- ✓ Analyze the characteristics of natural gas pipelines for the applicability of intrusive and non-intrusive methods.
- ✓ Study the possible responses and mitigation to prevent the early formation of corrosion products.

CHAPTER II: BACKGROUND INFORMATION

2.1 Corrosion

One of the most common problems in the oil industry is the control of corrosion since the constant humidity and contamination of the environment affect the metallic structures.[5] In addition, the lack of maintenance and corrosion has caused the collapse of structures, for example, according to a BBC report in which oil spills were studied from 2000 to 2010 in Ecuador, it was mentioned that corrosion caused 28% of all accidents, that is, due to corrosion, the metallic structures fractured and spilled oil. In addition, corrosion caused 17% of mechanical failures that were solved with preventive maintenance. [6]

The main problem in the oil industry is corrosion in the transportation of petroleum derivatives through pipelines, either because of internal or external corrosion. Corrosion is the most destructive attack that metallic structures can face since it originates from the reaction with the environment, becoming a worldwide problem.[7]

External corrosion usually arises when there are defects in the external coating of the metal structure, which causes the contact of the metal and the humidity of the environment. To identify external corrosion in metallic structures, the following characteristics must be analyzed:[1]

• The pH level of the environment

• The humidity of the environment in contact with the metal.

• Pores, cracks, and detachment in the coating

• The resistivity of the metal.

• Analyze the cathodic protection system.

Corrosion is a great threat to the integrity of piping systems as this phenomenon grows exponentially over time. This is because the corrosion process locally reduces the metal cross-section (thickness) and as time passes the remaining stress is reduced, consequently, the pipeline decreases its ability to contain the internal pressure of petroleum derivatives, which would cause a break in the area containing the damage.[3]

Corrosion is a problem that affects the entire industrial sector, for that reason, many institutions and scientists have dedicated part of their research to combat this phenomenon. In addition, time, money, and technology have been invested to mitigate and eliminate corrosion. In the process of fighting against corrosion, it was identified that the effective methods to mitigate corrosion are: internal and external mechanical coating in piping systems, cathodic protection, and well-designed maintenance programs.[7]

2.1.1. Definition of corrosion

Corrosion is defined as the degradation of the material through its interaction with the environment. This definition covers all materials such as natural, man-made, metallic, and metals. However, this study analyzes the corrosion of metals, especially the corrosion of low-alloy carbon steels used in pipes. Consequently, it is established that corrosion in metals is determined by the thermodynamics of the reaction, which indicates that corrosion will occur and the kinetics of corrosion that provide the durability of the pipe. [8] On the other hand, to extract a metal from a mineral (hematite or bauxite) it must be placed in a high energy state. According to the principles of thermodynamics, a material always looks for a lower energy state to be stable. That is, most metals are thermodynamically unstable and for that reason, they will seek lower energy states such as an oxide or another compound. As a result, corrosion is the process from high-energy metals to lower energy oxides.[9]

Corrosion commonly occurs in aqueous environments (water content) and at room temperature. The aqueous medium is called the electrolyte and in the case of underground pipes, the electrolyte is the moist soil. The corrosion process is the transfer of electrons (oxidation) from the metal to the medium surrounding the metal. The oxidation reaction is called an anodic reaction and the reduction reaction is called a cathodic reaction. These two electrochemical reactions are necessary for corrosion to be passed. In the oxidation reaction, the metal gives up its electrons to be consumed in the reduction reaction to maintain the neutrality of the charge.[10]

Oxidation and reduction reactions are sometimes semi-cellular and can occur at the same site in the metal (locally) or they can be physically separated. If the electrochemical oxidation process is physically separated, the phenomenon is called a differential corrosion cell. As shown in figure 1, this is a schematic of a differential corrosion cell. This figure shows that the site where the metal is oxidized is the anode or anode site. On the other hand, the positive flow of charge travels from the metal surface to the electrolyte where oxygen, water, or some other species are being reduced. This site is known as the cathode or cathodic site. Corrosion in pipelines submerged in water or underground is usually the result of differential corrosion cells of which can be classified as differential aeration cells and galvanic corrosion.[11]

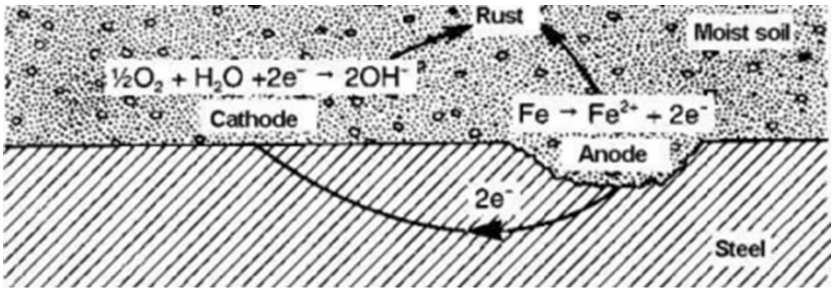

Figure 1 Example of differential corrrosion on a pipeline in soil[12]

2.2. Types of corrosion

In the next section, the different types of corrosion that can attack pipelines that transport natural gas will be studied. The types of corrosion that can attack gas pipelines are uniform corrosion, localized corrosion, galvanic corrosion, corrosion due to the presence of CO2, corrosion by H2S, and microbiologically induced corrosion.

2.2.1. Uniform Corrosion

Uniform corrosion is corrosion that is evenly distributed over the surface of a material. This uniform / general corrosion can happen in isolated places along a pipeline due to its isolated environment.[14] However, the damage should be uniform within that location as shown in figure 2.

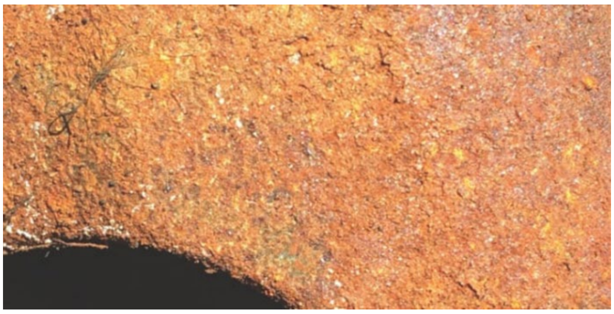

Figure 2. Uniform pipe corrosion [13]

2.1.2 Localized Corrosion

Local corrosion is the oxidation concentrated in a small area of the surface, also, these areas are cavities that are called pits. Localized corrosion can develop in areas outside the global environment, such as under washers and flanges. In addition, this type of corrosion produces holes in the metal or fissures that can enlarge over time and form craters as shown in figure 3. In this way, a pipe in good condition can have local corrosion and collapse at any time.[14]

Figure 3. Localized crater-forming corrosion in a good pipeline.

2.1.3. Galvanic corrosion.

Galvanic corrosion is oxidation when electrically connecting two materials, in which one acts as an anode and the other acts as a cathode as shown in figure 4. Galvanic corrosion can occur under various conditions, such as the difference between metals. , also, when the same metal is provided in different media or different ages. On the other hand, it is important to take into account the relative areas of the anode and cathode in a galvanic corrosion system since the corrosion rate must be equal to the cathodic area exposed to the electrolyte. That is, the oxidation rate must be equivalent to the total reduction rate in the environment where the reaction occurs.[14-15]

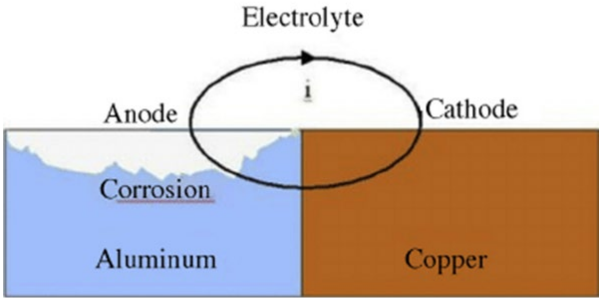

Figure 4. Galvanic corrosión of aluminum [15]

2.1.4. Corrosion by presence of CO_2 (Sweet corrosion)

One of the most common problems in the oil and gas industry is corrosion caused by the presence of varying amounts of gas and water. The corrosive agent is produced by the presence of sweet gas at high depths and the use of recovery techniques that are based on the injection of chemicals. To better understand sweet corrosion, it should be known that CO_2 dissolves in water and generates electrochemical reactions (cathodic and anodic) on the surface of the metal, giving rise to corrosion products as shown in figure 5. In the First steps a rapid dissolution occurs in the metal layer, then, the dissolved ferrous ions are transported to the liquid where they mix with the carbonate ions and form a layer of iron carbonate or sulfide on the metal surface.[16]

Figure 5. Metal surface attacked by CO_2 corrosion (sweet corrosion) taken[17]

2.1.5. H_2S Corrosion (Sour Corrosion)

One of the most common corrosion in the oil industry due to its high concentration and existence in oil fields is H_2S corrosion. H_2S is a gas that harms human health in high concentrations, however, when this gas is in contact with metals such as production pipes, this gas tends to be a highly corrosive agent as shown in figure 6. Hydrogen sulfide is soluble in hydrocarbons and water and will separate from these depending on local pressure, temperature and pH. Sour corrosion occurs in fluids containing H_2S and depends on the partial pressure of the acid. The partial pressure of a gas in a mixture is the measure of the thermodynamic activity of the molecules of said gas and is proportional to its temperature and concentration.[17]

Figure 6. H_2S-induced corrosion on a metal Surface [17]

2.1.5. Microbiologically Induced Corrosion (MIC)

Microbiologically induced corrosion (MIC) is the wear of the metal because of the processes of microorganisms (bacteria, fungi, algae, and protozoa). Generated by the metabolic activities of microbial communities, the interface between the metal surface and organisms is physically and chemically altered by these organisms.[6] The products of these reactions are acids, alcohols, ammonia, carbon dioxide, hydrogen sulfide, and other by-products that can corrode various metals. In addition, microbes can consume oxygen, causing anions to concentrate in pits or cracks in the metal.[10] Consequently, they can break passive surface films, and accelerate corrosive attack through a variety of mechanisms as shown in figure 7.

Figure 7 . Microbiologically Induced Corrosion (MIC) [10]

2.2. Offshore platform system

Offshore gas platforms are a set of structures and facilities in different seas and oceans whose objective is the oil extraction and natural gas from the seabed. The main task of these platforms is the operation of drilling the subsoil until reaching the depth where the reservoir that contains them is located (800 and 6000 meters), likewise, these structures must control the production operations, primary processing, and the channeling of the extracted hydrocarbons.[18-20]

There are several types of marine platforms such as fixed, self-elevating, and semi-submersible. The main objective of these platforms is the exploration and production of natural gas and/or oil. However, over time, other functions have emerged for the use of these platforms, such as the use of energy from the sea, airports, wind turbine supports, and the base of buildings. The same design and construction principle of an offshore platform can be used for all these functions. [20]

2.2.1. Types of offshore platforms and their use

The platforms can be divided into two blocks, which, the first block can be differentiated by its functionality and the second by its position and/or support form. In this way, it can be distinguished that a platform can be fixed drilling or self-lifting drilling. It is important to mention that it is important to know the types of seabed depths in the waters of the seas where the platforms will be installed.[21] According to the standards of PEMEX NRF-037-PEMEX-2012, it is mentioned that shallow water: is the water depth less than 500 meters, deep water: is the water depth that is in the range of 500 to 1500 meters, and ultra-deep waters: is the water depth greater than 1500 meters.[22]

2.3. Natural Gas

Natural gas is a fossil fuel made up of several hydrocarbons, which are reservoir conditions, they are in a gaseous state or solution with oil. In general, in nature, it is found as associated natural gas when it is with oil in its chemical structure and when it does not have the presence of oil it is known as non-associated natural gas. The main chemical component of natural gas is methane, which usually makes up 90% of it. Its other components are ethane, propane, butane, and other heavier fractions such as pentane, hexane, and heptane.[23] Table 1 shows the physical-chemical characteristics of natural gas.

Table 1 Physicochemical characteristics of natural gas[24]

Property	**Natural gas**
Composition	90% Methane
Chemical formula	CH_4
Specific gravity	0,60
Calorific power	9200 kcal/m^2
Supply pressure	21 mbar
Physical state	Gaseous with no compression limit. Liquid at -120 ºC and atmospheric pressure
Color / Smell	Colorless / Odorless

Natural gas reaches consumers through pipes or pipeline networks since this is the safest and most economical way to transport hydrocarbon. Natural gas is an inexpensive and versatile fuel that is used as fuel in different activities at the domestic, commercial, and industrial levels.[24]

2.3.1. Natural gas value chain

Natural gas is a mixture of different gases as shown in table 2, although methane predominates. The gas originates as a consequence of the decomposition over thousands of years of organic matter buried in other sediments at high pressures and high temperatures inside the reservoir at great depths.[19-25]

- Extraction and treatment of stored gas
- Liquefaction and transportation in the form of liquefied natural gas (LNG)
- Subsequent regasification and/or transportation as a gas through gas pipelines

- Storage
- Distribution to points of consumption

Table 2 Composition of natural gas[26]

Element	Formulation	%
Methane	CH_4	70-90%
Ethane	C_2H_6	
Propane	C_3H_8	0-20%
Butane	C_4H_{10}	
Carbon dioxide	O_2	0-8%
Oxygen	O_2	0-0,2%
Nitrogen	N_2	0-5%
Hydrogen sulfate	H_2S	0-5%
Other gases	A, He, Ne, Xe	Small amount

On the other hand, the activities that make up the natural gas value chain from the exploration phase until it is consumed by the end customer is the following also shown in figure 8:

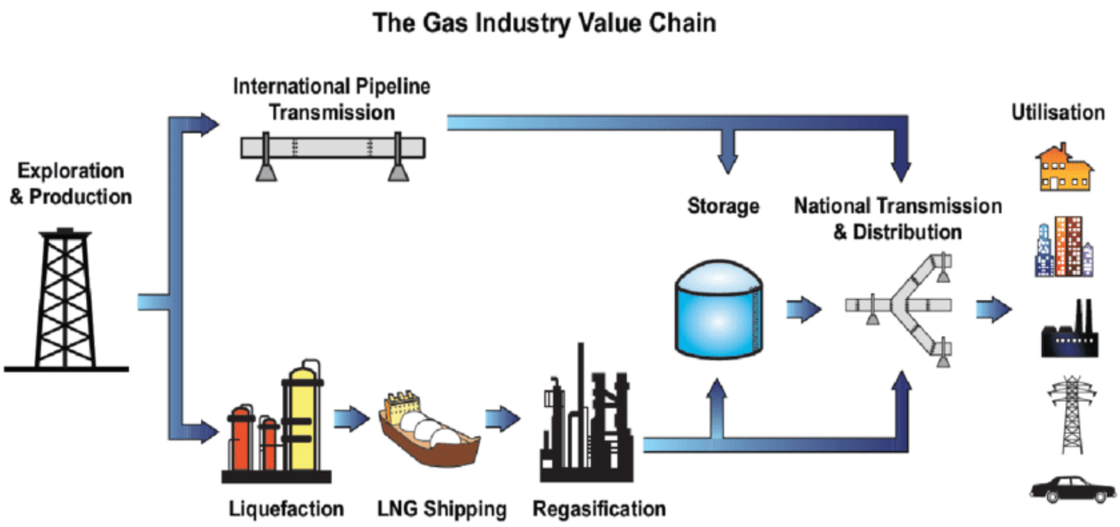

Figure 8 Natural gas value chain: from the exploration to the consumer.[27]

2.3.2. Natural gas transportation

This subchapter will develop the transportation of natural gas previously established in the natural gas value chain. The cost of transporting natural gas is the link in the value chain because it makes the final price more expensive and can make a gas supply not economically viable for the transporter, depending on the means used. In this case, the transport must be analyzed according to the demand to be attended to and the distance of the transport. Among the means of transportation of natural gas stand out:[22]

Roads:

This medium is used to transport compressed natural gas (CNG) in cylindrical tubes, at high pressures usually between 200 bar (2,900 psi) and 250 bar (2,626 psi).[22]

Gas pipelines:

The most used system to transport natural gas between two specific points is the gas pipeline (carbon steel pipes, with high elasticity). These pipes can be buried in the terrestrial surface or at the bottom of the oceans. To know the transport capacity of gas pipelines, the difference in pressure between their ends and their diameter must be determined (if the diameter is increased, the transport capacity increases). To circulate the gas through the pipes, pressure must be entered at different points. This is done through compression stations, which regulate the flow of gas, compensating for pressure losses that occur in transport. Gas flows are controlled from facilities where they receive the measurements of pressures, temperatures, flows, and calorific powers (control centers).[24-25]

Marine

In general, this type of transport is used to move Liquefied Natural Gas (LNG). This has been converted to liquid through cryogenic plants (through liquefaction processes). In this way, their volume is reduced by 600 times for efficient storage and transport to take them long distances and at low cost.[26]

According to the three means of transport, it can be concluded that the best mobilize natural gas is by gas pipeline since this means is the safest and most efficient way.

2.4. Black Powder

Black powder is a term that describes the corrosion found in pipelines that carry natural gas, hydrocarbon condensate, and liquefied petroleum gas. This phenomenon can be generated from pipes to downstream processes and damage equipment through plugging and erosion. This type of corrosion can be a dry powder, a liquid suspension, or an intermediate sticky mud depending on the type of pipe and its operation.[33]Black powder can be generated by chemical or microbial processes. The presence of liquid water is essential for reactions to occur. Also, there must be the presence of oxygen, hydrogen sulfide, and carbon dioxide. The presence of these chemicals favors the corrosion of a ferrous steel pipe. In general, pipelines that transport natural gas offshore meets these conditions for the formation of black powder since with only 1ppm of H2S it can cause high levels of corrosion.[33-34] Over time, it has been recorded that extraordinary amounts of black powder have been documented in cleaning operations, ranging between 500 and 5000 kg, extracted from pipes scraped by execution.[35]

2.4.1. Consequences of the formation of black powder

Black powder is a chemical substance made up of fine particles that facilitate its transport through piping systems. Black powder is harder than the carbon steel used to make the pipes for that reason it poses an abrasive threat to erode the pipe and the components of the pipe. Therefore, the presence of black powder can have a large number of detrimental effects on gas pipeline operations and gas delivery points for further treatment.[31]

2.4.1.1. Equipment affected by the formation of black powder

Compressor dirt (figure 10): Black powder build-up on compressors can lead to costly maintenance. At worst it can lead to catastrophic failures and lost production.

Figure 9 Compressors for natural gas pipelines[36]

Blockage of orifice meters (figure 11): when the orifice meters are affected by the formation of black powder it is difficult to obtain an exact measurement of the flow rate and this can cause losses of the gas inlet for further treatment.

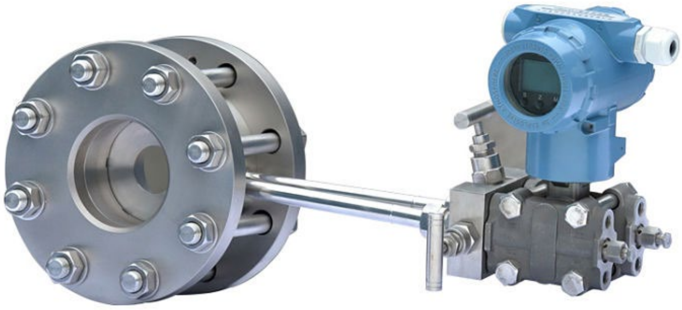

Figure 10 Orifice plate with pressure gauge[37]

Contamination of instrumentation and control valves (figure 12): Black powder in instrumentation and control valves can cause poor measurements, increasing labor for cleaning, own to erosion, and the need for replacement parts.

Figure 11 Instrumentation and control valves.[38]

Clogging of filter systems (figure 13): When there is an excessive amount of black powder in the piping system, they cause a decrease in the useful life of a filter. Consequently, it generates the use of more labor and an additional expense of replacement cartridges.

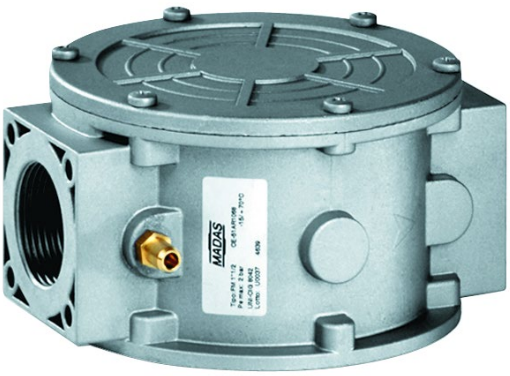

Figure 12 Filter for natural gas treatment[39]

Pipes: Black powder causes pipes to increase their surface roughness on the inside wall of the pipe. On some occasions, black powder accumulates in the walls of the pipe and prevents the flow of gas in the gas pipeline system as shown in figure 14. Consequently, this problem generates a pressure drop and greater force is required to achieve the results. same flow rates resulting in additional operating expenses. If the corrosion caused by black powder is severe and uncontrolled, it can cause the failure of the pipe until its collapse and create safety hazards and a significant loss of production.

Figure 13 Black powder in natural gas pipeline[40]

2.5. Operational integrity of natural gas pipeline

Operational integrity can be defined as a Process that includes the inspection of the hydrocarbon transport systems, evaluation of the indications obtained from the inspections, characterization of the indications, evaluation of the results of the characterization, classification by defect and severity, and the determination of the integrity of the pipeline by means of analysis techniques.[27]

2.5.1 Operational reliability of pre-corroded pipes

The integrity of pipeline transportation systems (pipelines) of hydrocarbons is an increasingly difficult problem for oil companies because the length of the pipelines. Corrosion is a more active and dangerous mechanism in pipes, for that reason, it is necessary to analyze the fracture mechanisms to verify and predict the stability of the pipe. The operational confidence of pre-corroded pipes can be defined as a process that includes the inspection of the hydrocarbon transport systems, evaluation of the indications obtained from the inspections, characterization of the indications, evaluation of the characterization results, classification by defect and severity, and the determination of the integrity of the pipeline through analysis techniques.[28] The different disciplines that interact with each other in a systematic and integrated way provide the means to improve the safety of piping systems.[29]

Optimal management of the integrity of pipeline systems is essential for the operation and operational reliability of the pipeline. Pipelines that carry gas are statistically very safe and reliable, yet pipeline failures have resulted in fatalities, environmental damage, and an erosion of public confidence in the oil industry. To maintain the reliability of the pipes, reliable maintenance methods must be implemented to prevent corrosion or any other threat that endangers the integrity of the pipeline system (gas pipelines).[30] To maintain the operational reliability of a pre-corroded gas pipeline system, an integrity management program must be implemented that must include the following plan:

- A description of the risk analysis method used
- Documentary backup of all applicable data for each segment
- A documented analysis to determine the integrity assessment intervals and mitigation methods (repair and prevention)
- Generate documented performance matrix

Figure 9 shows the flow chart recommending ASME standards for pre-corroded pipes.

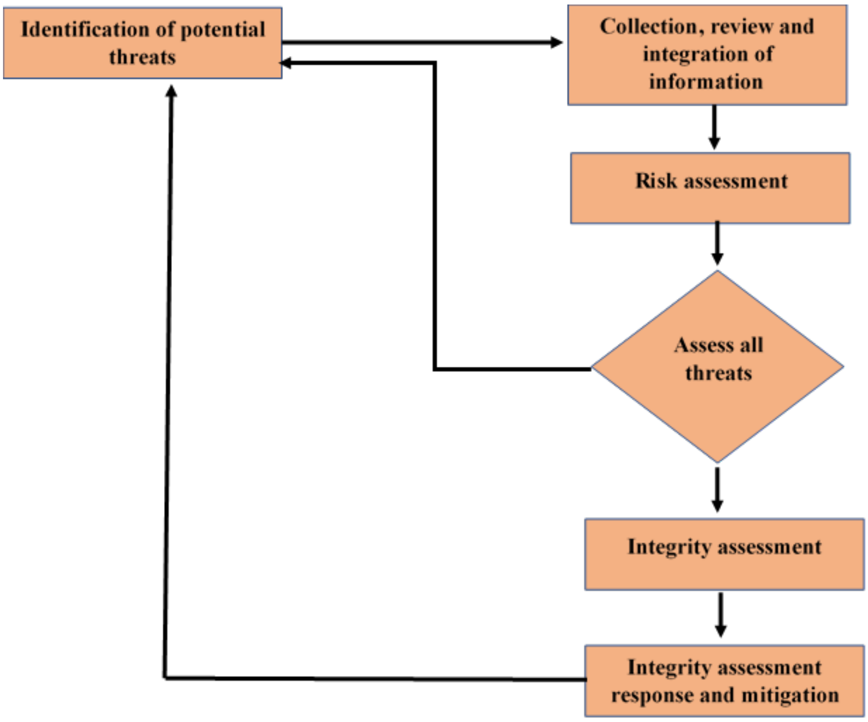

Figure 14 Integrity Analysis Process[6]

2.5.2 Identification of potential threats

Potential threats that can affect the integrity of the pipeline must be identified. For that reason, all threats to pipeline integrity must be considered, analyzed, and evaluated. Consequently, the Pipeline Research Committee has classified some root causes. These causes represent different threats to the integrity of the pipeline, which must be controlled or eliminated.[29]Next, the categories for identifying potential threats are shown in Table 3.

Table 3 Threat classification.[30]

TYPE	CATEGORY
DEPENDING ON TIME	External corrosion Internal corrosion Stress corrosion cracking
STABLE	Manufacturing-related defects • Faulty longitudinal seam • Defective piping Welding / Fabrication Related • Faulty circumferential weld including taps and T-joints • Faulty manufacturing weldArrugas o dobleces

	• Bad threads / broken pipe / failure in coupling Instruments • Failure of gasket or O-ring type seals • Equipment malfunction • Failures in pump packing or seals
INDEPENDENT OF TIME	Mechanical damage • Previously damaged pipes (dents) Incorrect operational processing

2.5.2.1. Analysis of the collection of information on potential threats in gas pipelines

Assessment is the first step in detecting potential threats to a pipeline segment or system. For this, the necessary data is defined and collected from each segment of the pipeline and each potential threat is detected in each section. Consequently, the operator must perform the initial collection and must review and integrate important information to understand the condition of the pipe. Then, you must identify the specific threats related to the location in the pipeline, which affects its integrity, and understands the public, environmental and operational consequences of an incident. For that reason, it is important to have information on operation, maintenance, design, history of operation, specific failures (repairs) and concerns, of each piping system.[31]This information is important because it includes conditions or actions that affect the increase of the defect, reduces properties of the pipe, or are related to the introduction of new defects.[28]

2.5.2.2. Risk assessment

The data collected in the previous section is used to assess the risk of the piping system. In this way, the risk assessment process identifies the specific events and/or conditions that could lead to a pipeline failure and provides an understanding of the probability and consequences of a pipeline failure. Consequently, risk assessments should include the nature and location of the most significant risks in the pipeline.[6-29] In the risk assessment process, priority and order of segments are given to assess the integrity of the pipelines.

2.5.2.3. Valuation of integrity

There are several methods for assessing the integrity of gas pipelines such as online inspection, pressure tests, direct or indirect assessment. The selection of the integrity assessment method is based on the threats that have been identified. Consequently, it is possible that more than one integrity assessment method is necessary to address all threats to a pipeline segment.[31] For this valuation, the piping systems must be inspected, that is, the possible anomalies that are discovered during inspections must be examined and evaluated to determine if they are real defects or not. Indications can be evaluated using an appropriate review and evaluation tool. [29]

2.5.2.4. Response and mitigation of integrity assessment

In this section, the valuation of integrity is analyzed and it is answered through mitigation (repair and prevention) and determination of inspection intervals. In addition, schedules are developed to respond to the indications of the inspections. Consequently, anomalies discovered in inspections are identified, valued, and repaired by standards and practices accepted by the industry.[41] In this section, preventive practices for the risks found must be implemented. To finish with the analysis of pipeline integrity, each anomaly found and costs assigned to each one must be described. In this way, a gas pipeline integrity management plan is generated, in which each step must be followed cyclically, updating the information, periodically assessing the risks, and executing the necessary maintenance to ensure the reliable operation of the pipeline. piping system.[6-29]

2.6. Methods for assessing the integrity of pipeline systems for early prevention of corrosion in gas pipelines

Next, in this section, several methods for assessing the integrity of pipes are analyzed, which will classify intrusive and non-intrusive methods into two blocks.

2.6.1. Intrusive methods

2.6.1.1. Inspection of the different lines of the gas pipeline system

This integrity assessment method is suggested by ASME and API standards, this inspection is performed with instrumented technological equipment called pig “devils”. This is one of the most reliable methods because it can detect internal and external anomalies and examine the geometry of the gas pipeline. The inspection process begins when the cleaning pig passes through the piping system to remove sediment inside the duct. So when the cleaning devil checks the condition of the pipe, it is recommended to send it one more time depending on the amount of sediment collected during the first cleaning run. Then, a pig of discs is sent that will remove all the sediments that the pipeline can contain, then a pig of brushes and a pig with discs with magnets are sent. Finally, a pig of sealing discs with aluminum plates is sent through the pipe to detect the possible restrictions that the pipeline could have.[41] A pipe pig is instruments that are inserted and travel inside the production piping system.[42] The use of pig is a mechanical method to describe the removal of paraffin, asphalt, scale, crystalline, corrosion, and other accumulated deposits inside pipes and to determine the internal integrity of the pipe.[41]

2.6.1.1.1. Cleaning pigs

Cleaning pigs: They are mechanical instrument used to clean sediments, deposits of semi-solid impurities adhering to the interior surface of the duct. Cleaning pigs include the polly pig (Figure 15), pig with sealing discs (figure 16) and magnet pig with brushes (Figure 17).[40]

Figure 15 Polly pig used for cleaning pipes[43]

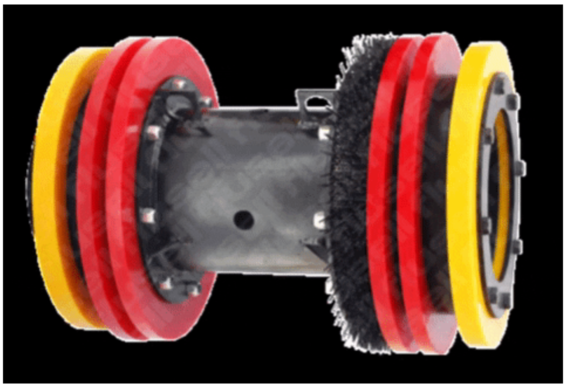

Figure 16 Pig with sealing discs [44]

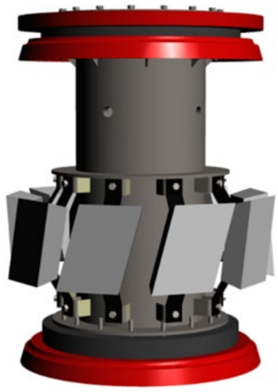

Figure 17 Pig of discs with brushes and magnets[45]

2.6.1.1.2. Hydrostatic pressure test

The pressure test is an accepted method in the oil and gas industry as a method to validate the integrity of pipelines as shown in figure 18. This titration method is a force test and leak test of the current flow of the pipe. The selection of this method depends on the threat being assessed. For this reason, the operator will have to consider the results of the risk assessment and the types of anomalies existing in the pipes.[46] Pressure testing is commonly used to address time-dependent threats such as external corrosion, internal corrosion, corrosion cracks, and other environmental mechanisms that influence corrosion.[6-29]

Figure 18 Hydrostatic pressure test[47]

2.6.1.3. Direct assessment of external corrosion

Direct assessment is an integrity assessment method used for a structured process by which the operator can integrate the knowledge of the physical characteristics and operational history of a piping system. Consequently, external corrosion is directly assessed and used to determine integrity becaude of the external threat of corrosion in pipe segments. This process should integrate data from installations, current inspections and verifications, and histories of the piping system. Direct testing and analysis confirm the ability of indirect inspections to locate active and past corrosion locations. Then, the evaluations are analyzed to determine a corrosion index that allows delimiting periods for the re-inspection re-evaluation and its applicability. Finally, the process is summarized in the following four components.[48]

• Pre-evaluation

• Inspections

• Tests and evaluations

• Post-evaluation

2.6.1.4. Direct assessment of internal corrosion

The direct assessment of internal corrosion is used to determine the integrity because of the threat of corrosion in certain sections of the gas pipeline since they can transport wet gas or free water (electrolytes). To analyze internal corrosion, low spots on slopes along a pipeline must be assessed, which forces electrolytes (water) to accumulate. This evaluation provides information on the rest of the pipeline since, if the low points have not corroded, then the other downstream locations are less susceptible to electrolyte accumulation. Therefore, these points can be considered free of corrosion.[6]

2.6.2. Non-intrusive methods

In most pipe systems (gas pipelines) an NDE (Non-Destructive Examination) type inspection is carried out. To perform this type of analysis, x-ray or ultrasonic instruments are used to measure the thickness of the retaining wall at points in the pipe. Non-intrusive methods are used for the monitoring of internal corrosion and instruments such as coupon, probe, ultrasonic sensor are used for an operator to extend the pre-inspection periods and take advantage of the supervision of the locations most susceptible to internal corrosion.

2.6.2.1. Non-intrusive methods for pipeline evaluation.

With the rapid improvement of signal processing technologies, the accuracy of the defect profile, size and mapping, and the performance of the ILI tool continue to improve. And that leads to more profitable decisions about pipeline integrity management. A variety of ILI technologies are widely used in the pipeline field, such as Magnetic Flux Leakage (MFL), Ultrasonic Tools (UT), Electromagnetic Acoustic Transducers (EMAT), Eddy Current Testing (ET).[49]

Electromagnetic Acoustic Transducers (EMAT) are non-contact ultrasonic transducers that are generally held 5 mm from the sample surface to obtain a sufficient signal-to-noise ratio (SNR). A major problem associated with operation on a ferromagnetic plate is that the strong attractive force of the magnet can affect measurements and make scanning difficult.

The Eddy current technique is an important non-destructive electromagnetic evaluation technique that is widely used in the energy, aerospace, petrochemical, and other industries for the detection of surface cracks and subsurface damage in components made of metallic materials. In addition, it is also traditionally used to evaluate the suitability of the heat treatment of alloys, since eddy currents are sensitive to changes in microstructure and stresses, which alter the electrical conductivity and magnetic permeability of the material.

2.7. Risk management

Offshore platform accidents are unavoidable due to unexpected reasons. The nature of its operations involves unstable materials sometimes subjected to extreme pressure in aggressive environments that increase risk, so accidents and tragedies can cause greater severity to platform workers. Risk assessment in the oil and gas (O&G) industry is essential to protect humans and the ecosystem from harm, as it helps to raise awareness and identify whether existing control measures are adequate enough or vice versa to hazards and risks before an accident occurs, in figure 19. The consequence of failure (COF) is a part of the risk assessment process that consists of four categories which are loss of people, loss of assets, environmental loss, and loss of reputation. In the current standard. [6-29]

Risk Assessment Matrix Model of O&G Pipeline Integrity Management

Consequence of failure (COF)	People (P)		Slight Injury	Minor Injury	Major	Single Fatality	Multiple Fatalities
	Asset (A)		Slight Damage	Minor Damage	Local Damage	Major Damage	Extensive Damage
	Environment (E)		Slight Effect	Minor Effect	Localized Effect	Major Effect	Massive Effect
	Reputation (R)		Slight Impact	Local Impact	Industry Impact	National Impact	International Impact
	Severity rating		1 Negligible	2 Minor	3 Moderate	4 Major	5 Catastrophic
Probability of failure (POF)	E Very likely to happened	Happens several times per year at location	Moderate	High	High	Very High	Very High
	D Likely to happened	Happens several times per year in company	Low	Moderate	High	High	Very High
	C Possible to happened	Incident has occurred in company	Low	Low	Moderate	High	High
	B Unlikely to happened	Heard of incident in industry	Very Low	Low	Low	Moderate	High
	A Very unlikely to happened	Never heard of in industry	Very Low	Very Low	Low	Low	Moderate

Figure 19 Risk Assessment Matrix Model of O&G Pipeline Integrity Managment

One could quantify the losses present in any hydrocarbon transport system, such as the costs of interrupting the service, the cost of the lost product, the cost of cleaning, among others. The consequences are sometimes grouped into direct and indirect categories, where direct costs are inclusive of integrity and influence the processes of risk control against hydrocarbon leaks. [50]

CHAPTER III: DESIGN METHODOLOGY AND STUDY CASE

In this section, the descriptive methodological bases are designed which purpose is to identify the characteristics, properties, dimensions, and regularities to mitigate corrosion with operational criteria of the piping system. In addition, the risks that this entails in gas production are analyzed. For this reason, the methodological method to identify threats, risk assessment, integrity assessment, and responses and mitigation will be qualitatively analyzed.

3.1. Case of study

It is important to know the operational integrity of the natural gas pipelines, which provides operational confidence in the system. For this reason, a process is generated for the identification of potential threats, risk assessment, integrity assessment, and integrity assessment response and mitigation. The steps described above are summarized in figure 22. The integrity assessment process is cyclical since the gas transport pipeline system must always be analyzed to avoid production drops.

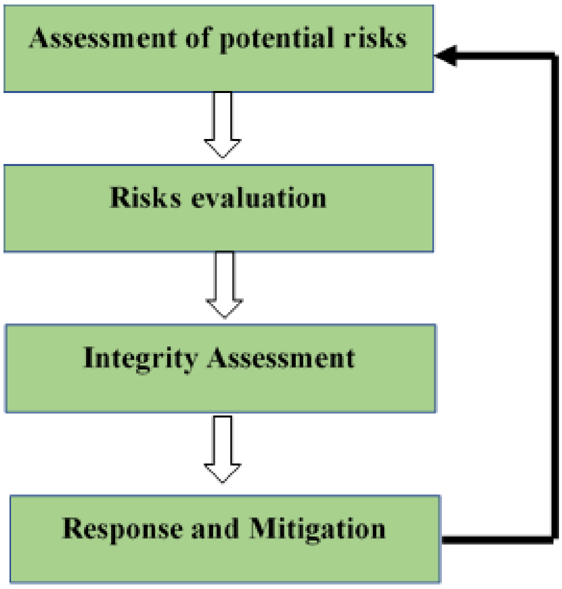

Figure 20 Process for knowing the operational integrity of the gas piping system.

3.1.1. Identification of potential threats

Identification of potential threats: The threats to whom must be identified, the documentation and history of the pipeline system will be analyzed and a study will be carried out detailing the possible threats. Then, the specific threats related to the location of the pipeline are identified and an attempt is made to understand the public, environmental and operational consequences of the incident.

3.1.2. Risk assessment

Risk assessment: there are risks associated with the construction and operation of natural gas transportation systems. The risks associated with natural gas arise during the commissioning process, where the gas is used to purge air that remains within the system before it is put into operation. The commonly recognized risks associated with the operation of the pipelines during their operation are then evaluated in descending order of importance.

- Mechanical damage
- External corrosion
- Loss of ground support

- Fatigue
- Sabotage or intervention by third parties

Risk is a function of the probability of occurrence of a risk situation and the consequence of the event. However, without a previous real study, the risks could not be quantitatively evaluated, for that reason, the analysis shown in table 4 defines five categories of the probability of occurrence of risk situations in a qualitative way.

Table 4 Categories that define the qualitative probability of the occurrence of a risk situation

PROBABILITY CATEGORY	QUALITATIVE DEFINITION
A	There is a high probability of occurrence of the event during the useful life of the project
B	The event could occur sporadically. There could be isolated events
C	There is a reasonable probability that the event will occur at some point
D	The event is unlikely to occur at any point
E	It is almost impossible for the event to occur

Then, the consequences of the event must be analyzed and the seriousness of the effect caused by that reason is represented, five categories of consequences of the event are developed as shown in table 5. Where the possible consequences in health, human safety.

Table 5 Categories of consequence of the event for risk assessment.

CONSEQUENCE CATEGORY			CONSIDERATIONS	
	Impact on health and safety	Impact on the environment	Level of significance and public concerns	Legal impact
I	Death / Serious Impact on Public	SEVERE: irreparable destruction. Long lasting impact. It requires responses on a large scale.	Would cross regional / national borders	Operational stoppage. Review of responsibilities. Major restoration Sanctions
II	Serious injury to employees. Limited impact on the public	SERIOUS: of moderate duration. Partial destruction of communities and severe deterioration of the environment. Requires significant resources for mitigation	It is limited to the region	Citation / fines. Lawsuit for compensation Minor restoration
III	Medical assistance for affected	MODERATE: short-lived. Requires a short and limited response	Crossing the company boundary.	Warning

	personnel. No impact on the public		It affects the local community.	
IV	Minor impact on staff	MINOR: requires only minor or no response	Minimal or no significance.	It requires explanation, but has no legal consequences.

With the aforementioned, the two qualitative analyzes can be interpolated to obtain the probability of their occurrence as shown in table 6 .

Table 6 Risk matrix that indicates the high (H), moderate (M) and low (L) risk levels based on qualitative interpolation from table 4 and 5

Consequences	**Probability category**				
	A	B	C	D	E
I	H	H	H	M	M
II	H	H	M	M	M
III	H	M	L	L	L
IV	M	L	L	L	L

High (H): Events with a high probability of occurrence and high consequences.

Moderate (M): Events in the middle range of probability of occurrence and consequence.

Low (L): Events with a low to moderate probability of occurrence

3.1.3. Valuation of the integrity of the piping system

Valuation of the integrity of the pipeline system: All threats against the integrity of the pipes must be considered, analyzed, and evaluated. Threat identification can be done through intrusive and non-intrusive methods. These methods identify and assess the integrity of the pipeline, likewise, it must be distinguished that intrusive methods are those that analyze the pipeline and interfere with its structure. On the other hand, non-intrusive methods are methods that do not interfere with the structure of the pipeline system and are the method most used by the oil industry since they do not affect the infrastructure of a pipeline.

For the research, a hierarchy of intrusive methods has been generated.

1. Use of "pig" for cleaning and analysis
2. Pressure tests
3. Direct assessment of external corrosion

In contrast, non-intrusive methods are ranked

1. Magnetic Flux Leakage (MFL)
2. Ultrasound (UT)
3. Electromagnetic Acoustic Transducers (EMAT)
4. Eddy currents (ET)

To select some type of method, it is necessary to know the characteristics of the duct, however, at a general level, several characteristics can be given for the applicability of the intrusive methods that are described in table 7.

Table 7 Features for the selection of the intrusive method in a piping system

FEATURES	APPLICABLE DUCTS	DUCTS NOT APPLICABLE
PRESSURE	300 a 1450 psi	Low: 75 to 200 psi Very high:> 2000 psi
FLOW, FLOW RATE AND OPERATING SERVICE	• Moderate to high flow: 6 to 21 feet / second • Unusual bi-directional flow • Regular and consistent flow	• Low to moderate flow: 1.5 to 6.4 feet / second • Two-way flow • Irregular flow and operation
TEMPERATURE	Lower than 65 ^{0}C	Above 65 ^{0}C
ACCESSORIES AND CONNECTIONS	• T-connections have anti-camber bars and are not located at the bottom of the tube • “Full Port” valves • No flexible pipe sections	• T-connections without bars and / or oriented in the lower quadrant of the tube. • Contraction bore valves • Sections of flexible pipe
ELBOWS	Most non-typical elbows have been removed	Joined elbows "back to back"
LAUNCH AND RECEIPT TRAPS	• Traps designed with a length of at least 1.5 times the length of the tool	• Launch and / or receipt traps that do not meet the minimum

		dimensions. No launch and / or receipt traps, or only one access point for the tool
INSPECTION HISTORY	• Has been inspected multiple times in the last three years • Unknown anomalies have been discovered and resulted • Documentation available	• Lack of inspection • Unknown data • Inspection and construction documentation are not available
CLEANING	• Performed online during normal operation • There is always the possibility of cleaning runs • Standard flow handling	• Can be done online or offline with another product • Bidirectional flow is common

On the other hand, to select the non-intrusive methods, certain characteristics of each method must be taken, which are detailed in table 8.

TYPE OF TOOL	RACKS	LOSS OF METAL	METALLURGICAL CHANGES	GEOMETRIC CHANGES	OTHERS (WELDING CHARACTERISTICS)
MFL	N	Y	Y	S	S
UT	Y	Y	N	N	S
EMAT	Y	N	N	N	S
ET	Y	N	S	N	S

Y: if the tool can detect this type of defect

N: the tool cannot detect this type of defect

S: Some types of tool can detect this type of defect, and others cannot

3.1.4. Response and mitigation

Response and mitigation: Gas pipelines exposed to the seabed are subject to external corrosion caused by the action of electrolytes in the chemical composition of the water. The external lining material is used in this type of system to protect the pipeline from external corrosion. The liner is chosen according to the economy and ability to protect the pipeline. The outer jacket is usually a plastic material that is wrapped or extruded over the pipe or by fusion bonded to the surface.[45] In addition, external coatings have to be designed to serve as a barrier against corrosion and to resist damage during shipping, handling, and filling.

Coatings are considered the main tools to prevent corrosion as they isolate metals from the aggressive environment. The application procedures are of utmost importance in terms of the effectiveness of the protection against corrosion, since the thickness, porosity, and the very nature of the layers obtained are a function of the application process. The most common types of liquid coatings are:

Organic: acrylics, rubber, chrome, phenolic, urethane, vinyl, acrylic vinyl, among others.

Inorganic: rich in zinc, cement, plastic coating, tapes, among others.

On the other hand, fluids within piping systems must be considered as they contain corrosive components such as saltwater, hydrogen sulfide, or carbon monoxide/dioxide, which can cause internal corrosion. Many of these problems can be avoided with the selection of appropriate materials for the fluid to be transported.[46]

To mitigate corrosion, the pipe must be sized to limit flow rates below the critical rate at which erosion-corrosion begins to occur. Critical speed is the point at which speed is a significant factor in removing films, inhibitors, or corrosion products.

Selection of materials for early mitigation of internal corrosion of a piping system. The pipelines that transport gas are made of materials that are mainly regulated by the following standards:

PI 5L:

Material composition

Mechanical strength

Unique identification number for the pipeline to be able to make its traceability

- ASME B31.8, "Piping Systems for Transportation and Distribution of Gas"
- ASTM A53, "Standard Specification for Black Steel Pipe"
- ASTM A135, "Electric Arc Welded Steel Pipes"

Piping systems are generally manufactured from ASTM A53 grade 5L steels. ASTM A53 grade 5l steel has mechanical characteristics that satisfy the aforementioned requirements.

On the other hand, the maintenance of a gas pipeline must be taken into account because this is the most important stage in the transportation of natural gas since this factor depends on its effectiveness. For this reason, aspects such as: where the pipe is located, the type of flow, and perform periodic operations on the structure must be taken into account. The maintenance of gas pipelines is established by the ASME B31.8 Standard (Construction of gas pipelines) which establishes the following:

- Periodic surveillance of gas pipelines
- Patrolling the gas pipeline
- Leak study
- Protective coatings
- The run of "Pigs"
- Potential measurement at short intervals
- Thickness measurement

CHAPTER IV*:* RESULTS AND ANALYSIS

4.1. Result of case study

The knowledge is then integrated into a conceptual map shown in figure 21 for the analysis of potential risks in gas pipelines.

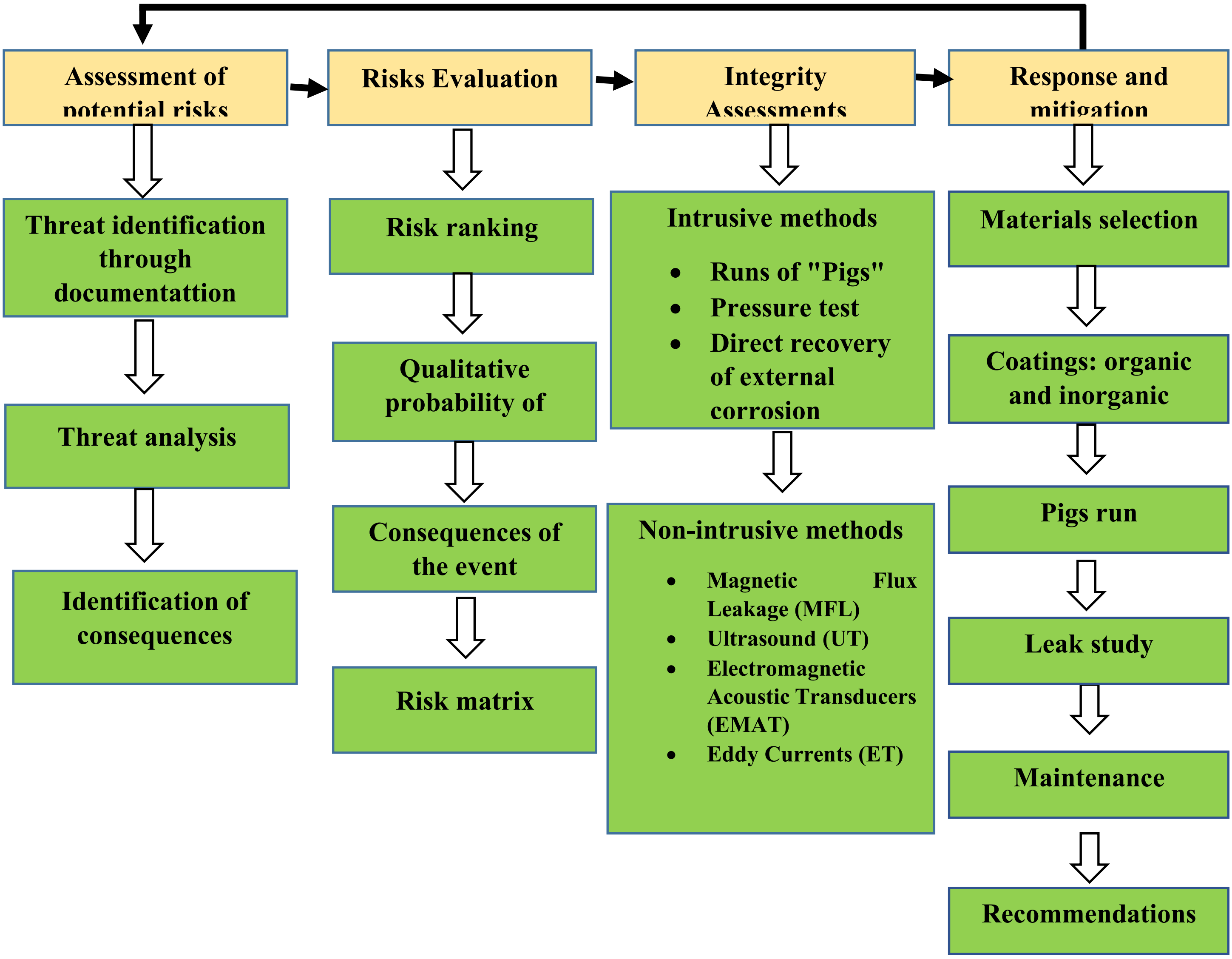

Figure 21.Concept map of the internal and external corrosion mitigation process of the pipeline system that transport natural gas.

This analysis integrates the knowledge of risk prevention to control corrosion and analyzes its consequences in the pipeline system that transports natural gas. The importance of the operational integrity of the gas pipelines provides the information and gives the operational confidence of the pipelines. As one can see in figure 21, the first step in the prevention of risks related to corrosion is the identification of potential threats, where it will be identified through the operation history, threats will be analyzed and possible consequences will be identified. Then, the next step is followed, which is the evaluation of the risks through the ranking of the same, the probability of occurrence, the consequences of the event will be quantitatively evaluated and the information will be interpolated to develop a risk matrix.Thus, intrusive methods are ranked from greater to lesser importance for the valuation they generate in the pipes as follows:

1. Runs of “Pigs”
2. Pressure test
3. Direct recovery of external corrosion

On the other hand, non-intrusive methods are ranked according to the assessment of the integrity of the pipelines as follows:[48]

1. Magnectic Flux Leakage (MFL)
2. Ultrasound (UT)
3. Electromagnetic Acoustic Transducers (EMAT)

For the selection of intrusive and non-intrusive methods, it is necessary to know the characteristics of the ducts. However, in most gas pipeline systems integrity assessment is performed with NDE (Non-Destructive-Examination) type inspection. This is because these methods do not interact with the physical structure of the pipe, and the ducts do not have to be adapted to use non-intrusive methods. As a result, you get a reduction in maintenance costs because pipes and equipment do not have to interrupt the service operations.

In the next step, the responses and mitigation of the threats found are analyzed. The first step in preventing the corrosion of the gas transport piping system is the selection of the gas material. To fulfill this task, the standards API 5L, ASME B31.8, ASTM A53, and ASTM A135 must be followed. These standards establish the mechanical characteristics that the construction materials of natural gas pipelines must meet. Then, for the prevention of corrosion, coatings that can be organic and inorganic must be applied. Coatings are the main tools for corrosion prevention because they isolate and protect metals from the aggressive environment. Also, to avoid the formation of black powder or any type of internal corrosion in the piping system, the “Pigs” must be run. This method is used to clean the ducts and find anomalies, however, to use this method the pipes must be adequate with special equipment that sends and receives the pigs. Likewise, the conditions of the pipes must be evaluated since, as analyzed in previous sections, there are ducts where pigs can be run and there are pipes that are not applicable for this method. On the other hand, in a leak study, the necessary corrections through maintenance and recommendations must be made to avoid the same risks in future service operations. Lastly, it should be mentioned that the steps described are a process to minimize internal and external corrosion of gas pipelines. For this reason, the process is cyclical since it begins with the identification of potential threats and ends with their mitigation. However, the process does not end and the gas extraction operations do not end for that reason the process must continue to avoid catastrophic threats such as the collapse of the pipeline, environmental contamination, and human losses.

It is important to mention in this section that the map illustrated in figure 23 is an interpretation to instill general knowledge for the mitigation of corrosion in natural gas pipelines. In other words, the illustrated map can be used both by university students who analyze the corrosion of pipelines that transport gas and professionals who begin their professional work in fields and gas extraction both offshore and within the continental territory.

CHAPTER V: CONCLUSIONS AND RECOMMENDATION

5.1. Conclusions

The operational integrity of natural gas pipelines is important because it prevents corrosion inside and outside of gas pipelines. For this reason, a series of processes is developed that provides the operational confidence of the system.

The process to prevent corrosion is the identification of potential threats where the necessary documentation must be reviewed to analyze the threats before occurred, the risks and their consequences will be analyzed. Then, the risks will be evaluated where the qualitative probability and its consequence are defined and then interpolated to generate a risk matrix. Then, the integrity of the pipes must be valued, for which, intrusive and non-intrusive methods must be used. For the selection of the method, certain criteria must be taken into account, operations of the piping system. However, non-intrusive methods are the most used to assess the integrity of a pipeline because this method does not interfere with the structure of a pipeline. Finally, the threats are responded to and each one of them is mitigated with anticorrosive methods such as the selection of material, coatings, leak study, thickness measurements, preventive and corrective maintenance. Finally, the recommendations must be sent so that the threat is not repeated or if it occurs it is mitigated quickly,

The process for the prevention of corrosion in the natural gas piping system is a cyclical process. This happens because the natural gas extraction process is continuous, therefore, the corrosion mitigation process must also be continuous and cyclical since the risks for their mitigation must always be analyzed.

The conceptual map made in this work is an illustrative process aimed at students who want to know the corrosion prevention processes of pipeline systems that transport natural gas offshore and in the continental territory. Likewise, this process can illustrate general knowledge to professionals who start their work in companies that are dedicated to extracting natural gas.

5.2. Recommendations

This work prioritizes the processes of assessing the integrity of pipeline systems that transport natural gas. These processes are analyzed for the prevention of corrosion in gas pipelines, however, everything expressed in this work was investigated and qualitatively conceptualized. For this reason, it is recommended that for future work an investigation be carried out where the assessment of risks associated with the corrosion of pipelines that transport gas can be quantified. Likewise, a study of the operating values is recommended for a study that focused on the investigation of real operational values for the mitigation of corrosion in gas pipelines. With these values, simulation studies could be proposed in programs such as PRO II to identify operational solutions to avoid corrosion in gas pipelines

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